Standards for exchanging digital geo-referenced information

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Summary

The purpose of this dissertation is to assess digital geo-referenced information and standards for exchanging such information, especially the South African National Exchange Standard (NES).

The process of setting up a standard is exacting. On the one hand, the process demands a thorough scrutiny and analysis of the objects to be standardised and of all related concepts. This is a prerequisite for ensuring that there is unanimity about their meaning and inter-relationships. On the other hand, the process requires that the standard itself be enunciated as succinctly, comprehensibly and precisely as possible. This dissertation addresses both these facets of the standards process in the context of standards for exchanging digital geo-referenced information.

The dissertation begins with an analysis of geo-referenced information in general, including digital geo-referenced information. In chapters 2 and 3, the various aspects of such information are scrutinised and evaluated in more detail. The examination of concepts is backed up by a comprehensive Glossary of terms in the domain under discussion.

Chapter 4 examines the nature of standards. It also proposes a novel way to approach a standard for the exchange of digital geo-referenced information: namely, that it can be viewed as a language and can accordingly be specified by a grammar. To illustrate the proposal, NES is fully specified, using the Extended Backus-Naur Form notation, in an Appendix. Apart from the advantages of being a succinct and precise formal specification, the approach also lends itself to deploying standard tools such as *Lex* and *yacc* for conformance testing and for developing interfaces to NES, as illustrated in a second appendix.

As a final theme of the dissertation, an evaluation of such standards is provided. Other standards that have been proposed elsewhere for purposes similar to that of NES are surveyed in chapter 5. In chapter 6, features of NES are highlighted, including the fact that it takes a relational approach.

Chapter 7 concludes the dissertation, summarising the work to date, and looking ahead to future work.

Key words

Alternate Spatial Attribute, Classification, Data Quality, Exchange Standard, Feature, Geographical Information System, Geo-referenced Information, Grammar, Language, Non-spatial attribute, Relational Model, Spatial Attribute, Topology

Samevatting

Die doel van hierdie verhandling is om versyferde geo-verwysde inligting en standaarde vir die uitruil van sulke inligting te ondersoek, met spesifieke verwysing na die Suid-Afrikaanse Nasionale Uitruilstandaard (NES).

Die proses om 'n standaard op te stel is veeleisend. Aan die een kant vereis die proses 'n volledige bestudering en ontleding van die objekte wat gestandaardiseer gaan word, asook van al die verwante konsepte. Hierdie is 'n voorvereiste om te verseker dat daar oor hul betekenisse en onderlinge verwantskappe eenstemmigheid bestaan. Aan die ander kant vereis die proses dat die standaard so kernagtig, volledig en presies moontlik gestel moet word. Hierdie verhandeling spreek beide hierdie fasette van die standaardiseringsproses aan, en wel in die konteks van standaarde vir die uitruil van versyferde geo-verwysde inligting.

Dié verhandling begin met 'n oorhoofse analise van geo-verwysde inligting, insluitend versyferde geo-verwysde inligting. In hoofstukke 2 en 3 word verskeie aspekte van dié inligting in meer detail ondersoek en geëvalueer. Hierdie ondersoek van konsepte word deur 'n omvattende woordelys van terme in die veld onder bespreking gesteun.

Hoofstuk 4 ondersoek die aard van standaarde. Dit stel ook 'n nuwe manier voor om 'n standaard vir die uitruil van versyferde geo-verwysde inligting te benader, naamlik dat dit as 'n taal beskou kan word, en dat dit gevolglik deur middel van 'n grammatika gespesifiseer kan word. Om die voorstel te illustreer, word NES volledig in 'n aanhangsel deur middel van die Uitgebreide Backus-Naur Vorm notasie gespesifiseer. Afgesien van die voordeel van 'n kernagtige en presiese formele spesifikasie, ondersteun die benadering ook standaardgereedskap soos *Lex* en *yacc* wat vir konformeringstoetsing en vir NES koppelvlakke gebruik kan word, soos in 'n tweede aanhangsel illustreer word.

As 'n finale tema van die verhandeling word 'n evaluasie van tersaaklike standaarde voorsien. Standaarde wat elders vir soortgelyke doeleindes aan dié van NES voorgestel is, word oorsigtelik in hoofstuk 5 beskou. In hoofstuk 6 word kenmerkende eienskappe van NES uitgelig, insluitend die feit dat dit op 'n relasionele benadering gebaseer is.

Hoofstuk 7 sluit die verhandeling af met 'n opsomming van werk tot op datum en 'n blik op toekomstige werk.

Sleutelwoorde

Alternatiewe Ruimtelike Attribuut, Datakwaliteit, Geografiese Inligtingstelsel, Geo-verwysde inligting, Grammatika, Klassifikasie, Nie-ruimtelike attribuut, Relasionele Model, Ruimtelike Attribuut, Taal, Topologie, Uitruilstandaard, Verskynsel

Acknowledgements

> "Kom ons drink op die een wat sy drome oorleef,
> op die een wat kry wat hy vra."
>
> [Gereformeerde Blues Band 1989]

This dissertation, and the work behind it, has taken several years, from original conception to the completion of this document. As a result, there are many people who have contributed to developing my understanding of the fundamental nature of digital geo-referenced information and the design of exchange standards, as well as contributing ideas directly to the National Exchange Standard itself. In addition, several people helped me actually get this thesis completed!

First of all, I should like to thank my supervisor, Derrick Kourie, for his patience and insightful comments on the many drafts of this dissertation. There can be no doubt that I found him to be invaluable as a supervisor.

I should like to thank Duncan Martin, the last Director of NRIMS, for allowing me time to work on the original NES project, which formed the basis of this dissertation, the NPRS for funding the original project, CDSM for funding work that I performed on Version 2.0 of NES, and Siemens Nixdorf for purchasing the *Lex* and *yacc* code discussed in Appendix B.

The other members of the NES project team, Derek Clarke, Hester van Rooyen and Elri Liebenberg, made a significant contribution towards my understanding of exchange standards and what NES should do, for which I am grateful. I should like to thank Ken Lester, who guided the development of NES and who kept us on track, and David Palmer who called for such a standard, and who contributed to the team's early thinking.

I was fortunate to have learned all the ins and outs about the fundamental nature of digital geo-referenced information in the stimulating environment that was the Computer Science Division of NRIMS during the mid-1980s. Phil Roets, as head of the Division, was the catalyst that made it possible, but I learned much from my colleagues such as Andrew Boake, Rudie Breedt, Greg Cronin, Bruce Crouch, Pen Gorringe, Tim Jobson, Anton Koen, Frederick Mentz, Chris Reynecke, Jacques Smit, Innie Snyman and Willem van Biljon. Ray Boyle also contributed much during his brief visit at the start of the NES project. During the CACDS days, Peter Greenwood was my main source of inspiration, and recently, Paul Ducklin has helped me with *Lex* and *yacc* and other problems, and Isabel Meyer helped me with translating the "Samevatting". Thank you.

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I have been fortunate to travel overseas on several occasions to meet with the developers of other standards, and I would like to thank them for their support and advice, in particular, Hal Moellering (who even allowed me to take part in a meeting of the NCDCDS!), Peter Haywood, Robert Rugg, and the members of the ICA Commission on Standards for the Transfer of Spatial Data. I should like to thank the Trustees of the Education Trust of The Royal Institution of Chartered Surveyors (RICS) for awarding me a RICS/Auto Carto London Educational Trust Award, which made one of my trips possible — for the other trips, I should like to thank Duncan Martin (NRIMS and CACDS) and Ben Fouché (INFOTEK) for making them possible.

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I should like to thank the anonymous external examiner for this dissertation who provided detailed and incisive comments on an earlier draft.

This dissertation was produced using emTEX, LATEX and TEX (I doubt that it could have been produced as smoothly using conventional word processors), and I should like to thank Eberhard Mattes, Leslie Lamport and Donald Knuth for making such powerful tools available. I should also like to thank Ivan Derzhanski for providing that most obscure of characters, the ISO currency sign; all those who responded to my query about ANSI and NIST that I posted to the Usenet newsgroup, `comp.std.internat`; and Fred du Toit for finding the article on Dr John Snow and the Broad Street pump.

I do not have a dog to thank and no one made me coffee through long nights! I typed this all myself, though Werner Wolfer produced the colour plot for me.

Finally, I should like to thank my parents, who for ten long years would ask, every week, after progress on my dissertation! I would like to thank them for their patience, their encouragement and their support.

The opinions expressed in this dissertation are those of the author and not necessarily of the CSIR or the University of Pretoria.

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Chapter 1

Introduction

1.1 Statement of the problem

The author helped to develop the South African standard for the exchange of digital geographically referenced information, known as the National Exchange Standard (NES) [Clarke *et al* 1987b, Standards Committee 1991]. This dissertation reviews such exchange standards in general (see Chapter 5), and NES in particular (see Chapter 6), though it is beyond the scope of this dissertation to assess the extent to which NES is used and has been accepted by its intended user community. While such an assessment is necessary to ensure that NES becomes more than a theoretical exercise, it would require an extensive investment, including the drafting of a questionnaire to be circulated to users and holding extensive interviews with key users. One of the distinguishing characteristics of the use of digital geographically referenced data, is that the same, common, base data sets are used by many different users for many diverse applications. Hence, a critical factor in facilitating the use of such data, and in controlling costs, is the ability to exchange such data between users. At this stage, most of the leading vendors of geographical information systems in South Africa have implemented interfaces to NES (the author assisted directly with two of the implementations), and the others are in the process of doing so.

To provide a background essential for understanding such exchange standards, the fundamental nature of digital geographically referenced information is analysed later in this opening chapter, as well as in Chapters 2 and 3. A thorough literature search has revealed that published compendiums have concentrated more on the application of digital geographically referenced information, and techniques for exploiting such information, rather than the fundamental nature thereof, for example, the two-volume set "Geographical information systems: Principles and applications" [Maguire *et al* 1991]. This dissertation provides a detailed analysis of the fundamental nature of digital geographically referenced information. The author was involved to various degrees in the development of some of the concepts presented herein, some of which have not been published in readily-accessible sources. Moellering [1991b] provides a list of research topics on digital geographically referenced information, which is discussed in Capter 7.

The nature of standards in general is assessed in Chapter 4, where it is also argued that an exchange standard can be construed as a language[1], and a formal definition of exchange standards is developed.

A formal specification of NES, using the metalanguage the Extended Bacus-Naur Form (EBNF), is provided in Appendix A. No such formal specification of NES has been published to date, though the author has submitted the contents of this Appendix for publication [Cooper 1993]. It is widely asccepted in Computer Science that such formal specifications are essential for avoiding ambiguities and aiding in understanding [Meyer 1990]. The structure of EBNF is largely the same as that used in the standard UNIX compiler tool, *yacc*, and an implementation of an interface to NES using *yacc* is discussed in Appendix B. Also as a part of this dissertation, the author prepared a comprehensive glossary of terms related to geographical information and standards (see Appendix C).

The author designed much of the structure of NES. This includes the relational structure of NES, as well as the format of all the relations. The author also determined what entries and relations were needed, based on the functionality that the developers of NES determined that NES should provide. The author studied various exchange standards (several of which are assessed in this dissertation), and aimed at designing a standard that would be more comprehensive and flexible than other standards, and that would also be relatively easy to understand and implement.

A standard must reflect the current state of the art and must allow for envisaged developments in the future. Thus, as the field of digital geographically referenced information is still maturing, NES was developed to provide immediately the required mechanisms to exchange those aspects that are currently in use, and to provide the ability to expand the standard to cater for future developments, once they become widely used.

The rest of this opening chapter provides an analysis of digital geographically referenced information, as follows:

- Section 1.2 provides the background to the work performed for this dissertation, discusses some of the current confusion over terms used in the field, and explains the difference between using a geographical information system (GIS) and studying the fundamental concepts of digital geographically referenced information;
- Section 1.3 then analyses the nature of geographically referenced information in general;
- Section 1.4 analyses the digital version of geographically referenced information; and
- Section 1.5 analyses GISs themselves.
- Finally, the chapter ends with Section 1.6, which introduces the rest of this dissertation.

[1]In this dissertation, the word "language" is a technical term, meaning a set of strings generated by a grammar. This is the conventional meaning of the term in the context of Formal Language Theory, Compiler Theory, and other branches of Computer Science.

The terminology of NES is used in this dissertation, both because this dissertation is based on work performed when developing the standard, and because the author considers that it provides a clean model of digital geographically referenced information.

1.2 Preliminary remarks

1.2.1 Background to the development of NES

The following background information on the National Exchange Standard (NES) is taken largely from [Cooper 1988c].

In April 1986 a joint project was established by the National Research Institute for Mathematical Sciences (NRIMS [2]) of the CSIR and the Chief Directorate of Surveying and Mapping (CDSM [3]) to draw up proposals for a national standard for the exchange of digital geographically referenced information. The project was funded mainly by the former National Programme for Remote Sensing (NPRS) of the Foundation for Research Development (FRD), now independent, but then part of the CSIR.

When the project began, no reasonable standard for the exchange of digital geographically referenced information existed anywhere in the world. However, several exchange standards were completed in other countries either within the six months before or after completion of the design of Version 1.0 of NES. The various project teams drawing up these exchange standards have benefited from each other's work.

To gauge the state of geographical information systems (GIS) in South Africa, in mid-1986 the project team distributed a questionnaire [Clarke *et al* 1986a] and a glossary of GIS terms [Clarke *et al* 1986b] to those users and potential users which the project team was able to identify in Southern Africa. The replies received indicated that few organizations in South Africa had much experience with GIS or automated cartography and that there was a need for an exchange standard. These mailings were followed by visits to a number of the organizations for discussions on the nature of the exchange standard to be provided. In addition, a number of workshops were held around the country.

In March 1987 the draft exchange standard [Clarke *et al* 1987a] was completed and distributed for comment. Unfortunately, the response was very poor — written comments were received from only two organizations. Nevertheless, the project team was able to improve the draft version.

The project terminated in September 1987, when Version 1.0 of NES [Clarke *et al* 1987b] was completed and released to the public, and the project team submitted its final report to the NPRS [Clarke *et al* 1987d].

The project team was small, consisting of only four members, DG Clarke (CDSLI) and

[2] In 1987, NRIMS became a part of the Centre for Advanced Computing and Decision Support (CACDS), which in turn in 1991 became a part of the new Division of Information Services (INFOTEK), of the CSIR.

[3] In 1990, CDSM became the Chief Directorate of Surveys and Land Information (CDSLI).

MH van Rooyen (NRIMS), the co-leaders, Prof EC Liebenberg (UNISA), and the author, who was also the secretary of the team. The small size definitely helped the team finish its work on time, as it was easier to reach consensus. Version 1.0 of NES took 18 months to develop, while in comparison, the American exchange standard has taken ten years (though this does include the time to get the standard through all their bureaucratic processes for approval as a standard). In addition, the project team felt that the small size of the project team helped to reduce the complexity of NES, as there were less "special interests" that had to be catered for in NES, and a cleaner, generic model for NES could be developed. For example, the latest version of the American standard has 30 vector objects (some of which are of a theoretical interest rather than of a practical value), while NES has five (see Section 5.3 below). Having too many options for the same object makes it much more difficult for a user to use the standard. The disadvantage of a small team is its narrow outlook, but it was felt that this was counteracted by the diverse backgrounds of the team members and the discussions held with users and colleagues.

More information on the history of the project may be found in Cooper [1986a and 1987d] and Clarke *et al* [1987c].

1.2.2 A confusion of terms

Geographically referenced (geo-referenced) information consists of all information that refers to the human-environment system and that can be localized in space and time [Cooper 1989a].

Surprisingly, there is no "standard" definition for geo-referenced information in the literature. In the survey of definitions of geographical information systems (GIS) in the definitive compendium on GIS [Maguire *et al* 1991], Maguire [1991] concludes that all GISs "have a single common feature, namely that GISs are systems which deal with geographical information". However, he does not define geographical information. While not actually defining spatial (that is, geographical) data, Goodchild [1992] lists three criteria that distinguish them from other types of data:

1. The spatial key is based on two continuous dimensions;
2. Geographical data have spatial dependency — the propensity for nearby locations to influence each other and possess similar attributes;
3. Geographical data are distributed over the curved surface of the earth.

There is some confusion over the use of the term "geographically referenced information", as some feel that it refers only to information used by geographers, such as demographic and land use information. However, the term is meant to encompass *all* spatial information referring to the human-environment system — hence the use of "geographically referenced" as opposed to just "geographical". Perhaps some of the confusion arises from the much abused terms *geographical information system (GIS)* and *land information system (LIS)*, which are used to describe computer systems that utilize digital geographically referenced data.

The implication is that a GIS is used for environmental information (and hence is the domain of social scientists) and that an LIS is used for cadastral information (and hence is the domain of the land surveyor). According to Rhind [1989], Dale and McLaughlin [1988] have proposed that the difference is that a GIS uses small scale data and an LIS uses large scale data. Dale [1989] goes further and indicates that an LIS is a specialized form of a GIS, namely one that is concerned with discrete data, and is a complement to the large scale map. Later, Dale [1991] suggests that an LIS is a system embracing institutional arrangements and the form and use of the appropriate technology (that is, the organisation and people as well as the equipment and data), while a GIS is a set of hardware and software tools (and hence a component of LIS). However, he also acknowledges that the difference between his definitions and those of others is merely one of terminology [Dale 1991].

Previously, the present author has contributed to the confusion as well, defining a GIS as a system that dealt with statistical or abstract phenomena and an LIS as one that dealt with physical phenomena [Clarke *et al* 1987b]. However, the author agrees with Rhind [1989] that there is no difference between a GIS and an LIS — particularly as much data are now derived from non-map sources (and hence are scale independent) and some users perform analysis on physical and abstract phenomena together. A GIS or an LIS is a computer system using digital geographically referenced data for a specific application, whether the application be broad or narrow, at a small or large scale (or both) or deals with physical or abstract phenomena, or both. In a manner similar to the related term *MIS* (management information system), the terms GIS and LIS could be extended beyond the technology to refer to the *institutional context*, that is, the *people* using the GIS or LIS, as well as the computers, peripherals, software and data [Dale 1991].

This emphasis on the distinction between a GIS and an LIS is unfortunate, and has probably been counter-productive. Some users have considered their problems to be unique to GIS (or LIS), and have probably ignored the approaches taken by LIS (or GIS) users, as they have felt them inappropriate for their problems. For example, Dale [1991] reports that at the 1978 FIG (Fédération Internationale de Géomètres)[4] International Symposium on Land Information Systems, some 50 papers were presented on all aspects of LIS, but the term "geographical information system" was not used at that meeting[5].

The situation is actually worse, as there is yet another "branch" that uses digital geographically referenced data, namely *automated mapping/facilities management (AM/FM)*. The term AM/FM is normally used by utility companies to refer to the digital versions of their distribution networks.

The terms GIS, LIS and AM/FM all refer to the same concept, namely computer-based systems that efficiently capture, store, retrieve, maintain, validate, integrate, manage, manipulate, analyse and display digital geographically referenced data. These systems

[4]FIG is the international association for land surveyors.

[5]The term "geographical information system" was first coined in late 1963, as the name for the first such system, namely the Canadian Geographical Information System [Tomlinson 1988]. The first usage of the term in the literature is not certain, [Coppock & Rhind 1991], but by the mid-1970s, it was in common usage.

are applied to many different fields (or combinations thereof) and to varying degrees of sophistication (from using the system as a more cost-effective way to update maps, to using the system for complicated modelling). Ultimately, these systems are used to satisfy the information and decision support needs of managers and planners.

GIS could be defined in narrow technological terms, or in a wider organisational/institutional perspective [Maguire 1991]. The following are a sample of the definitions of a GIS that Maguire collected:

- a system for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the Earth [DOE 1987].
- an institutional entity, reflecting an organizational structure that integrates technology with a database, expertise and continuing financial support over time [Carter 1989].
- a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world [Burrough 1986].
- a decision support system involving the integration of spatially referenced data in a problem-solving environment [Cowen 1988].

As can be seen, the definitions differ widely in some aspects. However, these definitions relate more to the ideal GIS, rather than the reality of today, which is:

> [A GIS is] a database containing a discrete representation of geographical reality in the form of static, two-dimensional geometrical objects and associated attributes, with a functionality largely limited to primitive geometrical operations to create new objects or to compute relationships between objects, and to simple query and summary descriptions [Goodchild *et al* 1992].

Perversely, the Americans insist that the *G* in the acronym *GIS* stands for *geographic* and not *geographical*, as the latter term is deemed to be of "British usage" [Abler 1987]! Ironically, the British chose to use the term *geographic* for the title of their umbrella organisation for the British GIS community, namely the Association for Geographic Information (AGI), which was launched in January 1989. Even more ironically, the latest edition of *The Oxford English Dictionary* has the following entry:

> **geographic** *adj.* = GEOGRAPHICAL. Now somewhat *rare* [Oxford 1989, pg 459, vol VI]!

In Afrikaans, a geographical information system is a *geografiese inligtingstelsel*, and a land information system is a *grond inligtingstelsel* — fortunately, they both have the same abbreviation, namely *GIS*!

1.2.3 Applying GISs *vs* studying GISs

As maps are used by many different people in many different occupations, and indeed outside of their occupations, so are GISs used by many different people. Most see a GIS as a tool, and exploit it as such, without needing to know much about how it works. An analogy would be to a secretary using a micro-computer for word processing — the secretary probably knows very little about the word processing software itself, and probably does not understand binary code, for example. In the author's experience, it is not uncommon for a GIS user to say that they are "in GIS", when in fact, they are applying GIS to solve problems in town planning, resource monitoring, or whatever. The thrust of this dissertation is on GIS *per se*, rather than the application of GIS.

Nevertheless, to use a GIS (or a map, for that matter), one has to have a feel for the spatial data that are being represented. If one struggles to orient a map in the field, for example, then one will probably struggle to understand what a GIS is depicting. Hence, for most applications, the user of a GIS has to understand something of how digital geo-referenced data are stored in a GIS.

Unfortunately, digital geo-referenced data are complex. Abstract concepts describing the fundamental nature of digital geo-referenced data have to be made concrete in a GIS so that they can be rendered to data structures and code.

In addition, GISs have matured to reflect the changing understanding of the fundamental nature of digital geo-referenced data. As a result, obscure or obsolete features and primitives are present in the architectures of some GISs. The original architecture of these GISs reflected the state of the understanding of the fundamental nature of digital geo-referenced data at the time they were first designed, but their architecture has been modified and enlarged over the years to accommodate the changes. A result is anomalies in the way they are used.

These issues are discussed in section 3.6, which appears after all the fundamental concepts of digital geo-referenced data have been analysed.

1.3 Geo-referenced information

Geographically referenced (geo-referenced) information consists of all information that refers to the human-environment system and that can be localized in space and time [Cooper 1989a].

The components of the above definition are discussed below.

1.3.1 Human-environment system

Information about the human-environment system includes all information about people, about the environment around them, and about the interaction between people and their environment. Examples of such information are:

- **humans** — population statistics, opinion surveys and market surveys, cadastral and administrative boundaries.
- **environment** — pedology, oceanology, hydrology, hydrography, geomorphology, geology, geophysics, climatology, meteorology and vegetation;
- **interaction of humans and environment** — land use (such as industrial, recreational, agricultural and mining), communication networks (such as roads, railways, pipelines, powerlines and air corridors), buildings, bridges, dams and breakwaters.

The information can be real or abstract (such as buildings vs market surveys), and tangible or measured (such as geology vs geophysics).

Thus, geo-referenced information is used across a wide spectrum of disciplines.

1.3.2 Localized in space

To be useful, sets of geo-referenced information have to be related to one another — this is done through their locations in space and time.

The spatial domain of geo-referenced information is usually contained in three dimensions. As these are usually with reference to a celestial body, such as the earth, the axes are usually defined with reference to the surface of the body — two of the axes being at right angles to each other on the surface (known as the planimetric dimensions) and the third perpendicular to the surface (known as the vertical dimension). These three axes can define uniquely any position on, above or below the surface of the celestial body.

Unfortunately, the earth is not flat, so to represent part or all of the earth on a flat surface (such as a map), one has to distort the reality — that is, project the real co-ordinates onto the flat surface. The earth is actually irregularly shaped (it is an oblate ellipsoid[6] whose radius at the equator is about 21,7 kilometres greater than its polar radius [McCormac 1985]), so to project the planimetric co-ordinates onto the flat surface, a simple approximation of the earth's shape (known as a reference surface) is used. Vertical co-ordinates are obtained using a more complex approximation of the earth's surface, known as a geoid.

There appears to be much confusion over these concepts, probably because most users of geo-referenced information have little training in surveying or cartography. It is not the author's intention to give complete or formal definitions of the concepts (for these, see the *Manual of Photogrammetry* [ASP 1980] and *Map projections — a working manual* [Snyder 1987]), but rather to introduce them briefly.

- **Map:** a representation (usually on a flat medium) of all or a portion of the earth or other celestial body, showing the relative size and position of features to some given scale or projection. A map may emphasise, generalize or omit the representation of certain features to satisfy specific requirements [ASP 1980].

[6] Oblate means flattened at the poles [Oxford 1983].

- **Datum:** a surface to which measured angles and distances are referred or reduced [Methley 1986]. Datums are an approximation of the surface of a celestial body. The planimetric datum is known as the reference surface (which is the surface of an ellipsoid) and the vertical datum (or height datum) is known as the geoid.

- **Ellipsoid:** "a surface whose plane sections (cross sections) are all ellipses or circles, or the solid enclosed by such a surface" [ASP 1980]. A *spheroid* is an ellipsoid with not much flattening. That is, its major axis is not much longer than its minor axis. However, the term spheroid is being phased out of use in favour of the preferred term, ellipsoid.

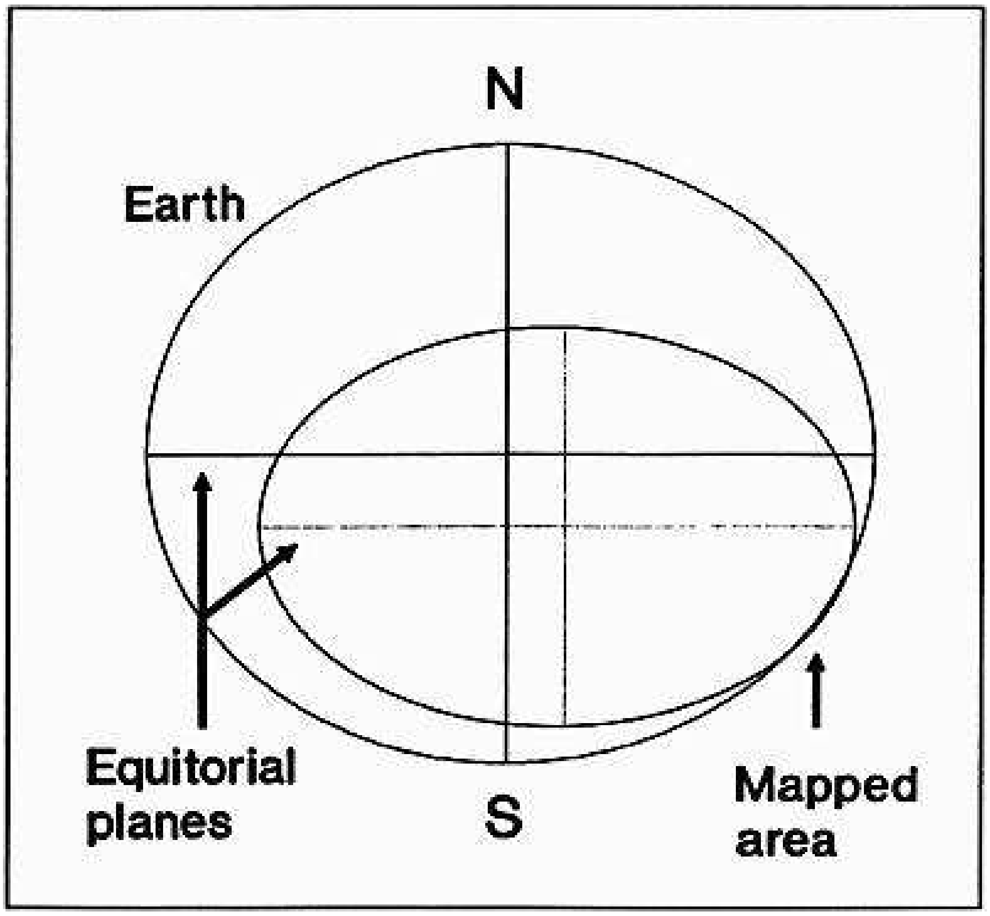


Figure 1.1: The position of a reference surface

- **Reference surface:** the surface of an ellipsoid, revolved about its shorter (polar) axis, that closely approximates the planimetric surface of a large section of the earth. The polar axis of the ellipsoid often does not coincide with the actual polar axis of the Earth, though it is made parallel. The same applies to the two equatorial planes. Figure 1.1 illustrates the offsets of the ellipsoid's polar axis and equitorial plane from those of the earth (the offsets are rather exaggerated). It also shows the area that would be mapped using the ellipsoid, which is where the origin of the ellipsoid would lie.

The discrepancy between the centre of the ellipsoid and the centre of the Earth is usually a few hundred metres at most. An ellipsoid is used with an initial point, or origin, with an assigned latitude, longitude and elevation above the ellipsoid, to "fix" the ellipsoid [Snyder 1984]. For small-scale mapping, a sphere could be used instead of an ellipsoid. In South Africa, the standard reference surface used is currently the Clarke 1880 (modified) ellipsoid, with its origin at Buffelsfontein. The equatorial radius (a) of this ellipsoid is defined as being 6 378 249.1 metres and the polar radius (b) as 6 356 514.9 metres. The flattening (f) of this ellipsoid is 1/293.46, which is derived from a and b [Snyder 1984]. However, as from 1992, the Clarke 1880 (modified) ellipsoid is being gradually replaced in South Africa by the World Geodetic System (WGS) 1984 ellipsoid, which is used by the global positioning system (GPS) satellites. In Namibia and the Walvis Bay enclave, the standard reference surface used is the Bessel 1841 ellipsoid. The equatorial radius (a) of this ellipsoid is defined as being 6 377 397.2 metres and the polar radius (b) as 6 356 079.0 metres. The flattening (f) of this ellipsoid is 1/299.15, which is derived from a and b [Snyder 1984]. There are no plans to replace Bessel 1841 at this stage.

- **Map projection:** the pair of mathematical functions that transform points on the earth's surface first to corresponding points on a reference surface and then to corresponding points on a map, is known as a map projection [ASP 1980]. All map projections are compromises between maintaining the scale of distance in all directions (*conformal projections*), and maintaining the scaled areas of small figures (*equal-area projections*). Sometimes, co-ordinates are transformed from the reference surface to a *developable surface* (one that can be unrolled into a flat surface, such as a cone, a cylinder or a plane), and then from the developable surface to the map. "The cartographer must choose the characteristic which is to be shown accurately at the expense of others, or a compromise of several characteristics" [Snyder 1987]. Unfortunately, there is no one "best" projection for mapping, and unless one is dealing with an application that has been artificially constricted, there is probably not even a "best" projection for that application [Snyder 1984].

- **Coordinate:** a value measured along one axis of a coordinate system [ICA 1980]. Coordinates are often grouped into tuples. A tuple is a related set of values [Longley & Shain 1982]. A coordinate tuple is an ordered set of n coordinates specifying a location in n-space. Typically, a coordinate tuple has two or three dimensions.

- **Planimetric dimensions:** the two dimensions in which coordinates are measured along the reference surface. As the reference surface is curved, the coordinates are not Cartesian coordinates but they are spherical. However, on large-scale maps, users often perceive the coordinates to be Cartesian as the curvature is slight. But, a close examination of maps in the South African 1:50 000 national mapping series, for example, will reveal that the left and right margins of the map are not parallel and that they converge far to the South of the map. In addition, both the top and bottom margins are curved.

- **Geoid:** "the figure of the earth considered as a sea-level surface extended continuously through the continents. The actual geoid is an equipotential surface to which, at every point, the plumbline (direction in which gravity acts) is perpendicular. It is the geoid which is obtained from observed *deflections from the vertical* and is the surface of reference for astronomical observations and for geodetic levelling" [ASP 1980]. That is, the geoid is a representation of the earth as if all surfaces were at sea-level. Normally the vertical dimension is measured with reference to the geoid.

- **Vertical dimension:** vertical distances of points above or below a geoid. Points may be plus (elevations) or minus (depths) according to whether the point is above or below the datum [ASP 1980].

- **Scale:** "the ratio of a distance on a map to its corresponding distance on the ground" [ASP 1980]. A scale of 1:10 000 is larger than a scale of 1:1 000 000.

Geo-referenced information refers only to that information about objects located on, above or below the earth's surface. However, objects located on, above or below the surface of any celestial body (such as the moon) could be viewed in the same manner. Hence, geo-referenced information is a subset of all *spatial* information. However, only the earth is of interest at this stage, and the term geo-referenced will be used.

1.3.3 Localized in time

According to Langran and Chrisman [1988], time is a phenomenon that can be perceived only by its effects. They mention that time is commonly viewed as a line without endpoints stretching infinitely into the past and the future, though it could also be viewed as multiple parallel lines, as a tree structure, as circular, as discrete, or even as non-existent [Langran & Chrisman 1988], without describing these alternatives. Additionally, time could be viewed as a line beginning at zero and stretching infinitely into the future, to coincide with the "big bang" theory. However, as a component of geo-referenced information, the key is the representation of the effects of time, rather than the nature of time itself [Langran & Chrisman 1988].

The temporal domain of geo-referenced information is usually given in standard calendar time, though sometimes it may be given relative to other events in the realm of geo-referenced information.

Time, like space, must be subdivided, ranked or measured before it can be analyzed [Langran & Chrisman 1988]. When *events* occur, the *state* of the geo-referenced information changes. An analogy to spatial information is that an event is a zero-dimensional boundary between two one-dimensional regions (states) — temporal units that share a common boundary are contiguous neighbours in time. Unlike spatial information though, a temporal unit may have only two contiguous neighbours (its immediate predecessor and its immediate successor). While temporal boundaries are no more discrete than spatial boundaries, sharp lines also prove useful in representing temporal boundaries [Langran & Chrisman 1988].

Time is very important in geographical analysis, for example, when studying and predicting changes in weather systems, and when studying and making provision for the growth and migration of human populations. Unfortunately, recording and modelling the effects of time in geographical information systems is not yet well understood. Section 2.7 below contains a brief discussion of attempts to include temporal information in GISs.

1.4 Digital geo-referenced data

Digital geo-referenced data provide a digital representation of part of the real or potential world — that is:

- **real world** — the world as it is or as it was. This would include current records of the cadastre, land use, geology, climate, the conditions of natural resources, social statistics, and so on, as well as historical data on some or all of them. The historical data would be used for time series analysis (studying the changes in the human-environment system) or for archaeological or historical purposes.
- **potential world** — the world as it might be or might have been. This would include simulations and scenarios, and would be used for planning purposes, or for filling "gaps" in the historical data, for example.

Typically, the location of digital geo-referenced data in space and time is recorded in two or even three spatial dimensions — only rarely is its location recorded in the temporal dimension [Cooper 1989a] (See Section 2.7 below).

The spatial component of digital geo-referenced data can be represented in two ways, namely as *vector* or *raster* data, though there have been attempts to combine the two into one hybrid format. Peuquet's *vaster* format [Peuquet 1983], is an example (see Section 1.4.6 below). However, such hybrid formats have not become widely accepted.

The vector and raster forms have their basis in computer graphics hardware — the vector form being based on stroke or storage-refresh display terminals [7], and the raster form on raster or television-like display terminals. Both forms have their advantages — the vector form is efficient for storing data and for performing network analysis, while the raster form is efficient for remotely sensed images and performing polygon overlays, for example. It is conceivable that in the future, a single model that is better than both the vector and raster models might be developed to replace them. In a similar manner, the same problems occur in computer graphics, where the vector and raster structures both have their advantages and disadvantages.

It is possible to convert vector data into raster data and vice versa, though generally the former conversion is easier than the latter (see Section 1.4.5 for details). Commercial

[7] Such vector display units are now largely outdated.

systems are now starting to offer full integration of vector and raster data as well.

The non-spatial component of digital geo-referenced data has many appellations, though they all refer to the same thing — examples are *alphanumeric*, *descriptive*, *textual*, *attribute* and *non-spatial*. The term *alphanumeric* will be used in this section for the broader concept of such data. These forms of digital geo-referenced data are related to each other through *features*, which are analysed below in section 2.1. Vector, raster and alphanumeric data are analysed generically below (see Sections 1.4.3 –1.4.7), and then in more detail in subsequent chapters.

1.4.1 Multi-media GISs

A recent development has been the inclusion of *pictorial* and *sound* data in a GIS. Such pictorial data consists of scanned documents, still photographs and video, and they are either attached to the feature being depicted or to the site from where the photograph or video was recorded. Such sound data consists of recorded and/or synthesised sound. The inclusion of pictures in GISs began with the well-known Domesday Project [8] in the United Kingdom, initiated and sponsored by the BBC to mark the 900th anniversary of the first Domesday Book [9] [DOE 1987], and similar projects in other countries, such as the TRINITY experimental multimedia GIS in Japan [Kubo 1986]. Commercial GISs with such multi-media capabilities began appearing during 1991.

The first application of multi-media in a GIS in South Africa is the Department of Water Affairs and Forestry's GIS of the Letaba River Catchment. It is a very successful example of the application of GIS, and it has been used to make well over 100 interactive presentations (using a video projector) at conferences, seminars, and to a broad range of interest groups — it is actually *used* in the management of the catchment. It highlights the problems and conflicting demands for water in a manner that can be both very easy to understand and rather depressing (South Africa is facing severe problems with its water supply)! It is also stimulating a lot of interest in GIS.

In relational data bases, *binary large objects* (BLOBs) are often used to store multimedia data. Such BLOBs are binary data streams that can store any large, unstructured data object, such as pictures, sounds or object-code programs [Shetler 1990]. The pictorial data that would be stored using BLOBs must not be confused with geo-referenced imagery (such as satellite imagery), which is structured. BLOBs would be used to store photographs of houses (for an estate agent's data base) or of geological samples (for a minerals data base), for example. The National Exchange Standard (NES) does not cater for pictorial or sound data at this stage.

[8] The project aimed at presenting a contemporary snapshot of the United Kingdom in the 1980s on two interactive video discs and in a series of TV programmes. The discs included 50 000 photographs and 250 000 pages of data, all referenced to scanned base maps [DOE 1987]. The project was related to the British Government's drive to increase computer literacy, and 12 000 schools were involved in gathering data of their local areas for inclusion on the discs [Hemenway 1985]. The discs contain contributions from about 1 million people [Openshaw & Mounsey 1987]. It has been described as the only GIS containing footage of *the* Royal Wedding!

[9] A record of lands in England made in 1086 by order of William I [Oxford 1983].

1.4.2 Cartographic licence

It is important to realise that like a map, digital geo-referenced data can be no more than approximate representations of the world that they model. The accuracy of the model is determined by many factors, and errors are introduced at all steps in the process from the real world to digital data. These factors and the sources of errors are outlined in the assessment of data quality below (See section 3.3). In addition, decisions have to be made on what data to include, what data to exclude, and how to represent the data. Such decisions form part of *cartographic licence*.

Cartographic licence is "the freedom to adjust, add, or omit map features within allowable limits to attain the best cartographic expression. Licence must not be construed as permitting the cartographer to deviate from specifications" [ASP 1980]. "A map may emphasise, generalize or omit the representation of certain features to satisfy specific requirements" [ASP 1980]. That is, a cartographer may introduce deliberate changes to the data when producing the map.

An example of cartographic licence is cartographic displacement. This occurs when two linear features are so close to each other in the real world, that they would overlap each other on maps smaller than a certain scale. For example, the centreline of a road running alongside a railway line would probably be within 10 metres of the centre of the railway line. 10 Metres in the real world is 0.5mm on a 1:50 000 map, and as both roads and railway lines are represented on South Africa's 1:50 000 maps by lines greater than 0.5mm wide each, the lines have to be displaced so that they do not overlap. Hence, such lines digitised off such a map are not an accurate representation of the real world.

Another example concerns the exact identification of the location of features, for example, the boundary surrounding a range of mountains, such as the Drakensberg. In traditional cartography, it is sufficient to label the mountain range and to use devices such as contours or relief shading to enable the user of the map to interpret the location of the mountain range. Unfortunately, with our current understanding of digital geo-referenced data, for inclusion in a digital system, the boundary of the mountain range needs to be identified explicitly. Currently, sharp boundaries are used, their position being at the discretion of the cartographer. One possibility is that fuzzy sets could be used to represent such "fuzzy" boundaries [Van Biljon 1987b, Wang *et al* 1990].

A further example relates to the time taken to prepare maps for a new national base mapping series, which is typically several years for each map (the maps are prepared in parallel). In an effort to maintain the currency of each map when it is published, the mapping authority might include features that are planned to be there in the area covered by the map, but that are not yet there when the decision was made as to what should be included in the map. Such features would include planned townships or roads. Of course, if the plans are subsequently changed (typically because of budget constraints), the maps might then show features that do not, and possibly will not, exist.

Hence, the user of digital geo-referenced information must never assume that the data being used are exact, literal representations of the real world. Unfortunately, people have a perception that computers are infallible and hence that all data in computers must be perfect. *Caveat emptor!*

1.4.3 Vector data

Vector data differs from raster data in that the positional data is recorded explicitly through co-ordinate tuples. Generally, vector data consists of points, lines joining points, and curves.

A point is represented by a single co-ordinate tuple. That is, the position of a point is determined by a set of two or three coordinates. A line consists of a sequence of points

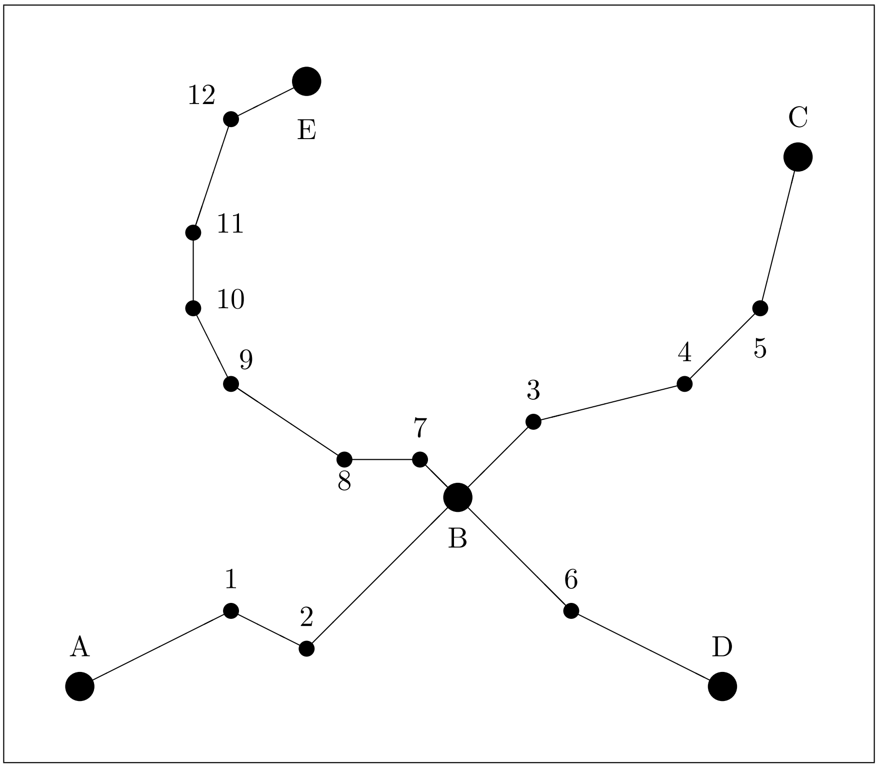


Figure 1.2: Lines and points

and the straight line segments connecting the points — in practice, only the points are recorded, though when the data are displayed, the line segments would be shown. Normally, the points at the ends of a line (terminals), and the point at the intersection of two or more lines (junctions), are given a higher status than the intermediate points along the line (the internal points). For example, in Figure 1.2, points *A, C, D* and *E* are terminals and point *B* is a junction. Two lines are shown in the example, namely the line running through the points *A, 1, 2, B, 3, 4, 5* and *C,* and the line running through the points *D, 6, B, 7, 8, 9, 10, 11, 12* and *E.* The points of a line that are not terminals or junctions are known as the *internal points* of the line. For example, in Figure 1.2, the internal points are the points *1, 2, 3, 4* and *5* in the line running from A to C, and the points *6, 7, 8, 9, 10, 11* and *12* in the line running from D to E.

A curve is the locus of points defined by a mathematical function [DCDSTF 1988]. Examples of these curves are a segment of the circumference of a circle or an ellipse, and a curve defined by a Bezier function or a polynomial. The points that define these curves do not necessarily lie on the curve itself, for example, the centre of the circle from which a segment is taken, or the control points for a Bezier curve. However, they invariably have terminal points, similar to lines. Figure 1.3, shows two joined Bezier curves, with

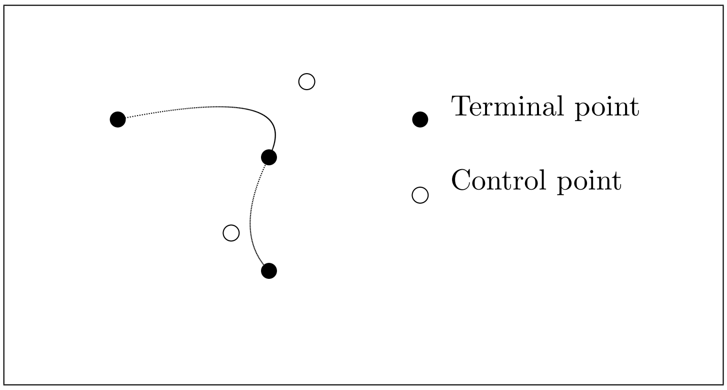


Figure 1.3: Bezier curves with terminal and control points

their terminal points (the solid circles) and control points (the open circles). The curves start and end at their terminal points, but their shape and position are defined by the control points as well as the terminal points.

At this stage, the only curves for which NES makes provision are segments of the circumference of circles and ellipses.

When lines are plotted on a computer screen or paper, a curve is occasionally passed through the points that make up the lines, instead of plotting the straight lines between the points. This is for aesthetic reasons, and is a form of cartographic license (See section 1.4.2). Some GISs allow one to specify for a set of points the curve that must always be passed through them.

Curves are very similar to lines in their use in digital geo-referenced data.

Some points are freestanding, to denote the position of an isolated feature that is sufficiently small to be represented by a single point at the scale being used. These points normally have the same status as the terminal and junction points. These point features are also known as 0-dimensional objects. For example, Figure 1.4, shows two point features, namely a windmill and a trignometric beacon.

Points and lines are used to represent linear features. A linear feature can consist of a number of lines joined end to end, or more rarely, a set of disjoint lines. They are also known as 1-dimensional objects. For example, Figure 1.5, shows two line features,

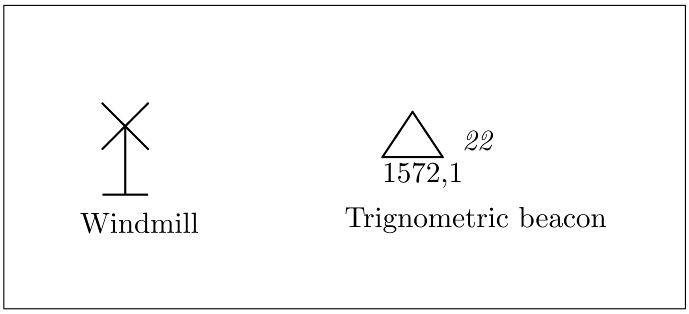


Figure 1.4: Examples of point features

namely a railway line and a political boundary.

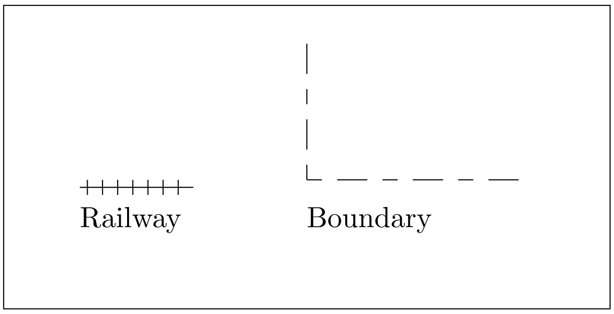


Figure 1.5: Examples of line features

Areas in digital geo-referenced data are an abstraction of points, lines and curves. The areas are not represented directly, but are normally represented by the space within an area enclosing boundary. This is because the number points that make up the boundary of an area is significantly less than the number of points that constitute the interior of the area. Areas are also known as polygons. Figure 1.6 shows an area, with its boundary and interior points. The boundary consists of the straight lines passing through the boundary points, and the boundary encloses the interior points. The boundary itself consists of points and lines and/or curves. The boundary often makes up one or more line features as well. For example, a field (an area feature) might be enclosed by a fence (a line feature). A moot point is whether or not the boundary forms a part of the area feature which it delineates. This uncertainty is probably caused by the boundary of an area feature being confused with a linear feature that lies along the boundary, for example, a hedge around a field. Herein, the boundary will be considered to be a part of the area feature that it delineates.

Area features are not represented directly in a GIS. The co-ordinate tuples that make up the boundary of the area (the polygon vertices) are stored in the GIS, as opposed to

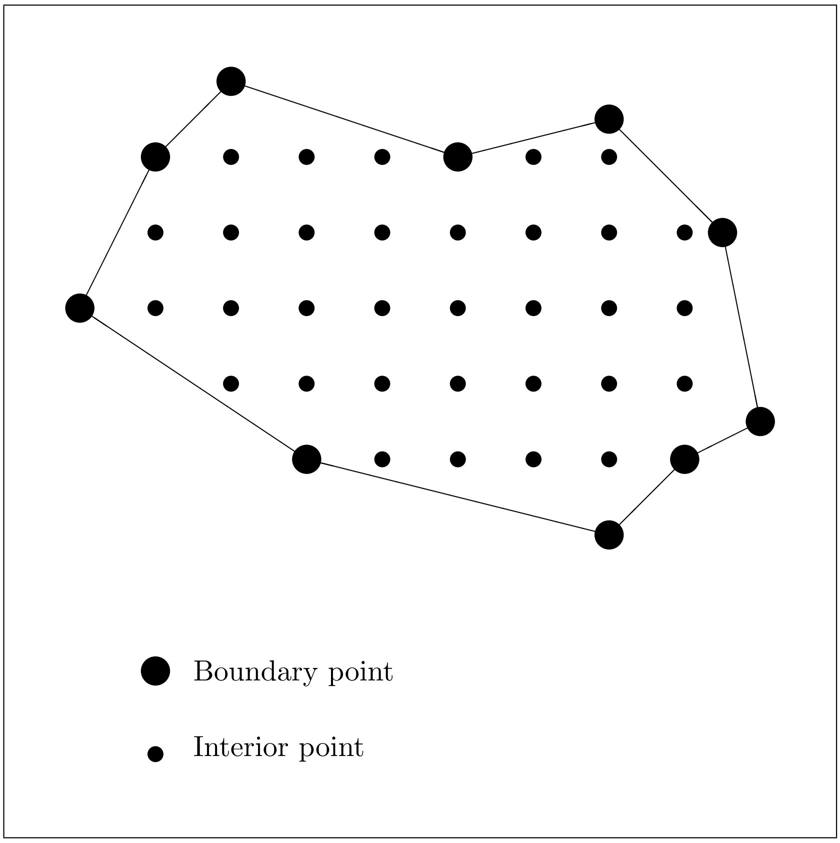


Figure 1.6: The representation of areas

the co-ordinates of the points that make up the area's interior. Historically, this indirect representation of area features was difficult to conceptualise. As a result, the concept of a *centroid* was introduced, where the centroid was any point contained within the boundary of the area feature. The centroid would then be used to represent the area feature, and hence would be treated in a manner similar to point features. For example, non-spatial attributes (see Section 2.2) would be attached to the centroid. See section 3.6 for a more detailed discussion on centroids.

Area features are also known as 2-dimensional objects. For example, Figure 1.7, shows two area features, namely a cultivated field and a building.

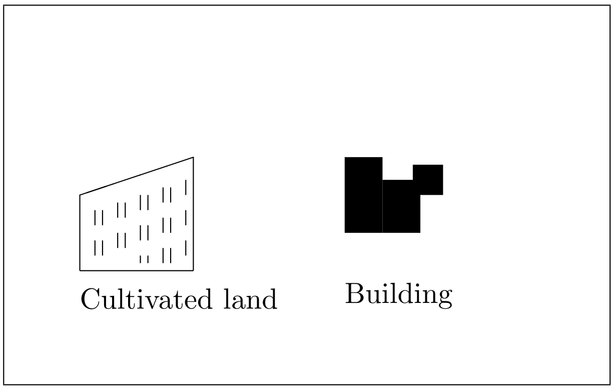


Figure 1.7: Examples of area features

0-, 1- and 2-dimensional object primitives are *fairly* well understood [Moellering 1991b]. For example, as mentioned above, 2-dimensional object primitives are not represented directly. It is possible that in the future, better primitives could be found.

The representation of 3-dimensional vector data is not yet well understood. Two fundamental 3-dimensional objects could be the *solid* (being the interior of a continuous and closed space) and the *surface* (being an area warped in three dimensions). It is uncertain how these objects should be defined using the 0-, 1- and 2-dimensional objects, or whether other primitive objects should be used to define them.

1.4.4 Raster data

With raster data, the positional data of individual elements is recorded implicitly through their positions vis-à-vis each other.

A *tessellation* is a repeating pattern of either regular or irregular shapes [Moellering 1985]. If the shapes are rectangles, then the tessellation is said to be rectangular. Figure 1.8 shows a few examples of tessellations. More complicated and interesting tessellations may be seen in the works of the Dutch artist, MC Esher.

Raster data consists of data stored as a $2\frac{1}{2}$-dimensional rectangular tessellation, with

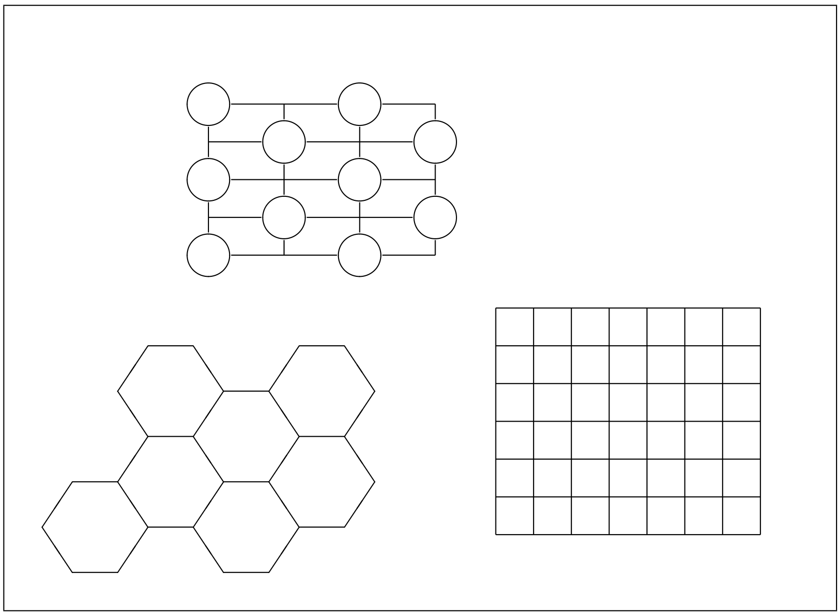


Figure 1.8: Examples of tessellations

a 2-dimensional matrix of elements as a base and one or more values associated with each element (*cell*) [Clarke *et al* 1987b]. The 2-dimensional base provides two of the dimensions of the tessellation which locate the elements in space. All cells represent fixed areas on the earth all of the same size, or measurements taken at regular intervals across the earth. The origin of the tessellation is given by a single coordinate tuple, and given the orientation of the tessellation, one can determine the geo-referenced location of any cell from its position in the tessellation and the dimensions of the cells. Figure 1.9 shows the structure of raster data. With some forms of raster data, especially geocoded satellite imagery [10], it is common for several data sets to be coincident, such as the different spectral bands of satellite imagery. Figure 1.10 shows three coincident data sets, that is, they all share the same coordinates for their origins, they all have the same orientation, and their cells are all of the same size.

Raster data has $2\frac{1}{2}$ dimensions and not 3 dimensions because at each cell one or more values are, or may be, recorded, rather than there being a third dimension. Even in the case of a digital elevation model (DEM) [11], the elevations recorded in each cell do not constitute a third dimension — they are attributes of the cells rather than part of the locational data of the cells.

[10] Geocoded satellite imagery is imagery that has been rectified to correct for spatial distortions caused by movement of the satellite and atmospheric conditions, and that has been projected into a standard map projection so that the data may be combined with other digital geo-referenced data.

[11] A digital elevation model is a tessellation of elevations of the earth's surface above a geoid. Each cell's value represents the elevation above or below the earth's surface at a single point, typically at the centre of the cell or at the bottom left-hand corner of the cell (see Section 3.1).

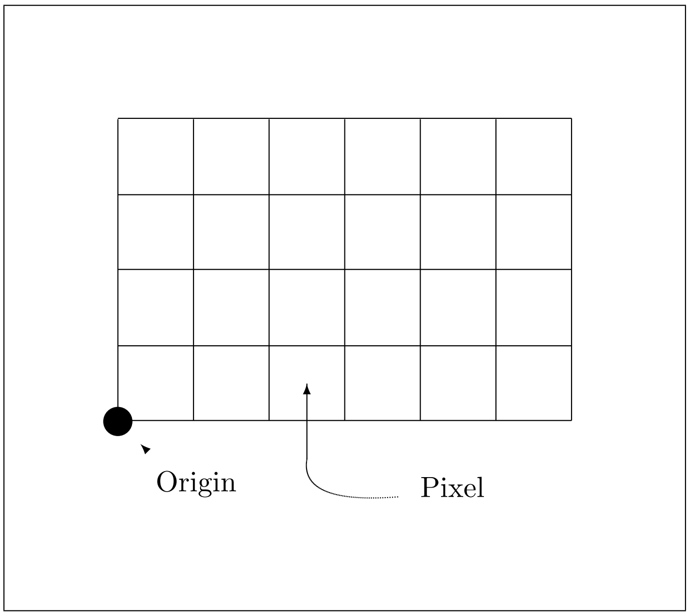


Figure 1.9: The structure of raster data

A DEM is the most common form of a digital terrain model (DTM) (see Section 3.1 below), and confusingly, the terms DEM and DTM are often used interchangeably.

In raster data, each value is referred to as a *pixel* (picture element), which is a data element having both spatial and spectral aspects [ASRS 1983]. That is, it has a size and position, and it has a value, such as the intensity of light reflected at a certain wavelength.

1.4.5 Converting between, and combining, vector and raster data

In general, vector data consist of interpretations of the world drawn manually, though some vector data are derived from raster data (for example, contours generated automatically from a digital elevation model), and some from data typed in (for example, cadastral data typed in from individual erven plans).

In general, raster data consist of interpretations of the world recorded by special sensors (for example, remotely sensed imagery) or data derived from vector data by interpolation (for example, a statistical surface). Generally, the data recorded by sensors has to be classified (be that by manual, unsupervised or supervised classification [12]) before it becomes useful.

To rasterise vector data (that is, convert to a raster format), one places a grid over the vector data and one assigns values to the cells based on the degree of presence or absence

[12] For information on remote sensing and classification, see [ASRS 1983, Cracknell & Hayes 1991].

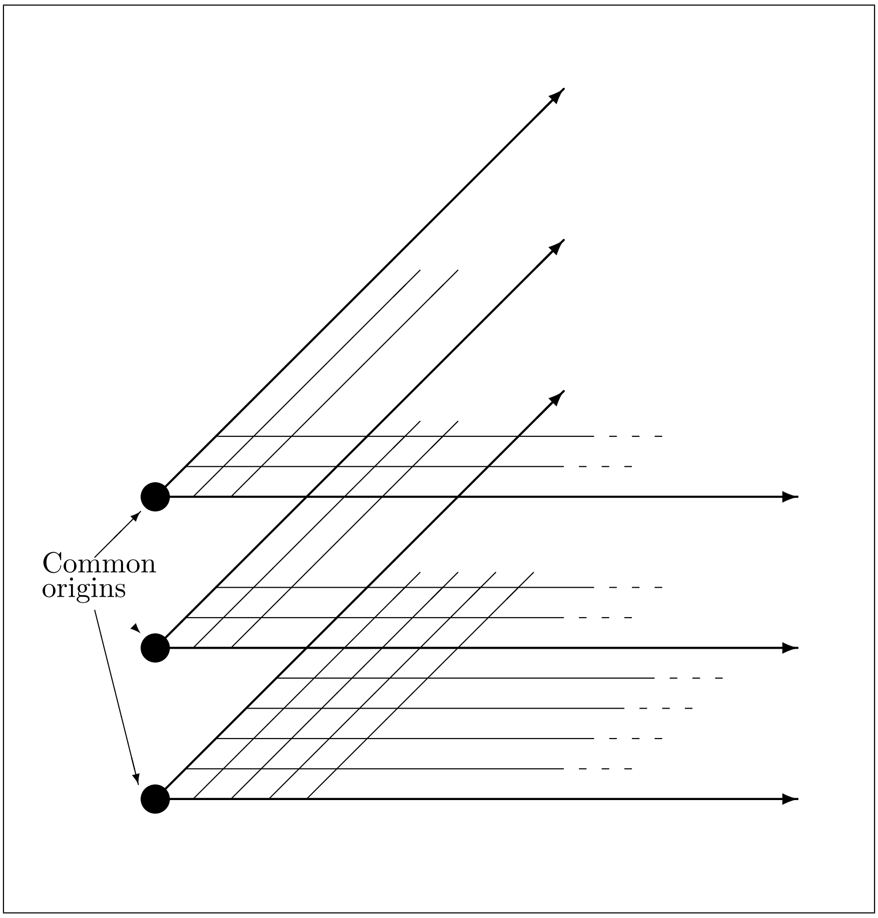


Figure 1.10: Coincident raster data sets

of vector data in the area covered by the cell. The coarseness of the grid determines how much data is lost in the process.

Vectorising raster data (that is, converting to a vector format), is a more difficult task, due to the variability of pixel values (that is, noise) normally found in raster data. It is first necessary to *classify* the pixels according to some criteria, and then extract linear features by following them through the raster, and area features by detecting their boundaries.

Vector and raster data are often combined for display purposes. In many applications, such as those studying the effect planned changes to the environment, such displays are particularly useful if they are done as three-dimensional perspective views. To generate such views, raster data, especially digital elevation models (DEM), are used to provide the basis of the three-dimensional perspective view, and other data sets, such as remotely sensed images and vector data, are then draped on top of the DEM to provide details of the surface features. The three-dimensional effect is heightened by the use of anaglyphs, or by stereo pairs (see Section 3.1 for details).

1.4.6 Hybrid vector and raster formats

An alternative to continually converting data between vector and raster formats would be to use a hybrid format that provided the benefits of both. Unfortunately, researchers have not had much success with developing a good hybrid format. Perhaps the best-known hybrid format is Peuquet's *vaster* format [Peuquet 1983], which is illustrated in Figure 1.11.

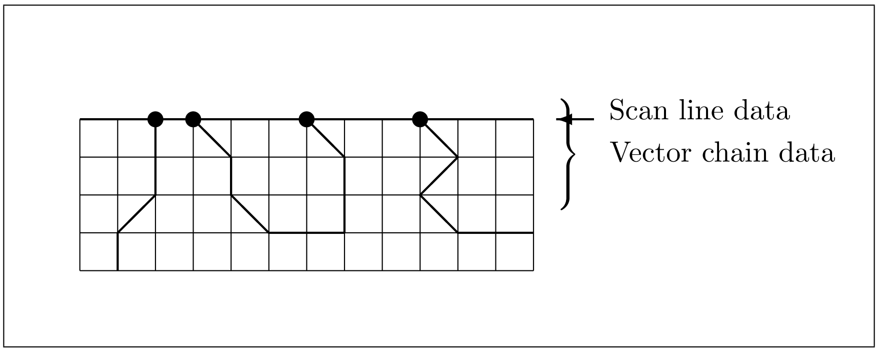


Figure 1.11: The vaster hybrid format: a swath of data

The basic logical unit of the vaster structure is the *swath*. Each swath spans a constant, known range over the y axis of the data, and corresponds to a group of contiguous rows if the data were organised in raster format. Each swath contains a raster component and a vector component. The leading edge of each swath (that is, the minimum y value for each swath) is recorded in raster format as a single row of pixels, and it functions as the index record for the swath. The data contained in the remainder of the swath are recorded in vector format using chain coding [13] [Peuquet 1983].

It is possible that such hybrid formats will no longer be needed, as there are several commercial GISs allowing the user to use both raster and vector data in the same system (though perhaps not simultaneously). The introduction of binary large objects (see Section 1.4.1 above), which can store almost anything, will further obviate the need for special hybrid formats.

1.4.7 Alphanumeric data

Alphanumeric data consists of textual and numeric data that are given meaning in a spatial context through its relationship to vector and raster data. This relationship is conveyed through features (analysed below in Section 2.1).

Alphanumeric data include those data which are used to identify the type of the feature, normally known as the classification of the feature, as well as those data which are attached to the feature as attributes of the feature. These attributes are known as non-spatial attributes, and are analysed below in Section 2.2.

1.5 Geographical information systems

1.5.1 "Geographical information systems" before computers

The functionality of a computerised geographical information system (GIS) can be obtained without computers, although, because of the volumes of data that must be handled, computerisation has tended to become an integral component [Dale 1991]. Many GIS applications pre-date the introduction of computers in the mid twentieth century.

Examples of GIS-type applications that pre-date computers are the medieval maps in the collection of Durham Cathedral that were drawn up as evidence for the settling of disputes over the use of the water in the River Wear. Each map consists of a stylized representation of the river (a topological map) together with the relevant features along the river, such as weirs, tributaries and the lands held by the contesting parties. The maps are heavily annotated with all the relevant details for the cases linked to the features on the map.

Another famous example concerns the establishment of modern epidemiology. In 1854, a cholera epidemic struck the centre of London. Within 250 yards of the intersection of Cambridge and Broad Streets, more than 500 people died in little more than a week. A physician, John Snow, marked on a map of London where all the cholera victims had died. He discovered that nearly all the deaths had occurred near the Broad Street pump, one of many public water pumps in London. However, 10 deaths occurred nearer another street pump. Dr Snow interviewed the families of the deceased and learned that five of them regularly sent for water from the Broad Street pump as they preferred its taste,

[13] Chain coding reduces data storage by recording the direction and length of each line segment using short, simple codes, rather than by recording the coordinates of the points at the end of each line segment.

and three more of the deceased were children who went to school near the Broad Street pump. Dr Snow concluded correctly that the water from that pump spread the cholera. He had the handle removed from the Broad Street pump and within days the outbreak of cholera ended. It must be remembered that at the time, no one knew what caused cholera or how it spread [Jaret 1991].

1.5.2 Computerised geographical information systems

1.5.2.1 The development internationally

The use of computers in mapping and spatial analysis dates back to the 1950s. The first maps prepared using a computer were for the Plant Atlas of Great Britain, prepared by FH Perring and SM Walters in the early 1950s. They used punched cards that drove a modified tabulator that printed symbols on a preprinted map of the British Isles [Coppock 1988]. Also in the 1950s, geographers and transportation engineers at the University of Washington developed automated quantitative methods for transportation studies [Coppock & Rhind 1991]. As the 1960s began, DP Bickmore and AR Boyle at the Oxford System of Automated Cartography invented a machine for semi-automatic name placement, and Boyle invented the free-cursor digitizing table [Rhind 1988].

The first computerised GIS was CGIS — the Canadian Geographic Information System [Tomlinson 1988]. It began in the early 1960s as the core of the Canadian Land Inventory, which was set up to describe the agriculture, forestry, wildlife and recreation capabilities, census divisions and land-use across the commercially productive southern one-third of Canada. CGIS has also been very successful, and is still in use today.

Other pioneering GISs were developed by the Experimental Cartographic Unit (ECU) in England (ECU developed out of the Oxford System of Automated Cartography), and the Harvard Laboratory for Computer Graphics [Coppock & Rhind 1991]. By the end of the 1960s, use of GIS, and especially automated cartography, was becoming widespread. In 1968, progress was such that the International Geographical Union established a Commission on Geographical Data Sensing and Processing, which sponsored the first two major international conferences to be specifically identified with GIS, held in 1970 and 1972 [Tomlinson 1972]. In 1976, the Commission published a survey, *Computer handling of geographical data*, which revealed that about 300 different computer systems for handling spatial data had been developed by then [Tomlinson *et al* 1976].

1.5.2.2 The development in South Africa

In South Africa, the development of GIS and automated cartography began during the mid-1970s at the National Research Institute for Mathematical Sciences (NRIMS) of the CSIR, where pioneering work was done by NRIMS researchers in collaboration with Prof AR Boyle, of the University of Saskatchewan, on the automatic vectorization of scanned maps [Peuquet 1981]. This work ultimately led to the design and development of a comprehensive computer-assisted cartographic system, handling alphanumeric and vector data, as well as providing facilities for managing maps and aerial photographs.

This system was integrated with a comprehensive system for handling raster data [Cooper 1989c]. At the time, it was not considered by the developers themselves to be a proper GIS, though in reflection it was. During 1986 a comprehensive, true GIS was designed. Though only parts of it were built, the work laid the foundation for the development of the National Exchange Standard, and the development of the commercial South African GIS, ReGIS [Cooper & Hobson 1991].

Other GIS pioneers in South Africa include the Johannesburg and Cape Town municipalities, the Chief Directorate of Surveys and Mapping, the Departments of Environmental Affairs and Water Affairs, and the Universities of Stellenbosch (Institute for Cartographic Analysis), Natal (Department of Surveying, Computer Centre for Water Research and the Institute of Natural Resources) and RAU (Department of Geography). By 1989, the use of GIS in South Africa was sufficiently strong to make a major success of SAGIS'89, the Southern African GIS Conference and Workshop [Cooper 1989d].

1.5.2.3 The application of computerized GISs

There are many processes that have only been made possible by automation, such as the ability to combine many data sets; the ability to process geo-referenced data rapidly enough so that the final output (maps or reports) can be published before the data are hopelessly out of date; the ability to process multispectral satellite imagery; and in-car automatic navigation. Automation has also facilitated many processes, such as map revision, customised map production [14] and spatial analysis.

Computerized GISs have also changed the way data are viewed by users, and the way analysis is performed on the data. For example, the Geographical Correlates Exploration Machine (GCEM) used a Cray X-MP/48 supercomputer to explore digital geo-referenced data bases to search for evidence of possible geographical relationships that may be useful for descriptive purposes. The power of the supercomputer was used to process several large data sets and explore *all* the spatial relationships in the data. The ultimate objective was to use the new sources of geographical information to create new knowledge and theories about spatial phenomena [Openshaw *et al* 1990].

1.6 Summary and looking ahead

GIS applications are becoming increasingly widespread, both in terms of where they are used and the people who use them. In this chapter, the fundamental nature of digital geo-referenced data has been assessed. In the process, some of the controversies and some of the areas where much research needs to be done have been highlighted. For example, problems related to cartographic licence and integrating raster and vector data remain unsolved, while multi-media GISs offer much promise for making digital geo-referenced data more accessible and intelligible to the average person.

[14] For example, in the United Kingdom, one can walk into any office of the Ordnance Survey and within minutes get a printed map that is located anywhere (with one's house in the middle, for example), containing the data one wishes to see, and printed using customised colours.

Chapter 2 provides more details of the fundamental nature of digital geo-referenced data, specifically analysing concepts such as features, attributes and topology, and the treatment of temporal information in a GIS. Chapter 3 takes it further, and analyses special forms of digital geo-referenced data such as digital terrain models and alternate spatial attributes, and the process of integration. It analyses symbology (the representation of digital geo-referenced data) and the oft neglected, but very important, aspect of the quality of data. The chapter concludes with assessments of some out-dated concepts that are "locked in" in some GISs.

As digital geo-referenced data become more widely available from more suppliers, and as more people use such data, so the need for standards (and information on data quality) increases. Standards are analysed in general in Chapter 4, which also argues that an exchange standard is a language. Several other standards are assessed in Chapter 5, while NES itself is assessed in Chapter 6, which should be read in conjunction with Appendix A, which provides a formal specification of NES. The specification in Appendix A has not been published elsewhere.

Appendix B, assesses how the UNIX compiler tools *Lex* and *yacc* could be used to implement an interface to NES. The use of these tools has already proved valuable for one vendor implementing an interface to NES. Appendix C contains a comprehensive glossary on GIS and related issues, which could prove to be a valuable resource. This dissertation closes with the list of references used herein.

Please note that the appendices and the glossary form an integral part of this dissertation. They have been placed at the end of this dissertation for ease of reference.

Chapter 2

Features and attributes

This chapter analyses the fundamental nature of digital geo-referenced information, as follows:

- Section 2.1 analyses *features*, the fundamental entities of digital geo-referenced information.
- Sections 2.2–2.3 analyse the *non-spatial attributes* and *classification* of features, which define the features as humans view them.
- Section 2.4 analyses the *spatial attributes* of features, which describe the location and shape the features.
- Section 2.5 analyses *compound features*, which are formed out of other features. In effect, the constituent features provide the spatial attributes (and some of the non-spatial attributes) for the compound feature.
- Section 2.6 analyses *topology*, the inherent spatial relationships between features. Topology encompasses the relationships between features and their spatial attributes, amongst different spatial attributes and between compound features and their constituent features.
- Section 2.7 analyses *digital temporal information* as a part of digital geo-referenced information.

Significantly, in the definitive compendium on GIS [Maguire *et al* 1991], little mention is made of *features*, and even less of *classification*, and no attempt is made to define them comprehensively. This is possibly because they are still considered to be emerging trends.

2.1 Features

Features are the basic entities of digital geo-referenced information. A feature is a uniquely identifiable set of one or more objects in the real and/or potential world, where the defined characteristics of the objects are consistent throughout all the objects. Features can be man-made or natural, real or abstract [Cooper 1989a]. To be more precise:

- **uniquely identifiable set of one or more objects** — to be useful, a feature has to be uniquely identifiable (otherwise nothing can be recorded about the feature). A feature can consist of one of more objects. For example, a feature could be an individual mountain peak (such as Cathedral Peak), or a range of mountain peaks (such as the Drakensberg). The key is that the set of objects constituting the feature must be uniquely identifiable.

- **real and/or potential world** — features can be real (be they historical or currently existing), or they can be potential (that is, part of a simulation of what is or has been planned, or what might happen or might have happened).

- **defined characteristics** — a characteristic of a feature is a significant distinguishing aspect of the feature. That is, it may be used to differentiate that feature from other features. Only one, or several, defined characteristics might be needed to distinguish a specific feature from its peers.

  Not all characteristics of a feature will be defined and stored in a data base, because the effort to recognise and capture all of them is very large, and because most of the characteristics are irrelevant to the users of the data. For example, characteristics of the Ben Schoeman Highway that are likely to be defined are its name and the number of its lanes, while characteristics that are unlikely to be defined are the identities of the great-grandparents of the first three motorists to enter the southbound part of the highway after 12 noon on every alternate Tuesday.

- **consistent throughout all the objects** — if the *defined* characteristics are not consistent throughout all the objects, then the objects should not be aggregated together into one feature, as the utility of the aggregation is diminished. Other characteristics should rather be used to differentiate the feature. It is the defined characteristics, that is, those that have been selected to describe and differentiate the feature, that must be consistent, rather than *all* the characteristics of the feature.

Those characteristics of a feature that are defined are known as the *attributes* of the feature, and they can be *spatial* or *non-spatial*. *Classification* of features refers to the arrangement of features into classes or groups, and is done on the basis of the attributes of the features. Attributes and classification are analysed below.

2.2 Non-spatial attributes

Non-spatial attributes are those attributes of a feature that are independent of the position of the feature. That is, non-spatial attributes are the all data, excluding the spatial data, stored about a feature. They describe the nature and appearance of the feature.

The most common non-spatial attribute is the feature's name. Other non-spatial attributes could be the feature's function, its capacity, its composition, its owner or its colour.

2.2.1 Types of non-spatial attributes

In his seminal paper, Stevens [1946] identified the four ways of classifying non-spatial attribute data that generally used today:

- **Nominal data:** The nominal measuring level is employed when distinguishing among a set of features only on the basis of their intrinsic character, that is, the distinctions are based only on qualitative considerations without any implication of a quantitative relationship. An example is the classification of rocks, such as *granite*, *quartz*, *dolomite* and *sandstone*.
- **Ordinal data:** Ordinal scales involve nominal classification, and also differentiate within a class of data on the basis of rank according to some quantitative measure. Rank only is involved, that is, the order of the variables from lowest to highest is given, but no definition of the numerical values. An example is the classification of land parcels according to their suitability for various applications, such as *most suitable*, *moderately suitable*, *moderately unsuitable*, and *completely unsuitable*.
- **Interval data:** The interval level of measurement assigns an exact numerical value so that the difference between any two items on the scale is known precisely. Interval scales lack true zero points and can therefore be used only to measure differences and not absolute magnitudes. Scaling methods for measuring attitudes and preferences are usually given measurements at this level. An example is the Centigrade scale for measuring temperatures — it is an interval scale, which does not have a fixed zero (0°C does not indicate that there was no temperature [1]).
- **Ratio data:** This scale provides the maximum amount of information. All ratio scales possess a true zero point, as well as permitting precise differences to be calculated, so that measurements retain the same ratio to one another, no matter what units are employed. An example is the measuring of rainfall.

It is common to encode nominal and ordinal data, both for convenience and to reduce storage. The encoding, which is often reduced to numbers, then encapsulates the detailed data about the attribute.

Unfortunately, there is often confusion between these four categories! One common misconception is to view all data encoded by numbers as being ratio data. This is especially true when modelling is performed using several attributes of many features to produce a new set of data (for example, classifying areas of land according to their suitability for a certain usage). This is discussed below in Section 2.2.2 in more detail.

Flowerdew [1991] identifies five types of data:

[1] Absolute zero, which occurs at −273.15°C, is the true zero point for the *Kelvin* temperature scale, and not for the Centigrade scale.

- **Dichotomous or presence/absence:** This measurement scale indicates either the presence or absence of a non-spatial attribute, or it may be used when a feature does or does not have a particular non-spatial attribute. Examples are the presence or absence of a plant or animal species within an area, and whether or not a country is a full member of the United Nations. This is effectively a special form of Stevens' *nominal data* category.

- **Categorical:** This is exactly the same as Stevens' *nominal data* category.

- **Ranked:** This is exactly the same as Stevens' *ordinal data* category.

- **Count:** This measurement scale counts the number of items or the number of times something has happened in a place. Examples are population, the number of species, the number of television channels, the traffic count or the number of customers. Maguire & Dangermond [1991] consider it important to have a specific category for count data because with some statistical modelling procedures, count data must be considered quite differently from other data types.

- **Continuous:** This is exactly the same as Stevens' *ratio data* category. Flowerdew [1991] adds that sometimes this may be reducible to the ratio or sum of count variables, and sometimes not.

In addition, Maguire & Dangermond [1991] consider it important to distinguish between density measures (such as population density) and absolute measures (such as the number of people), as they have an important bearing on the type of analyses that can be conducted. However, they add that in spite of these problems, which in some cases may be very significant, in the absence of any real alternative, Stevens' *dimensionality/levels of measurement* typology remains the principal method of classifying geo-referenced data.

Other types of non-spatial attributes include free text, pictorial and sound data, the importance of which is expected to increase as the use of multimedia becomes more pervasive.

2.2.2 Numeric non-spatial attributes

Strictly, only interval and ratio data may be considered to be numeric non-spatial attributes. Even then, there are restrictions on the valid mathematical operations that may be performed on interval data. With interval data, one may only measure differences, and not absolute magnitudes. It is also invalid to add or multiply values together. For example, a some might consider 20° C to be twice as hot as 10° C, which has the equally invalid implication that 1° C is infinitely hotter than 0° C! However, the difference between 20° C and 10° C *is* ten times the difference between 1° C and 0° C.

Unfortunately, there is a temptation to consider ordinal data as numeric as well. The only "mathematical" operation that one may perform legitimately on ordinal data is to compare values based on their position in a ranking. For example, given the ranking of *most suitable*, *moderately suitable*, *moderately unsuitable* and *completely unsuitable*, one cannot compare the difference between *most suitable* and *moderately suitable* against the difference between *moderately unsuitable* and *completely unsuitable*.

There is even occasionally a temptation to consider nominal data to be numeric. For example, if geological classes are reduced to numeric codes, some users might attempt to rank the different classes. This is symptomatic of users placing too much emphasis on the coding scheme used (see Section 2.3.6 below). The only valid operation that may be performed on nominal data is to compare for equality.

2.2.3 Textual non-spatial attributes

Textual non-spatial attributes include nominal data and ordinal data, and also data that does not fall into Stevens' four classes, such as *free text* or *monologues* (unstructured, unclassified and unencoded data). For example, the GIS that the Department of Water Affairs and Forestry developed for the study of the Letaba River Catchment includes the reports of the consultants on the project, which are included in the GIS as free text documents.

Nominal non-spatial attributes are ideal for being used to classify features (see Section 2.3 below).

Sometimes, it is desirable to encode textual non-spatial attributes (in the same manner and for the same reasons that classifications are encoded — see Section 2.3.6 below).

With textual non-spatial attributes, the only operations that one could perform legitimately are to test for equality, or to test for the presence or absence of a string in free text. Unfortunately, where codes are not used to capture textual non-spatial attributes, the captured data might be almost, but not quite, what the user anticipates has been recorded when they compile a query. Such differences could be introduced by spelling errors, the use of different languages, and differences between official names and colloquial names. For example, *Cape Town* and *Kaapstad* both refer to the same city; the town of *Port Alfred* is known colloquially as *Kowie*; and names such as *Thohoyandou* and *Phuthaditjhaba* are invariably prone to being misspelt.

Some spelling errors can be prevented by using a spelling checker when entering the data. Unfortunately, however, spelling checkers are not perfect, and can reject valid spellings while accepting invalid ones. Ultimately, to ensure correctness, all data should be verified by an expert.

Expert systems could be used to address some of these problems as well. Unfortunately, they are not perfect and their indiscriminate use can be dangerous. Raymond [1991] cites the example of DWIM (Do What I Mean), a function designed by a programmer, Warren Teitelman, to fix his own typographic and spelling errors, which meant that it was somewhat idiosyncratic to his style. Unfortunately, it would often misinterpret the typographic errors of other programmers if they were syntactically different. When DWIM was added to the command interpreter at one site, it created havoc when it "corrected" a command typed in by another programmer to delete backup files that had already been deleted.

2.2.4 Other non-spatial attributes

As mentioned in Section 1.4.1 above, a recent development has been the inclusion of pictorial and sound data in GISs. Such multi-media data are non-spatial attributes.

It might even be possible to digitise geo-referenced data off such pictorial data, which would imply that the pictorial data are actually spatial attributes. However, to do so, the pictorial data would have to be rectified to identify control points and to orientate and locate each image. This process would convert the pictorial data from non-spatial attributes to spatial attributes.

2.2.5 Storing non-spatial attributes in a GIS

Generally, the storage of non-spatial attributes is well-supported in GISs. Most GISs have the capability of linking to standard commercial data bases, which are designed for efficient storage, retrieval and manipulation of textual and numeric data. Indeed, these same data bases are now offering BLOBs (see Section 1.4.1 above) for multimedia data.

2.2.6 Non-spatial attributes and their representation

The non-spatial attributes of a feature should not be confused with the way the feature is represented on a map. The non-spatial attributes refer to fundamental characteristics of the feature that occur in the real world, while the attributes of the feature's representation refer to a particular representation selected for a particular medium, for a specific type of map, and for a certain audience. *Symbology* encompasses the representation of features and is discussed below in Section 3.5. The symbology of a feature is indeed dependent on the non-spatial attributes of a feature, which is why the two are confused.

Unfortunately, some primitive GISs, especially those based on CAD systems, make the non-spatial attributes dependent on the symbology, as the base CAD system provides the symbology. For example, in such a GIS, roads might be represented by red lines, and the type of road (that is, one of the non-spatial attributes) might be differentiated by representing highways by twin parallel, solid lines; other surfaced roads by single, solid lines, and unsurfaced roads as dashed lines (as shown in Figure 2.1). When the data are exchanged, especially if through an inappropriate medium such as a CAD exchange standard, the symbology of the lines is exchanged, and not the types of roads they represent. The recipient would then have to *manually* classify all the features, and *manually* assign their non-spatial attributes to them. Often, this process is more laborious than digitising the features *ab initio*.

2.2.7 Sharing non-spatial attributes

In a sophisticated GIS, it might be beneficial to share non-spatial attributes between features, similarly to the way in which coincident features share the same spatial attributes. This is discussed in Section 2.3.8.3 below.

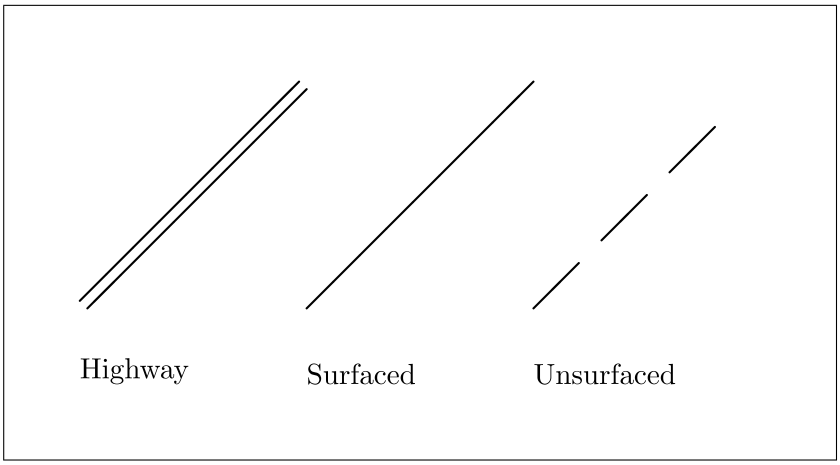


Figure 2.1: Examples of symbols representing roads

2.3 Classification of features

2.3.1 The notion of classification

Classification is the arrangement of features into classes or groups and should be done on the basis of the *qualitative* characteristics of the features' objects, such as their function, and not on the basis of their *quantitative* characteristics. Each resulting class has a *class name* and a unique definition.

- **Qualitative characteristics:** these are characteristics that describe the kind, relative nature or character of a feature. Examples are the difference between a dam wall and a retaining wall, the land-use zoning of an erf, and the minerals and rocks in a rock strata. Often, changes in the values of qualitative characteristics of a feature change the feature itself so significantly that it might need to be reclassified as a different type of feature, for example, when a dirt track is upgraded to a tarred road. Such changes are not necessarily possible (such as a building becoming an ocean!), emphasising how fundamental to a feature's classification the qualitative characteristics are.

- **Quantitative characteristics:** these are characteristics that are quantifiable, that is, may be represented as numbers. Examples are the population of a town, the number of lanes of a highway, the clearance of a bridge, and the amount of rain recorded by a rain-gauge over a period. Generally, changes in the values of quantitative characteristics of a feature do not change the feature significantly. For example, a highway is still a highway even if another lane is added to it; change in a town's population will only necessitate a change in the town's status if the change is significant, but even then the population change alone does not change the town.

- **Class name:** these are unique, meaningful appellations that differentiate one class from all other classes. The structure of the class name depends on the classification structure used (see Section 2.3.7). For example, with a hierarchical structure, the class name could consist of a *path* of names. That is, it could be a string of delimited names, where each name is unique on its level and where the full path name describes the class uniquely. An example of this is: *communication networks / roads / footpath*. Class names must not be confused with feature codes, which are internal abbreviations used by a GIS in the place of the full class names (see Section 2.3.6 below).

Thus, it is better to use qualitative characteristics as the basis for classifying features. They are the characteristics that differentiate between a road and a river and a tree and a mountain and a building and a vineyard and rainfall, for example.

It is not necessary to classify digital geo-referenced data (each and every individual feature could be deemed to be in a class of its own), but it would be difficult to do much with the data! The advantages of classification include faster retrieval of data, the ability to generalize features, and consistency of data.

- **Faster retrieval of data:** When features are classified, and one wishes to view or work with only a selection of features in a data base, the features can be selected on the basis of their classification. One does not have to go through each and every individual feature manually (or automatically using a complex search mechanism) and decide whether or not to include it in the working data set.
- **Ability to generalize features:** When features are classified, they are placed in classes. Each of these classes constitutes a generalization of the data, as those features in a class are grouped on the basis of only a subset of their attributes. Hence, it is essential, when defining a classification scheme, to select the classes appropriately. Generalization is especially facilitated by the use of a hierarchical classification, where one uses classifications at higher levels in the hierarchy for greater generalization. This is especially useful when the data base is used by many users, and one user's detailed data are another user's background data.
- **Consistency of data:** If one has a well designed classification scheme, it is easier for users to identify data correctly, both when storing features in the data base, and when retrieving them for use.

For these reasons, classification is very useful. Even the most basic of GISs, which are used only for displaying maps, benefit from classification. In such GISs (as in more complex ones), the symbology used to display the data is assigned to the various features through their classification.

The classification of digital geo-referenced information is a subjective process because people observe different properties in features and require information about the features to different levels of detail [Scheepers *et al* 1986].

For example, a forester would classify a stand of trees according to their species, and would record data about their age, the environmental conditions that would affect their growth, and the expected timber yield, while a civil engineer building roads would only need to know that there was a stand of trees there. On the other hand, a civil engineer would classify a road according to its use or construction, and would record data about the soil mechanics, expected usage, and maintenance requirements, while a forester would only need to know where the road was and the size of timber trucks that could use it.

There is a grey area between the classification of features and the non-spatial attributes of features [Cooper 1987c]. The class into which a feature falls could itself be viewed as a non-spatial attribute of the feature.

2.3.2 Defining the meaning of different classes

Perhaps the most tedious and time-consuming task involved in setting up a classification is defining exactly what each and every class is. Unfortunately, it is also a very important task. If the classes are not well defined (and the name of the class does not provide a sufficient definition!), users will often encounter features that they find difficult to classify correctly. In the classification supplied with NES [Clarke *et al* 1987b], definitions were not supplied as the size of the project team and the time constraints did not allow for enough time to draft the definitions. Unfortunately, because of the effort required, definitions have not yet been drawn up.

Perhaps the classification with the most comprehensive set of definitions is that supplied with the American Spatial Data Transfer Standard (SDTS) [2]. A team of five MSc students at the Virginia Commonwealth University (VCU) spent two years drafting the basic set of definitions [Moellering 1985]. The following are examples of their definitions, retaining their original American spellings (from [Moellering 1987a]):

Airport A leveled tract or water surface where aircraft can take off or land, usually equipped with hard-surfaced landing strips, a control tower, hangars, and accommodations for passengers and cargo. *Source:* modified from the American Heritage Dictionary. *Includes:* aerodrome, airdrome, alternate_aerodrome, auxiliary_aerodrome, controlled_aerodrome, heliport, seadrome, landing_area, seaplane_base, supplementary_aerodrome.

Approachway The airspace through which aircraft approach or leave a landing area. *Source:* Navigation Dictionary. *Includes:* airport_traffic_area, approach_path, approach_area.

Backwater An area of calm water unaffected by the current of a stream. *Source:* Adapted from Stamp and Monkhouse.

Cirque A deep natural hollow near the crest of a mountain. *Source:* New definition.

Similarly, the team at VCU defined all the attributes included in the classification, for example (from [Moellering 1987a]):

[2] Examples used in this dissertation to illustrate classification concepts have been drawn from various national and international exchange standards as they are the only general purpose classifications that are widely available.

Negotiated/unilateral Arranged or settled though consultation and agreement with two or more interested parties *vs* arranged or settled by one party without consultation or agreement with any other interested party. *Source:* Defense Mapping Agency. *Feature:* Boundary.

Physical_condition_of_surface_material The physical condition of a specified transportation surface which allows for use ranging from sustained use by heaviest vehicles to non-use due to disrepair or deterioration. *Source:* Ideas. *Feature:* Road, runway, bridge, tunnel.

Restrictions Limitations on the use for legal, safety, security or other reasons. *Values:* Customs, entry, international_regulations_for_preventing_-collisions_at_sea, navigational_rules_for_harbors_rivers_and_inland_waters. *Source:* New definition. *Feature:* Harbor, road, approachway, tunnel, lake, sea, bridge, boundary, runway, restricted_area.

2.3.3 Layers, levels & classification

In some GISs, classification is not done by assigning a class to a feature, but rather by grouping together all features in a particular class. That is, a feature's classification is determined indirectly from its logical position in the data base, rather than directly from a classification code attached to the feature. These groups are then usually called *layers* or *levels*. Often, each layer is stored in a separate file.

The use of layers derives from electronic computer aided design (CAD), where each layer represents the circuit tracks on a different layer on the printed circuit board. The use of layers can be very efficient for the storing and retrieving of data. Unfortunately, layers make it difficult to reclassify a feature (it has to be physically moved to the new layer). The more serious problem is that layers make the implementation of topology (see Section 2.6) between layers more difficult, and the spatial attributes are often repeated on several layers. This redundancy reduces the integrity of the data. For example, when a river is also a boundary, the coordinates delineating the river will be stored in one layer and the coordinates delineating the boundary will be stored in another layer — sometimes they will be the same coordinates, and sometimes not!

2.3.4 Classification schemes

A *classification scheme* is a defined method of classifying the set of features that are of interest to the user. Every class will have an unambiguous definition that will facilitate placing features from the set into the appropriate class. Note that a classification scheme does not have to be all-encompassing for all possible applications, but must provide the users of the data with the classes that are appropriate for their needs. For example, in a data base used for urban planning in inland areas, it would not be necessary for the classification scheme used with the data base to cater for oceanographic classes.

A classification scheme must also allow a classification to be expanded as new features are included in a data set. Many classification schemes have been unsuccessful because when they were first designed, an attempt was made to include every possible feature in the classification, without catering for expansion [Cooper 1986a].

If one intends exchanging information with other users, then those users' requirements must be considered. It is not necessary that all users use the same classification scheme, but there must be appropriate mappings between the various schemes. Normally these mappings would be one-to-one from the classes in one scheme to those in another, but that is not necessary. The mapping might aggregate the classes used by the producer of the data if the recipient does not need to distinguish between the producer's detailed classes.

Normally, data will be transferred from a user that has deeper (or the same) knowledge of the data being transferred than the recipient of the data. In particular, in the transfer of an individual feature, it is more likely to be transferred from the user that would classify the feature more precisely. Hence, either a one-to-one mapping (in the case when the feature is classified to the same precision by both users) or a many-to-one mapping (in the case when the sender has a more precise classification of the feature) between the classification schemes is the norm.

For example, a custodian of navigational information might use a classification (such as the Feature Attribute Coding Standard (FACS) of the International Hydrographic Organisation (IHO) [CEDD 1986b]) that differentiated at the feature level between a *beacon*, a *buoy*, a *leading light*, a *light*, a *lighthouse*, a *light sector* and a *light vessel*, while for many other users, a classification that aggregated such features into one feature class, such as *communication network / sea and inland water / marine navigation aid* (as is done in NES [Clarke *et al* 1987b]), would be sufficient. In this example, the transfer of information on marine navigation aids would almost certainly go from the user of the FACS classification scheme to the user of the NES scheme, rather than the other way around.

Under rare circumstances, the recipient of the feature would classify the feature more precisely than the sender. In these cases, the recipient of the data will have to decide manually on the classification of the feature, perhaps using other known data. That is, the recipient will have to split the features in the sender's class into a number of the recipient's classes. Such reclassification would be done on the basis of the non-spatial attributes of the feature, or other information known to the recipient.

For example, using the example above of the navigational aids, under very rare circumstances, a user of the more aggregated classification scheme might transfer corrected locational data about navigational aids back to the custodian of navigational information (perhaps, for example, when the navigational aid had been moved by a flood). The recipient would be able to use their detailed knowledge of navigational aids, and of the navigational aids in the vicinity of the update data, to refine the classification of the feature to their more detailed classification scheme.

Scheme	Classification	Attributes
	Power line & pipe line	
SDTS	Utility	Name, Relationship_to_ground_surface, Relationship_to_water_surface, Signal_type, Single_wire/Multiple_wires, Shape, Substance_transported
FACS	Culture / Communication/-transportation / Power transmission lines	Height, Width
FACS	Culture / Miscellaneous features / Pipeline	Radar significance factor, Location/origin, Existence, Use status, Product category, Height, Width, Directivity, Hydrographic location, Length, Angle of orientation, Accuracy category
NTF	Electricity transmission lines	
NTF	Pipelines	
	Golf course	
SDTS	Golf_course	Name
FACS	Golf course	Use status, Radar significance factor, Height, Length, Width, Directivity, Angle of orientation
NTF	Land use	Golf course, Enclosure, Use, Access, Entry
	Ruins	
SDTS	Place	Age, Physical_condition_of_feature, Name, Population, Area, Incorporated/-unincorporated
FACS	Culture / Miscellaneous features / Ruins	Radar significance factor, Hydrographic location category, Height, Width, Length, Angle of orientation
NTF	Antiquities	Type

Table 2.1: Different views (classifications) of the same data

2.3.5 Multiple classification schemes

Any one data set can be viewed or accessed through a number of classification schemes. Each separate classification scheme would provide a different view of the data, tailored for particular applications. For example, in Table 2.1, three different classification and attribute schemes (the American SDTS [Moellering 1987a], the International Hydrographic Organisation's FACS [CEDD 1986b] and the British NTF [Haywood 1986]) are used to view the same four features, namely a *power line*, a *pipe line*, a *golf course* and *ruins*. It will be noticed that there are significant differences between the three classification and attribute schemes for the four features. This is because each of the schemes was developed by different organisations for different applications, and hence, with different priorities with respect to what should be recorded for the features.

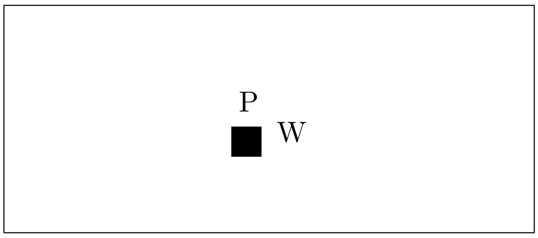


Figure 2.2: Three coincident features — a building, a post office and a general dealer

Within each classification scheme, a feature should fall into only one class. The temptation to classify a feature into a number of classes would occur when one feature is perceived as having a number of functions, for example, a building in a village that serves as a post office and as a general dealer. However, in this example there are actually three features. One feature is the building, with attributes such as its construction material, municipal rating and owner. Another feature is the post office, with attributes such as its name, postal code and the facilities it provides. The third feature in the example is the general dealer, with attributes such as its turnover, manager and target market. All three features in this example share the same spatial attributes. This is illustrated in Figure 2.2, where the three different features are each represented by different symbols — the building is shown by the filled rectangle, the post office by the character P, and the shop (winkel) by the character W.

2.3.6 Encoding a classification scheme

When a classification scheme is actually used, it is desirable to replace the full definitions of the classes, and even the class names, with *codes*, either numeric or alphanumeric, because the full definitions could be unwieldy to use. For example, in NES, the class *communication network / sea and inland water / marine navigation aid*, which has a rather long path name, also has the feature code *63* [Clarke *et al* 1987b], which is more compact, though less descriptive.

The *encoding scheme* used must be dependent on the classification, and not vice versa. That is, the classification must be designed without concern for how the classification will be encoded.

For example, the classification included in the IHO standard [CEDD 1986b], the Feature Attribute Coding Standard (FACS), is based on tree-like structures (see Section 2.3.7.3). In FACS, each feature is associated with an unique five-character code. The designers of FACS allocated one digit to encode the top level of the classification (called *major categories*) — hence, they restrict their major categories to a maximum of only 10 classes (though they do not use 0, and major categories 7 and 8 are "currently unassigned"). Each major category is further sub-divided into *subgroups*, for which a single letter is allocated in the code. Hence, each major category can have a maximum of 26 subgroups, and the major category *Culture* has 19 subgroups. Each subgroup is further subdivided into *features*, for which there is a three-digit code. For example, the feature *Ski Jump/Lift Area* has the code *1K150*, where *1* indicates the major category *Culture*, *K* indicates the subgroup *Recreational*, and *150* the feature *Ski Jump/Lift Area*.

The FACS classification is dependent on the encoding scheme, in that it is restricted to only 10 major categories, and within each major category, only 26 subgroups, and within each subgroup, only 1 000 features. While the FACS classification is comprehensive, it is not complete. It is based largely on the (non-digital) IHO Standard List of Symbols and Abbreviations, but does not provide unique codes for all items in the list. In addition, the world is evolving, and new types of features appear continually — for example, the first edition of FACS, published in 1986 [CEDD 1986b], does not make provision for a Global Positioning System (GPS) base station. It is possible that the restrictions imposed by the encoding scheme, especially on the number of subgroups, could be a problem in the future when the FACS classification is expanded.

Unfortunately, a number of classification scheme implementations have depended on encoding schemes. Such schemes have met with severe problems when new feature classes have had to be added to the classification. This is especially true of classification schemes based on a hierarchical structure (see Section 2.3.7.3 below), which had a poor success record in the early 1980s [Cooper 1986a].

2.3.7 Classification structures for classification schemes

2.3.7.1 Introduction

The classification scheme defines the classes of the features. A *classification structure* provides a mechanism for including the classes and their definitions into the scheme.

Commonly used classification structures are the *linear list* and *tree-like structures*, especially the *fixed level hierarchy*. Newer tree-like structures are the *variable level hierarchy* and the *partially ordered set*. Any structure may be used with the National Exchange Standard, but the variable level hierarchy is recommended. Each structure is analysed below, together with its advantages and disadvantages.

Mapping one classification scheme onto another should be independent of the structures used. The structure merely provides a mechanism for describing the scheme. Problems that would occur when mapping one scheme onto another will be caused by factors other than the mechanisms used; such as when the classification is based on quantitative characteristics and not on qualitative characteristics. For example, in Table 2.2, in the

Population centre		$<$	200		
Population centre	200	−−	499		
Population centre	500	−−	999		
Population centre	1 000	−−	1 999		
Population centre	2 000	−−	2 499		
Population centre	2 500	−−	4 999		
Population centre	5 000	−−	9 999	maps	Village
Population centre	10 000	−−	14 999		Town
Population centre	15 000	−−	19 999	into	City
Population centre	20 000	−−	24 999		
Population centre	25 000	−−	49 999		
Population centre	50 000	−−	74 999		
Population centre	75 000	−−	99 999		
Population centre	100 000	−−	499 999		
Population centre		$\geq$	500 000		

Table 2.2: A mapping between two classification schemes

classification scheme on the left of the table, the classification of urban areas (population centres) is based on quantitative attributes, namely the population of the urban areas (the example is taken from the old Australian standard [SAA 1981]). In the classification scheme on the right, population is an attribute of the feature, and the classification is based on qualitative attributes, namely the type of urban area, which might be based on classifications used in statutes or ordinances. There is no obvious way to map the classes on the left-hand side into the classes on the right-hand side, unless the status of the population centres is stored as an attribute of the features (in the old Australian standard, for example, they are not, unless they are defined by the donor as non standard feature modifiers — see Section 5.4.3 below).

Problems will also be caused when mapping between poorly designed classifications.

2.3.7.2 Structures based on linear lists

The *linear list* is merely a list of all the feature classes, all on the same level. There is no inherent relationship between any of the classes.

For example, the American exchange standard uses a classification based on a linear list. They have *standard feature terms* (features that are defined with valid attributes) and *included terms*, or aliases, which are alternative names for the standard feature terms. The included terms are cross-referenced to the standard feature terms. The following is an extract from their classification [Moellering 1987a]:

Bridge		standard feature term
Bridge_superstructure		standard feature term
Brigalow	*see:* **Woodland**	included term
Brine_well	*see:* **Well**	included term
Brook	*see:* **Watercourse**	included term
Brush	*see:* **Woodland**	included term
Building		standard feature term
Building_complex		standard feature term
Built_up_area	*see:* **Place**	included term

The advantage of the linear list is that new classes are added easily without affecting the structure of the classification — they are merely defined unambiguously, given unique names and codes, and added to the list.

The disadvantage of the linear list lies in its lack of a structure. As all the classes are in a long list (usually alphabetical) they can prove difficult and inefficient to use when there are a substantial number of classes [Rugg & Schmidt 1986] — which is invariably the case. In a linear list, the classes cannot be grouped together logically, as there are no relationships between the classes. The result is that users take longer to classify features (especially those in classes that are not used often by the user) and a significant number of features get classified into the wrong classes.

2.3.7.3 Tree-like structures

Tree-like structures include fixed and variable level hierarchies and partially ordered sets. Figure 2.3 illustrates a tree-like structure.

In general, tree-like structures may be used to introduce inherent relationships between classes. A few broad classes are defined on the first level, and are refined on each successive level to distinguish further between the classes. Refinements of a particular class are *child classes* of that class, and a class that has associated child classes is their *parent class*. A class that has no children is a *leaf class*.

In tree-like structures, each class on each level has a class name, known as a *label*. Each label should be unique within the classification scheme. The ordered set of labels from the first level down to level n, including the label from each intermediate level, is known as the *path name* of the class on level n. It is preferable to use the path name of a class rather than the label of the class for its *class name*, because the path name identifies the class fully and provides a better indication of the nature of the class [Cooper & Scheepers 1989].

One could view any tree-like structure as a linear list, by taking the path name of each class as its name and disposing of the structure. In fact, they are often implemented as linear lists, although the user sees them in the format of the defined tree-like structure.

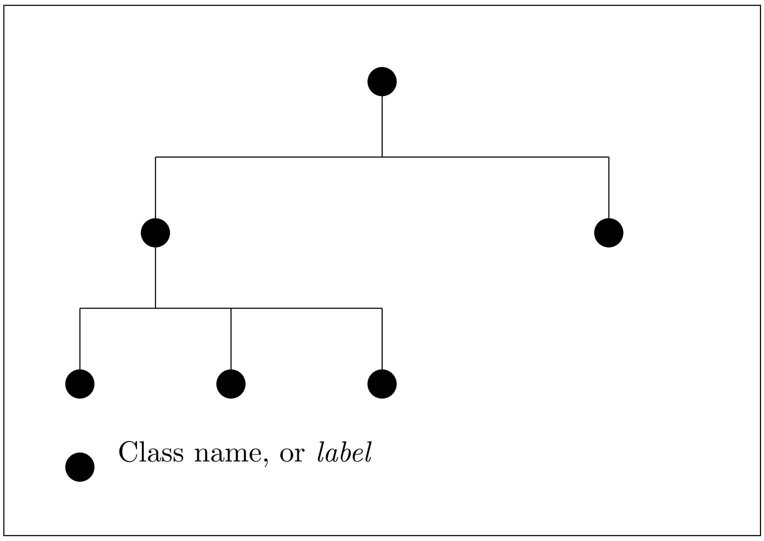


Figure 2.3: Tree-like classification structure

If a tree-like structure has several levels, path names may become rather long, especially if useful labels have been used, and specifying the complete path name for a particular class becomes inconvenient. Hence, use of encoding schemes, as assessed above, becomes desirable.

2.3.7.4 Structures based on fixed level hierarchies

The *fixed level hierarchy* is a tree-like structure with a fixed number of levels, with classes on every level, with all the leaf classes on the final level, and where each child class has one and only one parent class.

For example, the IHO's FACS is a classification based on a fixed level hierarchy. The following is an extract from FACS [CEDD 1986b]:

- Hydrography
  - Navaids
    - Beacon
    - Buoy
    - Leading light/Lights in Line
    - Light
    - Lighthouse
    - Light Sector
    - Light Vessel/Lightship
  - Dangers/Hazards
    - Danger/Hazard

Breakers (Offshore and dangerous)
Crib
Discolored Water
Eddies
Foul Ground
Kelp, Seaweed
Obstruction (Nautical)
Sunken Danger with Depth (Wire Dragged)

The main advantage of fixed level hierarchies over linear lists is that one is able to use the hierarchical structure to determine the correct class for a particular feature more easily.

There is a perceived disadvantage to fixed level hierarchies when compared to linear lists, namely that once the classification has been set up, it is difficult to add further classes. However, this disadvantage is only manifested when the user errs by making the classification scheme dependent on the coding scheme, and not vice versa (see Section 2.3.6 above). For example, in the NES classification, feature codes were assigned arbitrarily, and when the classification is expanded, the new feature classes will also be assigned arbitrarily.

The real disadvantage of the fixed level hierarchy is that all classes have to be refined down to the same (fixed) level — an unnecessary limitation.

2.3.7.5 Structures based on variable level hierarchies

The *variable level hierarchy* is a tree-like structure with classes on every level, where leaf classes may be on any level, and where each child class has one and only one parent class.

A variable level hierarchy is similar to a fixed level hierarchy with the exception that a class need only be refined if appropriate for one's view of the information. Thus, the classes within one's areas of specialty would be refined to many levels, while the first level classes that provide background information might not be refined at all [Scheepers *et al* 1986].

For example, the South African exchange standard uses a classification based on a variable level hierarchy. The following is an extract from its classification (from [Clarke *et al* 1987b]):

- Biology
  - Species Observation Point
  - Species Population Area
  - Biological Survey Site
  - Biome-type area
- Social and Cultural
  - Cadastral
    - Cadastral Beacon

Cadastral Boundary
Land Parcel
Servitude
Adminstrative Area
International
Provincial
Magisterial District
Proclaimed Restriction
State Forest
Nature Reserve
Social Statistical
Electoral Division
Polling District
Demographic Enumeration Area

The disadvantage of a variable-level hierarchy is that it is perceived as being difficult to implement because a complex coding mechanism is required. However, once the classification has been developed, the codes should be assigned automatically and transparently to the users. The implementation is then merely a case of mapping the path names of the classes (as they would appear in the user interface to a GIS) to their codes. Effectively, the classification is reduced to a linear list when encoded, but with the advantage that the user still sees the hierarchy which facilitates the correct selection of classes.

The disadvantage of the tree-like structures discussed above is that in the real world, a class might have more than one parent class. Thus, either the child class must be placed in more than one position in the hierarchy, or only one class may be selected as its parent. With the child class placed in more than one position in the hierarchy, there is a problem of ambiguity, in that the user of the classification might pick the incorrect class. With the child class having only one class as its parent, there is the problem that the users of the classification have difficulty finding the appropriate classification for a particular feature.

For example, in the British National Transfer Format (NTF) [Haywood 1986], a *Prison (Penal Institution)/Detention Barracks* appears in their classification and attributes scheme under both *Land Use* and *Buildings*.

2.3.7.6 Structures based on partially ordered sets

The *partially ordered set* (normally abbreviated to *poset*), is a variable level hierarchy where any child class may have more than one parent class, provided that the parent class is on any level in the hierarchy that is above the level of the child class. A parent may not be on the same level as its child [Van Biljon 1987a].

To date, to the best of the author's knowledge, no major classification based on posets has been prepared. Figure 2.4 illustrates a classification based on a poset structure (adapted from [Cooper & Scheepers 1989]). The following feature classes may be derived from this example:

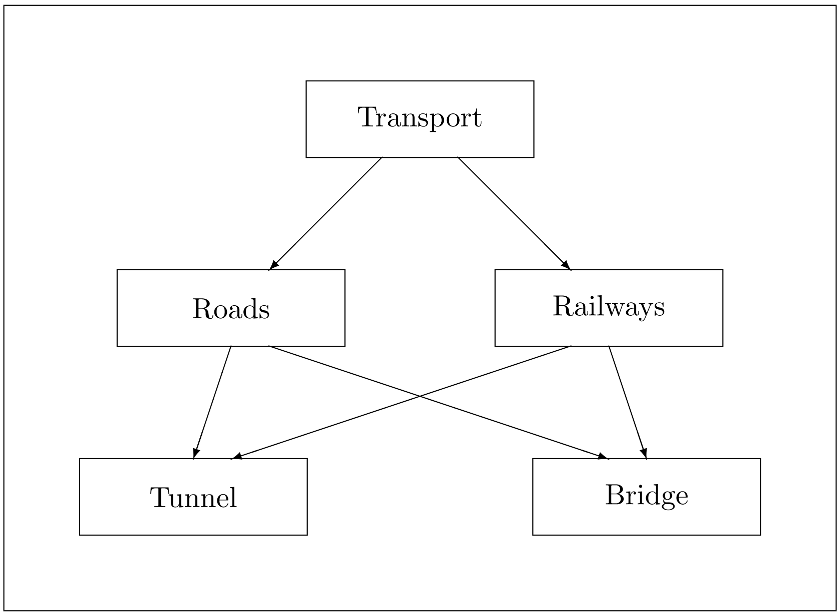


Figure 2.4: Classification based on a poset structure (adapted from [Cooper & Scheepers 1989])

Transport
Transport / Roads
Transport / Railways
Transport / Roads / Tunnel
Transport / Roads / Bridge
Transport / Railways / Tunnel
Transport / Railways / Bridge

Posets solve the problem of a class with more than one parent class. However, an interesting problem is introduced when one attempts to attach non-spatial attributes to child classes in a poset. This problem is discussed below in Section 2.3.8.

Another disadvantage of posets is that their visual representation may be complex. A graph drawn of a poset could have many intersecting connections and could have connections between levels that are far apart. However, through the coding mechanism and a menu-driven user interface, the complexity of the poset structure could be made transparent to the user [Cooper & Scheepers 1989].

When drafting a classification scheme based on posets, one must be careful to avoid ambiguous path names. These can be prevented by ensuring that all labels in the scheme are unique. This is not as onerous as it appears, as a scheme based on posets would need less labels than the same scheme based on a variable-level hierarchy.

2.3.7.7 Other structures

While it could be possible to use a network or relational structure for classification, infinitely long definition paths could be set up because of recursion [Cooper 1987a].

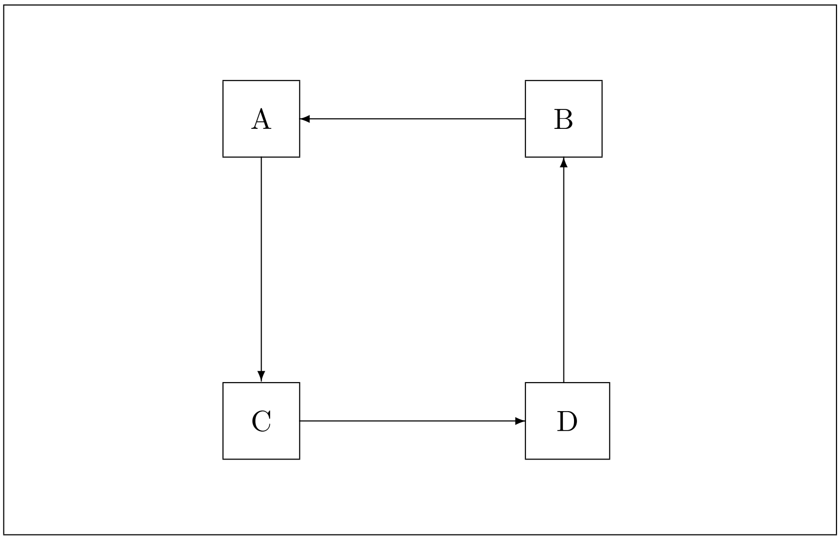


Figure 2.5: Recursion with a network classification structure

For example, in Figure 2.5, a recursive and infinitely long path name could be created, namely A / B / C / D / A / B / C / D / A / B / C / D . . . .

2.3.7.8 Recommendation of a structure to use

It is more natural for people to use a classification based on a hierarchical scheme rather than one based on a linear list, as shown by Rugg & Schmidt [1986]. Of the hierarchical structures for a classification scheme, it would appear to the author that posets are the most sophisticated and best yet devised. However, they are not yet well understood and much research has to be done on using posets for the underlying structure of classification schemes. Hence, the author would recommend the use of variable-level hierarchies, with the caveat that the implementer must bear in mind the problem of classes that logically fall under more than one parent class. The advantage of the variable-level hierarchy over the fixed-level hierarchy is that it is much more flexible and it is much easier to establish the classification scheme, as one does not have to define all the feature classes *ab initio*.

2.3.8 Classification structures and non-spatial attributes

There are some interesting problems which occur when one attaches non-spatial attributes to feature classes, some of which are related to the classification structure used. These problems are outlined below:

- **Inheritance:** should a class inherit the non-spatial attributes of its parent classes [Scheepers *et al* 1986]?

- **Common attribute definitions:** should non-spatial attributes be defined across all classes, or should they be defined for each class separately [Cooper & Scheepers 1989]?

- **Sharing attributes:** can non-spatial attributes and/or non-spatial attribute values be shared by more than one feature [Greenwood 1988]?

2.3.8.1 Inheritance of non-spatial attributes

The idea of the inheritance of non-spatial attributes is that a parent class could have a set of non-spatial attributes that are inherited by all its child classes. The attributes of the parent class would be generic to all the child classes, and defining the attributes at the parent level rather than for each of the child classes would help to ensure consistency. The example below is taken from Scheepers *et al* [1986]:

	Attributes:
Vegetation	*Species*
Trees	
Planted	
Forest	
Plantation	
Hedge	

In this example, the attribute *Species* is defined for the parent class *Vegetation*, and is inherited by all the child classes, namely *Vegetation / Trees*, *Vegetation / Trees / Planted*, *Vegetation / Trees / Planted / Forest*, *Vegetation / Trees / Planted / Plantation*, and *Vegetation / Trees / Planted / Hedge*. The consistency is ensured because all of the child classes of the parent class *Vegetation* should have the non-spatial attribute *Species*.

It is important to note that it is the set of non-spatial attributes that are inherited, and not the values of the attributes. That is, this mechanism is designed to facilitate the defining of a classification and non-spatial attribute scheme. However, by ensuring some consistency in non-spatial attributes, it also facilitates the use of the scheme.

With a poset structure, inheritance is complicated, as each of a class's parent classes would probably have different non-spatial attributes. The attributes inherited from one parent class might conflict with those inherited from another parent class. For example, using the example of the poset-based classification in Figure 2.4 above, the parent class *Transport/Roads* might have the non-spatial attribute *Surface material*, and the parent class *Transport/Railways* might have the non-spatial attribute *Rail gauge*. It would not be sensible for a single feature in the child class *Bridge* to inherit both these non-spatial attributes.

2.3.8.2 Common definitions for non-spatial attributes

In a classification and attribute scheme, should non-spatial attributes be defined across all classes, with the problem of ensuring classes are unique and definitions appropriate, or should the non-spatial attributes be defined for each class separately, with the problems of inconsistencies between classes and the effort of defining them for each feature class [Cooper & Scheepers 1989]? Research needs to be conducted to answer this question, as there is no clear answer yet.

An example of a scheme with attributes defined uniquely across all feature classes is the IHO's FACS [CEDD 1986b]. Each attribute is defined by an unique three-letter code. For example, the attributes *Radar Significance Factor*, *Existence category*, *Use status* and *Hydrographic location category* are common to many features. Unfortunately, because they are so wide ranging, the purpose of each attribute *vis-à-vis* each feature class can become vague. For example, the following are the 18 valid values for the attribute *Existence category* [CEDD 1986b]:

0	Unknown
1	Definite
2	Doubtful
3	Reported
4	Prominent
5	Under construction
6	Abandoned/non-operational
7	Destroyed
8	Dismantled
9	Non-traversable/non-navigable
10	Proposed
11	Temporary
12	Alternative
13	Unsurveyed
14	Marked
15	Unmarked
16	Limits and info unknown
17	Not to scale

In fact, it is common for a classification and non-spatial attribute scheme to have all attributes defined uniquely across all feature classes — this technique is used in the American SDTS [Moellering 1987a], the British NTF [Haywood 1986], and the South African NES [Clarke *et al* 1987b].

An example of a scheme with attributes defined separately for each feature class would be one where attributes such as *Height*, *Clearance*, *Width* and *Breadth* are defined independently for each feature without regard for their usage in other features. Then, what is defined as the *Height* of one feature (such as a *Bridge*) might be logically the same as what is defined as the *Clearance* for another feature (such as a *Tunnel*).

The advantage of defining non-spatial attributes across all classes is that one maintains consistency — it facilitates the user's understanding of the attributes. However, the disadvantages are that it is more difficult and time-consuming to define all the non-spatial attributes, and one could end up with possible values for an attribute that are not relevant for the particular feature class in question.

2.3.8.3 Sharing non-spatial attributes between features

Sometimes, it is desirable for two features to share the same data that comprises the value one of their non-spatial attributes, for example, two erven that share the same owner. In this case, the two features have a common non-spatial attribute, and share the same value for that non-spatial attribute.

It is also possible for two features to share the same data, but for different (but similar) non-spatial attributes. For example, an attribute of a catchment area could be the water that daily flows downstream out of it (its water export), while another could be the water that flows into it daily from upstream (its water import). The volume of water exported by one catchment is exactly the same as the volume of water imported by the catchment immediately downstream of it.

The sharing of non-spatial attributes by two or more features is similar to the sharing of spatial attributes by coincident features, which is addressed by topology (see Section 2.6 below). If the two features share the same non-spatial attribute, as opposed to each having a separate copy of it, then consistency is ensured in the data base.

The problem of sharing attributes was solved recently [Cooper & Greenwood 1993], and has been implemented in Version 2 of the NES [Standards Committee 1991]. Rather than attaching a non-spatial attribute (or set of attributes) directly to a feature, the attribute (or set of attributes) is defined in three relations[3], and a fourth relation attaches the non-spatial attribute (or set of attributes) to one or more features.

2.4 Spatial attributes

Unfortunately, many different terms are used to describe spatial attributes — for example, *polygon*, *area*, *region* and *face* are all terms used by different people to describe the same type of spatial attribute. One of the philosophies of the project team drafting the National Exchange Standard was to keep the terminology as simple as possible, and to have as few variables as possible. There are only five basic types of spatial attributes (not including those of three and higher dimensions), namely *nodes*, *chains*, *arcs*, *regions* and *matrices*. All other types two-dimensional of spatial attributes are special cases of these five.

By comparison, the original version of the American standard defined 17 cartographic objects (the term the Americans use for spatial attributes), together with 6 special

[3]Two relations define the structure of the non-spatial attribute, or set of attributes (which could be a table, for example), and the third contains the actual data.

cases [DCDSTF 1988]. In the latest version, they have 29 different types of objects [DCDSTF 1991]! The author would suggest that most GIS users would have difficultly distinguishing between a "G-polygon", a "GT-polygon composed of rings", a "Universe polygon composed of chains" and a "Void polygon composed of rings" — to name but four of their seven different types of polygon objects — and when confronted by such terminology, some users would be reluctant to try to implement the American standard.

These basic spatial attributes are described below generically for n dimensions. However, in practice they are used in only two or maybe three dimensions. The value of a spatial attribute is a subset of the n dimensional space within which the data are defined. Four feature types, whose positions are described by the five spatial attributes, are also defined below.

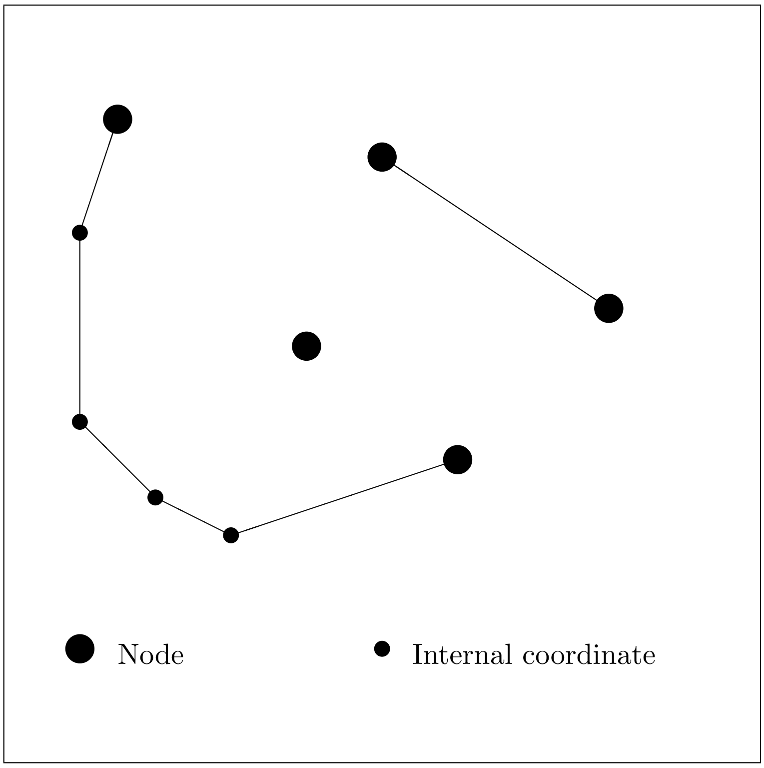


Figure 2.6: Nodes and chains

2.4.1 Node

A *node* is a 0-dimensional object with an n-tuple of coordinates specifying its position in n-dimensional space. That is, a node is a point that does not have any dimensions, and it can be in only one position at any one time. Nodes demarcate the ends of chains and the point of intersection of chains. Figure 2.6 illustrates nodes and chains.

The position of a *point feature* is described by a single node.

2.4.2 Chain

A *chain* is an ordered, undirected sequence of two or more connected n-tuples of coordinates. The first tuple in the chain and the last tuple in the chain are nodes — they could be the same node, in the case of a chain that forms the boundary of a region, for example. The *internal coordinates* of the chain are those coordinate tuples that lie between the start and end nodes, and they consist of a string of zero or more coordinate tuples. In the case where a chain consists of a straight line between two nodes, the chain does not have any internal coordinates. The direction of the chain is defined when the chain is used in a specific feature or region. Figure 2.6 shows a free-standing node, a chain with no internal coordinates, and a chain with several internal coordinates.

The sequence of coordinate tuples is ordered because they are stored sequentially in a GIS, but they are undirected (that is, the line segments connecting the internal coordinates are not vectors) because the chain may be traversed in either direction by the line feature or region whose position or part thereof is represented by the chain. For example, Figure 2.7 shows a chain XY that forms the boundary of two regions, A and B. Assuming that the start node of the chain is X and the end node is Y, that is, that the internal coordinates are ordered from X to Y, then region B uses the chain forwards,

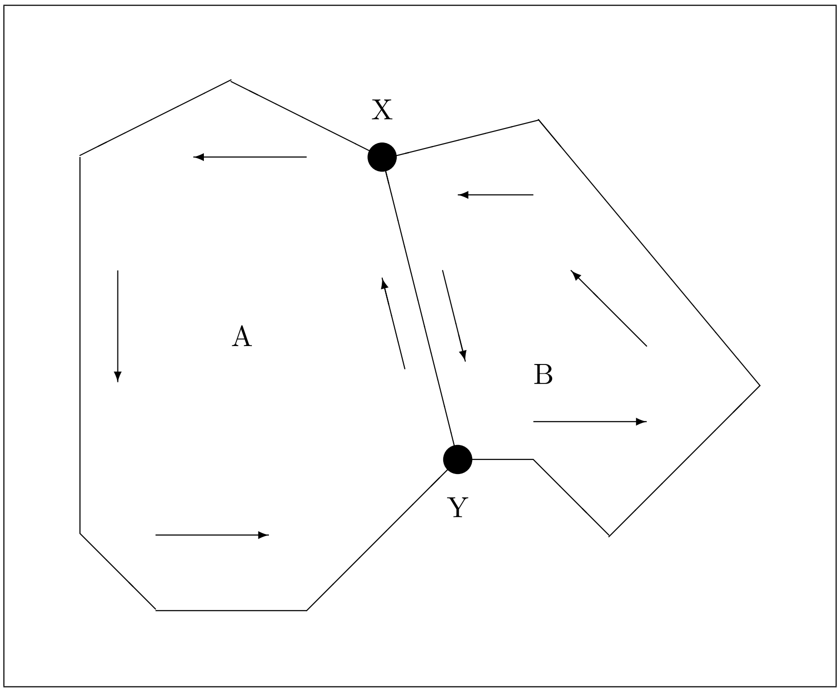


Figure 2.7: Chains

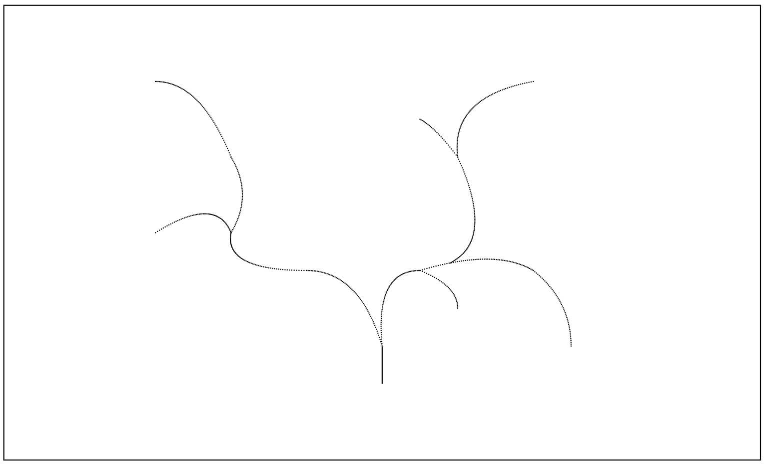


Figure 2.8: Line feature comprising several chains

that is, in the direction that the internal coordinates are ordered in the GIS. Region A uses the chain backwards, that is, in the opposite direction that the internal coordinates are ordered in the GIS.

The definition of a chain refers to the tuples that make up the chain, but not to the connections between the tuples. For analytical purposes, these connections are normally considered to be straight lines, though for display purposes, a curve (such as a Bezier curve or a B-spline) might be passed through the tuples.

2.4.3 Arc

An *arc* is any continuous part of the circumference of an ellipse with a node at each end of the arc. An arc would be used to describe the curve of a bend in a railway line, for example. Most curvilinear lines are described by chains (rather than arcs), with the density of tuples along the chain being increased at curves to approximate the curve. This is because it is easier to work with chains.

The position of a *line feature* is described by a set of one or more chains and/or arcs, which do not necessarily form a continuous object. For example, Figure 2.8 shows a stream which consists of several tributaries.

2.4.4 Region

A *region* is the interior of a continuous and closed sequence of one or more chains and/or arcs, known as the region's outer boundary. The region's outer boundary is formed in exactly the same way that line features are formed by chains and/or arcs. The boundary must consist of a continuous and closed sequence, that is, one without any breaks, otherwise it would not be possible to determine what constituted the interior of the boundary (and hence, the region). In other words, the boundary must start and end at the same node.

The boundary of a region may not intersect itself, as this would mean that the interior of the region would not be definable, but the boundary of the region may touch itself. This is illustrated in Figure 2.9, where A and B are two regions forming part of the same area feature, where D is excluded from region C (see Section 2.6 below), and where the boundary of region C touches itself at the position indicated by the arrow.

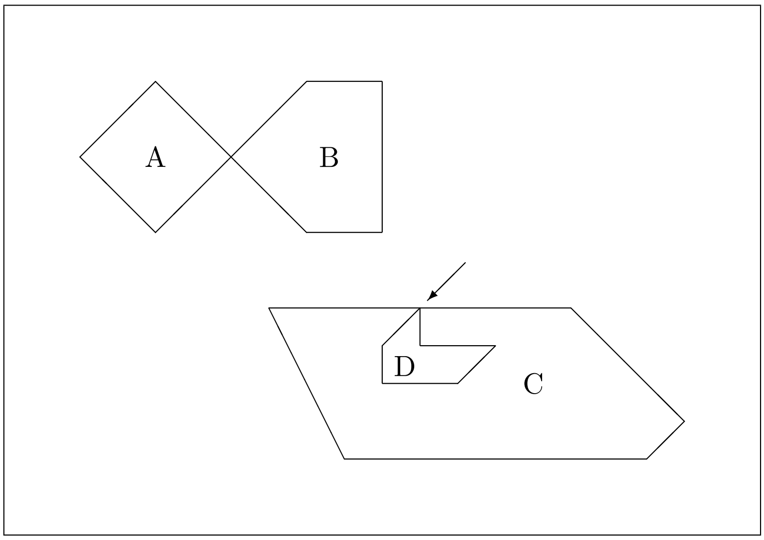


Figure 2.9: The boundaries of regions

The position of an *area feature* is described by a set of one or more regions, which do not necessarily form a continuous object. For example, the area in South Africa known as Bophuthatswana actually consists of six separate regions that are not contiguous.

2.4.5 Matrix

A *matrix* consists of an n-tuple of coordinates, specifying its position, and an m-dimensional rectangular tessellation [4] of cells or pixels, where each cell has a data value encoded in a pre-defined format. The position of each cell may be determined from the origin of the matrix, the cell's position within the matirx, and the dimensions of each cell.

The position of a *grid feature* is described by a set of one or more matrices, which do not necessarily form a continuous object. Each matrix also provides an array of non-spatial attributes for the grid feature. For example, a grid feature might consist of a pair of geocoded, overlapping stereo satellite images.

[4] A *tessellation* is a repeating pattern of either regular or irregular shapes [Moellering 1985].

2.5 Compound features

2.5.1 Introduction to compound features

A *compound feature* consists of one or more other features. This allows one to build a hierarchy of features, for those occasions when the individual constituent features have their own non-spatial attributes (and classification), but together they have other additional non-spatial attributes and a classification [Cooper 1989a]. A compound feature could consist of only one feature. For example, South Africa is divided into statistical regions, which could be modelled as compound features consisting of census districts. Most statistical regions consist of several census districts each, though there are some that consist of only one census district each.

The compound feature itself does not have any spatial attributes directly, but rather the spatial attributes of the compound feature are the aggregation of the spatial attributes of the constituent features.

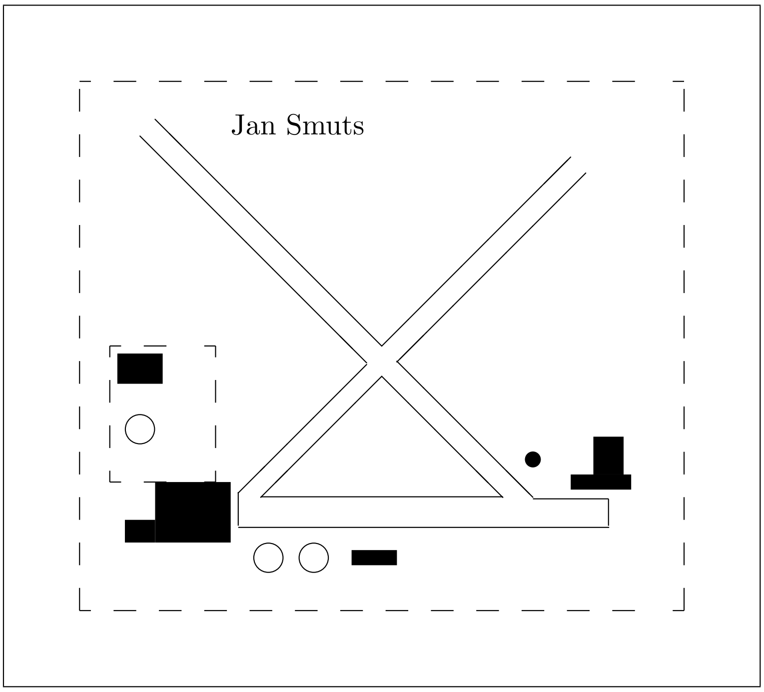
2.5.2 Using compound features

Figure 2.10 (a) shows an example of a compound feature, namely an airport. The airport consists of a number of constituent features, such as the runways, hangars, control tower, terminal building and the perimeter fence. Each of the constituent features have their own attributes, for example, the runways have attributes such as their length, width and loading capacity, while the terminal building has attributes such as the number of passengers per hour it can handle, and its amenities. The compound feature itself has attributes such as its name, its classification (domestic, international, private, commercial and/or military) and its destinations. The compound feature may also inherit attribute values from its constituent features.

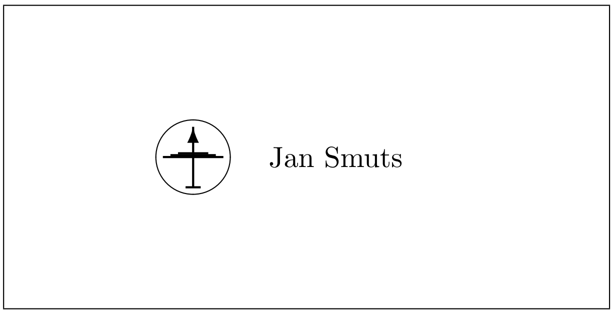
In addition, each of the constituent features have their own symbology. Through alternate spatial attributes (see Section 3.2), the compound feature could also have its own symbology. In Figure 2.10, the airport is shown at both a large scale (a) and a small scale (b). On the large scale map, each of the constituent features is represented by a different feature, and the compound feature itself is not shown (though it is labelled), while on the small scale map, only the compound feature is shown.

Compound features also allow one to perform operations on the constituent features as well as on the compound feature as a whole. For example, census districts consist of enumerator areas, and in a GIS, the census districts could be stored as compound features consisting of enumerator areas. In addition to ensuring consistency in the attributes (no demographic statistics would be stored for the census districts explicitly, but they would rather be drawn from the constituent enumerator areas), this would allow one to perform statistical analysis (and to display the results) for either the enumerator areas or the census districts. In addition, the demographic statistics could be combined with other statistics recorded for magisterial districts [5], such as statistics on economic activity.

[5] Census districts are largely the same as magisterial districts.



(a) The airport as a collection of constituent features



(b) The airport as a single feature

Figure 2.10: An example of a compound feature — an airport

2.6 Topology

2.6.1 Introduction to topology

In mathematics, *topology* is the "study of geometrical properties and spatial relations unaffected by continuous change of shape or size of figures" [Oxford 1983]. The topology of geo-referenced data is based on mathematical topology. "Topology is concerned with establishing the location of objects, identified by points, lines, polygons and surfaces, with respect to each other in a non-metric relational structure" [Dale & McLaughlin 1988]. That is, topology is information on the spatial relationships inherent in the data. These relationships are between the spatial attributes of the same or different features. In topological space, there is some arbitrariness in the positioning of locations and the shape of lines, but the only relation that matters is contiguity [Gatrell 1991].

Langran & Chrisman [1988] identify three advantages of topology:

- **Spatial structure:** topology makes the spatial structure of the data evident, "which means that many algorithms are simpler and speedier because spatial searching is reduced" [*op. cit.* pg 7].
- **Trapping data errors:** topology allows one to check whether or not the data's spatial structure adheres to the model's rules for topological integrity, which allows one to detect errors such as gaps, slivers and overshoots. This protects the quality of the data.
- **Reducing storage requirements:** topology reduces data redundancy, which in turn reduces storage requirements. Most digital spatial data consists of the internal coordinates of chains: since many chains may be shared by several features, being able to store the internal coordinates of a chain only once can reduce the storage requirement significantly.

Topology is used in:

- **Network analysis:** where the inclusion of sequences of connectivity of segments allows the selection of such details as shortest paths or emergency access;
- **Neighbour relations:** by knowing the neighbours of a given polygon such as a land parcel;
- **Overlay processing:** where new polygons can be created from the overlaying of existing polygons, such as soils over land use [Dale & McLaughlin 1988].

Topology has to be stored explicitly within a GIS, making it appear artificial. This is because, in a machine, human intuition is absent [White 1984]. However, topology is a natural part of many systems and the human eye/mind combination is used to associate by contiguity, for example [Chrisman 1987]. When one sees a bridge, for example, one associates it with the road that it carries and the river that it crosses, but these links have to be explicit in a GIS (typically, it is done by having a node at the intersection of the road and the river, where the node defines the location of the bridge).

Some people confuse the terms *topology* and *topography*. Topography is a detailed description or representation on a map or chart of natural and artificial features of a town district, etc [Oxford 1983].

2.6.2 Types of topology

The topology of geo-referenced data is not yet fully understood, but the following are types of topology:

- **Coincidence:** this occurs when more than one feature shares the same spatial attributes. An example would be the Orange River where it is the boundary between the Cape Province and the Orange Free State — the same chain then forms part of the boundary of the Cape Province and of the Orange Free State, and of smaller administrative units, such as magisterial districts.

- **Intersection:** this is a special case of coincidence, where two or more chains meet at one point, such as where a road crosses a river.

- **Inclusion:** this occurs when features lie wholly within the boundary of an area feature and form a part of the area feature [Cooper 1987c]. An example would be each of the towns in Natal — they all lie within the province . Inclusion is normally not modelled explicitly in a GIS as to do so would place an enormous burden on the GIS, and as it is relatively easy to calculate inclusion from the spatial data.

- **Exclusion:** this occurs when features lie wholly within the boundary of an area feature but do not form part of the area feature [Cooper 1987c]. These excluded features are also known as *islands*, as the most common example of exclusion is an island within a lake — the island does not form a part of the water body. Exclusion is dependent on the semantics of the data, and has to be identified explicitly. It cannot be determined automatically from the spatial data, but might be inferred by an expert system using the non-spatial data as well.

- **Containment:** this occurs when a feature lies wholly within another feature. Inclusion and exclusion are the two forms of containment.

- **Adjacency:** this occurs when area features share a common boundary and lie on opposite sides of the boundary. For example, the Cape Province is adjacent to the Orange Free State.

Some topologies have to be stored explicitly (such as exclusion), while others may be stored implicitly in the geo-referenced data, or may be calculated from the data — depending on the actual data structures used (see Section 3.6 for a discussion on some of these data structures). For example, in a properly organised GIS, it should be possible to detect intersections by identifying nodes shared by two or more chains, or to determine regions adjacent to a target region by identifying those regions that are not coincident with the target and that share boundary chains with the target region.

2.6.3 Topological maps

Perhaps the most famous topological map is the one of the London Underground issued by London Regional Transport, shown in Figure 2.11. Over the years, the shape or structure of the map has changed, for reasons of cartographic licence, to accommodate the addition of new lines and stations, and the removal of old stations. While the positions of some stations have moved on the map, their physical position in London has not changed. This emphasises that topological data are invariant under deformation.

A topological map allows one to emphasise the structure of data rather than the exact locations, which is important when relationships between features that are close together on the map have to be shown. For example, it has been observed that psychological distance in cognitive maps is primarily dependent on route distance rather than Euclidean distance. The design of the London Underground map (and many other subway maps) takes advantage of this fact [Buttenfield & Mackaness 1991]. This scheme is now also used by many transport companies for maps of bus routes and railway networks, as well.

2.7 Digital temporal information

While time is sometimes very important in geographical analysis, recording and modelling the effects of time in geographical information systems is not yet well understood. For example, Langran's book *Time in geographic information systems*, published in 1992, has been described as "the first book that tackles the conceptual and practical issues of handling time in a GIS" [Stuart 1992]. As digital temporal information is not yet a significant issue with respect to the exchange of digital geo-referenced information, such information is only described briefly here.

Similarly to the manner in which topological structures improve spatial information processing, *temporal* topological data structures could improve temporal information processing, through facilitating quality control and temporal analysis. Such a structure would facilitate queries such as (from [Langran & Chrisman 1988]):

- what was the previous state or version?
- what has changed (during a period, or at a place)?
- what is the periodicity of change?
- what trends are evident?

Langran [1989] describes three facets of temporal information that are particularly difficult to treat using standard data base methods, namely *constant identity*, *two concurrent clocks*, and *incremental attribute change*:

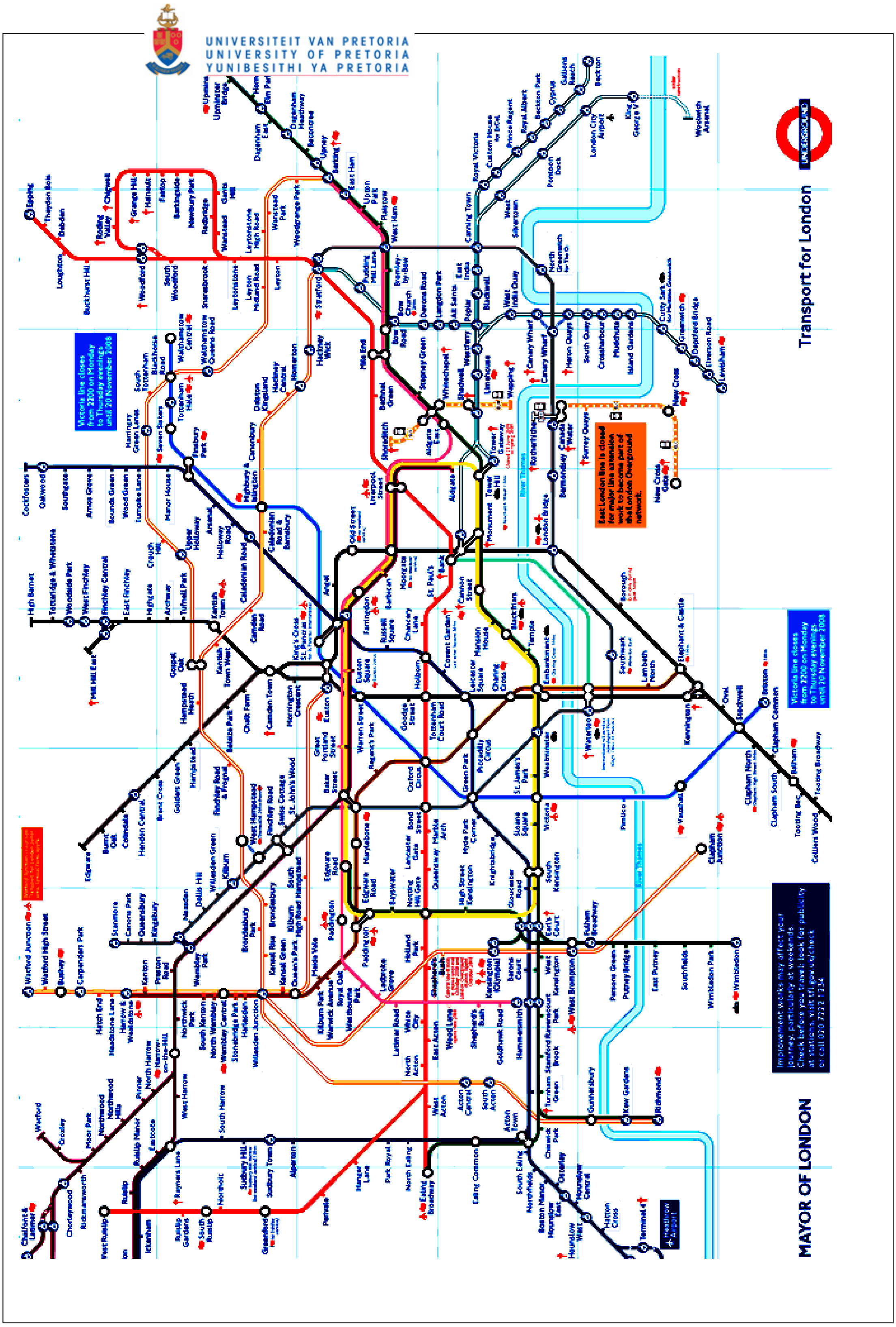


Figure 2.11: The map of the London Underground

- **Constant identity:** How does one recognise different versions of a changing object as the same object? What magnitude of change causes an entity to become a new entity rather than a new version of the old?

- **Two concurrent clocks:** It is critical to distinguish between when events occur in the real world and when the data base records the events — that is, *world time* vs *data base time*. Unless a system maintains records of both the world and data base times, it cannot describe properly events that did not occur as scheduled. That is, the data base should show the sequence in which events occurred in the real world, as well as the sequence in which such events were recorded in the data base. This is important in situations where current events affect one's perception of the past. For example, a particular decision might have been made based on the contents of the data base at the time the decision was made. If one is evaluating that decision at a later stage, and one cannot view the data base in the state that it was in when that decision was made, then that past decision could appear unjustly flawed, because of changes that had been made to the data between when the decision was made and when the decision was evaluated.

- **Incremental attribute change:** Change to a feature can involve one or more attributes. A feature may have only one set of attributes per time slice; a set of features may be defined to share one set of attributes, even when the attributes change; or a feature and its attributes may be clocked by several measures, for example, when a system traces both world and data base time. The problem is that these different relationships between features and attributes require different mechanisms for recording them.

Newell *et al* [1992] identified three additional problems that affect temporal information in a GIS data base:

- **Length of DBMS transactions:** While normal commercial data base management system (DBMS) transactions typically last a fraction of a second, GIS users often wish to work for a lengthy period, maybe even weeks, before releasing their updates for others to see [Newell *el al* 1992]. In the interim, other users will need to access the data being updated (even if it is an old version), so the traditional DBMS method of transaction locking could cause a problem.

- **Merging updates:** Updating a GIS's data base is an ongoing process, as data are captured or acquired from other GIS data bases. These updates have to be managed carefully, as one might receive simultaneously several updates from different sources that conflict with each other. This is also known as the *versioning* problem, that is, keeping track of different versions of the data.

- **Limitation of pilot studies:** To start a project, most organisations use a pilot study: a simplified data model, only one or two users, and test data that can be thrown away if the pilot data base becomes corrupted. However, the situation in a production environment is just the opposite: a complex data model, a large number of users, concurrent activities, and a large investment in the creation of the data base. The problem of version management could dominate all data base activities in a production system, and yet not manifest itself at all in a pilot project [Newell *el al* 1992]. Problems due to the limitations of pilot studies are, of course, not limited to the temporal component of a GIS.

There is also a need for keeping a history of changes, both for audit purposes and for providing historical information. For example, it has been reported to the author that in one leading European mapping agency, when they switched to digital production of their very large scale mapping, they stopped keeping records of the changes for a period. With their manual system, they had the paper maps prepared by their surveyors which provided the record of change. The result is that in the agency, there is now *no* record of changes that occurred for a period of 1–2 years at the end of the 1980s. In addition, a small part of the data set became corrupted, and the corruption was only discovered after the corruption had passed through all their generations of backup tapes. The result was that the area had to be resurveyed from scratch.

Langran & Chrisman [1988] identified three methods that have been used for conceptualizing geographical temporality, namely *time-slice snapshots*, *base map with overlays*, and *space-time composite*. Miller [1991] identified a further method, namely the *space-time prism*.

2.7.1 Time-slice snapshots

This model consists of a sequence of views (snapshots) of the data base taken at various appropriate times and showing the data base at that instance. The intervals between the time slices are not necessarily equal. Time-slice snapshots are illustrated in Figure 2.12.

The key to the problems inherent with snapshots is that they represent states, but do not represent the events that change one state to the next. They provide no explicit representation of versions of features or their mutations. Time-slice snapshots are the temporal equivalent of the formless spaghetti data structure, with which they share three major shortcomings (taken from [Langran & Chrisman 1988]):

- **Hidden structure:** Because snapshots capture states and not versions, the boundaries between versions are difficult to locate.
- **No error trapping:** With no understanding of temporal structure, rules to enforce logical integrity are difficult to devise.
- **Redundant storage:** Regardless of the extent of the change, a complete snapshot is produced at each time slice, which duplicates all the unchanged data.

2.7.2 Base map with overlays

An “opaque” base map is stored in the data base, defining the state of the data at T_0 (the beginning of time, as far as the data base is concerned). Similarly to the time-slice

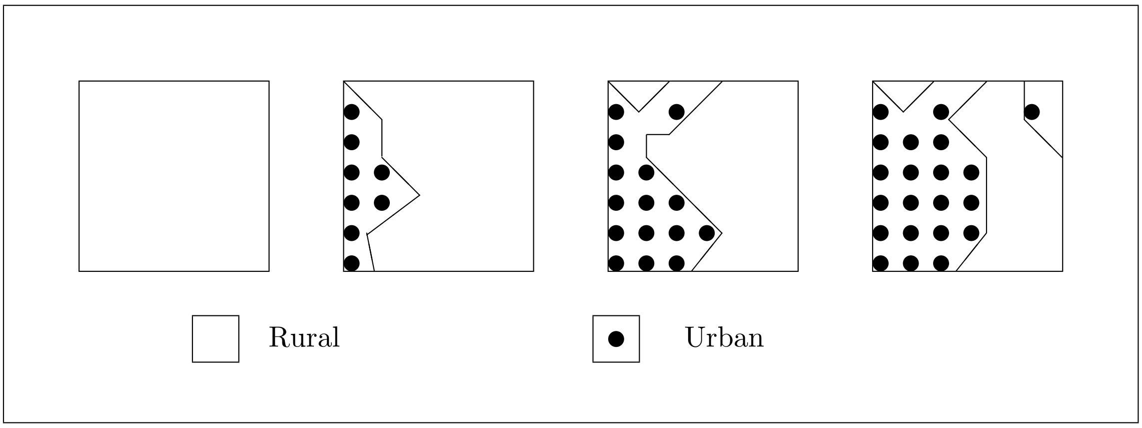


Figure 2.12: Images of time: time-slice snapshots, adapted from [Langran & Chrisman 1988]

snapshots, at appropriate (and not necessarily even) intervals, the changes that have occurred since the previous update are recorded, but in this instance, on "transparent" overlays. A base map with overlays is illustrated in Figure 2.13.

A new overlay is then created for each data base update session, to represent transactions in data base time. World time is recorded using dates or codes in the overlay's change notations. Thus, neighbours in data base time are located on adjacent overlays while neigbours in world time are not, unless these times are synchronized. These times would not be synchronized when the order of updates to the data base do not reflect the chronological sequence of the changes in the real world. Such problems would occur when updates are received from different sources, or when one is populating the data base with both current and historical data, for example.

Base maps with overlays are the temporal equivalent of a topological structure, and they have the following assets (taken from [Langran & Chrisman 1988]):

- **Temporal structure is evident:** Temporal neighbours are located by finding the mutation that separates them.
- **Errors can be trapped:** because improbable events can be prohibited.
- **Minimal redundancy:** Use of storage is spartan as each object version is stored only once.

2.7.3 Space-time composite

Space-time composites are a variation of the base map and overlays model. Rather than retaining the change information on separate overlays, the base map becomes a

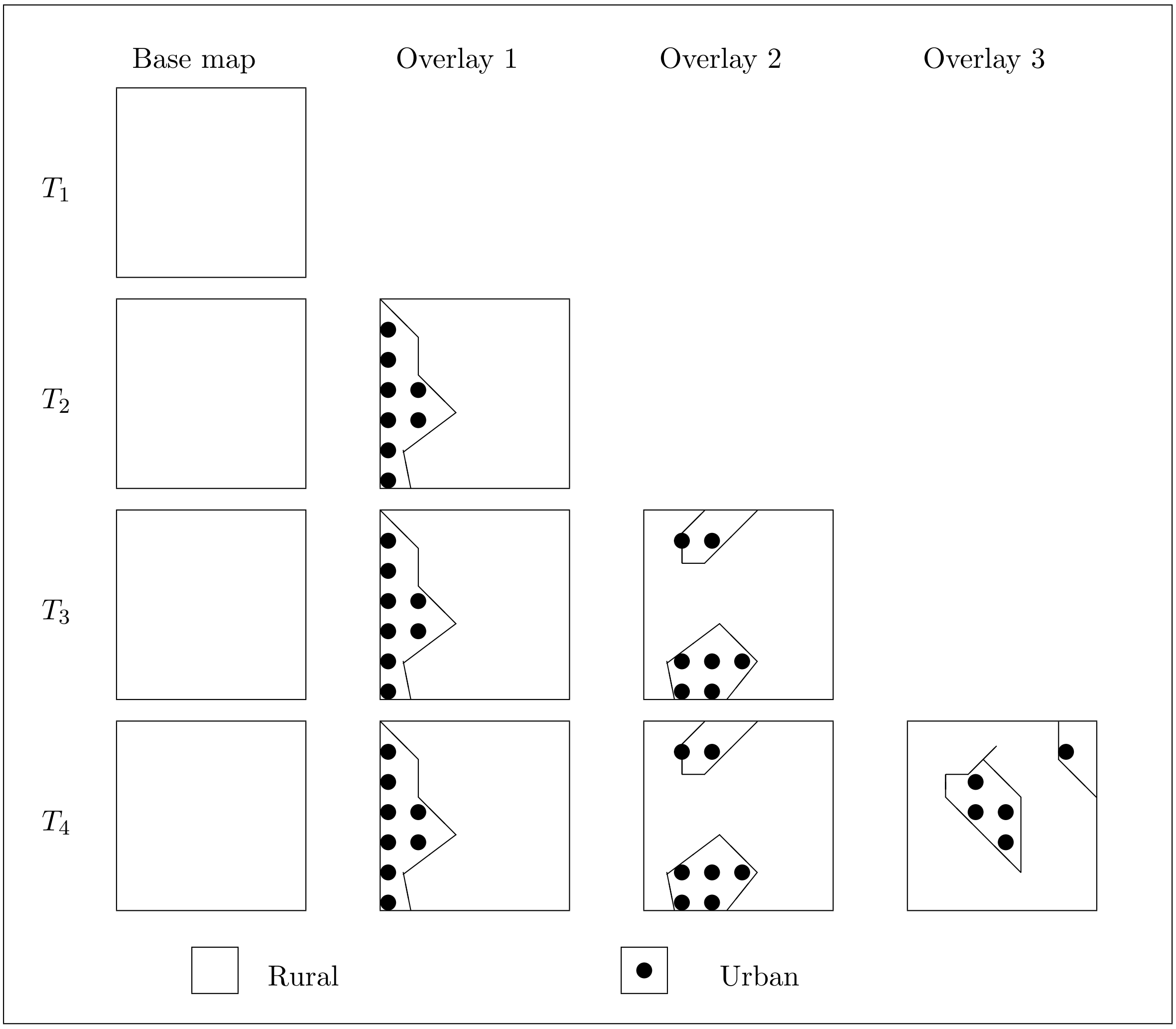


Figure 2.13: Images of time: base map with overlays, adapted from [Langran & Chrisman 1988]

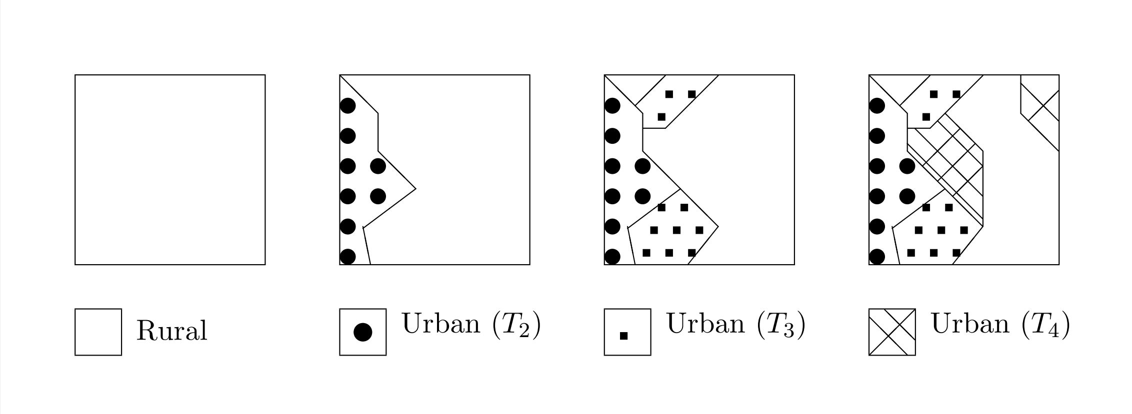


Figure 2.14: Images of time: space-time composite, adapted from [Langran & Chrisman 1988]

temporal composite built from accumulated geometric changes. Space-time composites are illustrated in Figure 2.14.

Each change causes the changed portion of the data to be separated from its parent object, becoming a new, discrete object with its own distinct history. Hence, the representation decomposes over time into increasingly smaller fragments, each of which references a distinct set of temporal attributes.

The advantage of the space-time composite model over the base map and overlays model is that the former is space-filling[6], which makes it less error-prone, and that no simple means of structuring the base map and overlay data is evident (though it might exist) [Langran & Chrisman 1988].

2.7.4 Space-time prism

> A *space-time prism* delimits what can be physically reached by an individual from specified locations during a given interval of time. The prism is determined by the location(s) at which the individual must be at the beginning and end of the interval, any time required for participation in activities during that interval, and the rates at which the individual can trade time for space in movement (ie: travel velocities) through the environment. The prism models of accessibility of an individual within a particular spatial and temporal context and can provide a valuable measure of individual accessibility [Miller 1991].

[6] A model is space-filling when for each data set, at any location in the area of interest, there is one and only one polygon. Most of the overlays will not be space-filling as they will only contain data for those areas where change has occurred, which is unlikely to be for the entire data set.

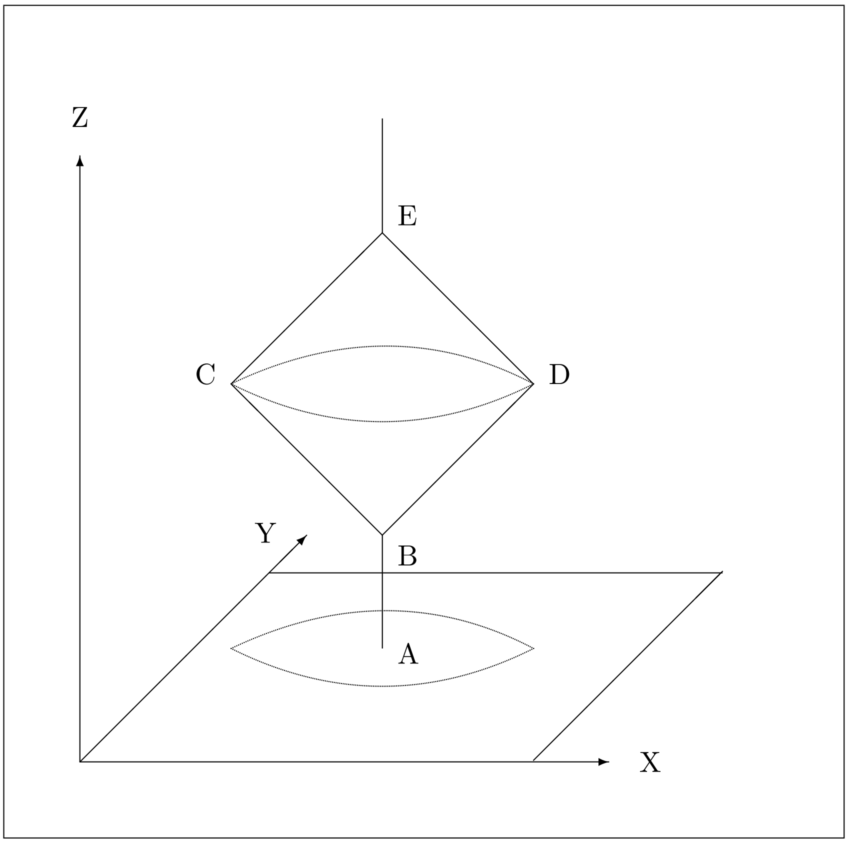


Figure 2.15: Images of time: space-time prism, adapted from [Miller 1991]

Space-time prisms are illustrated in Figure 2.15. The Z axis represents time, while the X and Y axes represent space. The space-time prism, or potential path space, delimits locations that the individual could visit at specific times. Figure 2.15 represents a simple space-time prism, in which the individual has to spend some time at one location (from point A to point B in the figure), and then has time to visit other locations, but must return to the same location by a certain time (at point E). The circle passing through points C and D delimits the boundaries of the spatial area that the individual can visit.

In this example, it is assumed that the individual has a constant and uniform velocity of travel. That is, the model does not take into consideration stop and start times, or variable velocities (such as walking *vs* running). It also assumes that the individual must end where they started. In fact, for modelling accessibility, the model is simplified even further by using just the projection of the prism onto the $X - Y$ plane, which is known as the potential path area (PPA). Miller [1991] concludes that "the most valuable aspect of the space-time prism is that it allows the direct incorporation of considerations of accessibility into locational analysis and transportation planning.

2.7.5 Modelling digital temporal information

As can be seen, the models that have been proposed for modelling the time component of digital geo-referenced information do not offer the perfect solution. Yet another alternative could be *alternate spatial attributes* (see Section 3.2 below).

2.8 Summary

In this chapter, an analysis has been presented of the fundamental nature of digital geo-referenced information, which is centered around the concept of a feature. Features have attributes, which can be spatial or non-spatial. Non-spatial attributes and their close link to the classification of features have been assessed. While classifying features is a long and tedious task, the development of classification structures is more interesting, and is an area that needs more research to determine what is the optimal structure to use.

The two-dimensional spatial attribute primitives, the topology that links spatial attributes together, and links spatial attributes to features, and compound features, which consist of other features, have been analysed. Much research needs to be done on three-dimensional geo-referenced information, and complex interactions between features, such as between compound features and their constituent features.

One aspect of the fundamental nature of digital geo-referenced information that requires much research is that of digital temporal information. The need for incorporating such information into a GIS and the problems associated with temporal information have been assessed, and the key models that have been proposed for digital temporal information in a geo-referenced context have been analysed.

Chapter 3

Geo-referenced data issues

Having analysed the fundamental nature of digital geo-referenced information, some of the higher-level types of information, and other issues, will be analysed, as follows:

- Section 3.1 reviews *digital terrain models*.
- Section 3.2 introduces *alternate spatial attributes*, a mechanism allowing a single feature to have any number of spatial attributes. Alternate spatial attributes are an advanced concept, and NES is the only exchange standard that caters for them.
- Section 3.3 assesses *data quality*, a very important, but oft neglected, aspect to digital geo-referenced information.
- Section 3.4 analyses *integration*, which is the manner in which various sets of geo-referenced data are combined.
- Section 3.5 analyses *symbology*, which is the graphical representation of digital geo-referenced information.
- Section 3.6 analyses several *abstract concepts made concrete*, which explain how the architectures of, and user interfaces to, GISs are affected by the developers' understanding of fundamental concepts of digital geo-referenced information.

3.1 Digital terrain models

3.1.1 Raster-based digital terrain models

A *digital terrain model* (DTM) is the most common form of raster digital geo-referenced information (see Section 1.4.4). A DTM is a digital model of any single-valued surface covering a portion of the earth's surface. The most common form of DTM is the *digital elevation model* (DEM), and confusingly, the term DTM is often used in the place of DEM (for example, in Baltsavias *et al* [1991]). DTMs can also model phenomena such as temperature, rainfall, gravity, population density and surface roughness.

To recap, a tessellation is a repeating pattern of some shape, and a rectangular tessellation is a grid of rectangles all of the same size. A DTM consists of data stored as a $2\frac{1}{2}$-dimensional rectangular tessellation, with a 2-dimensional matrix of elements as a base (providing the location) and a value associated with each cell. All cells in a DTM represent fixed areas on the earth all of the same size. A DEM consists of a tessellation of elevations of the earth's surface above or below a geoid. Each cell's value represents the elevation for a single point, typically at the centre of the cell or at the bottom left-hand corner of the cell. The elevations recorded in each cell do not constitute a third dimension — they are attributes of the cells rather than describing part of the location of the cells.

Such raster-based models of the earth's terrain, also known as *altitude matrices*, are useful for calculating contours, slope angles and aspects; for performing hill shading and creating perspective views (see below); for analysis of cross-country visibility; and for the automatic delineation of catchment basins. However, they have a few disadvantages:

- Because they consist of a regular grid, there is a large amount of data redundancy in areas of uniform terrain (such as in the flat parts of the Karoo, for example).
- They cannot be adapted to areas of differing relief complexity without changing the grid size. Often, the grid size is too coarse to be able to represent all the critical features of the terrain, such as peaks, pits, passes, ridge lines and stream courses. The misrepresentation of these features may lead to problems when attempting quantitative geomorphometric analyses [Burrough 1986]. This is especially important in areas of generally uniform terrain, such as the Karoo, where one might miss representing the stream beds, or one might misrepresent the nature of the koppies.
- Because they consist of a rectangular grid, whatever its orientation, there is an exaggerated emphasis along the axes of the grid for certain kinds of computation, such as for line of sight calculations [Burrough 1986].

Disc storage is continually reducing in cost and increasing in volume and speed. Since the early 1960s, in general, for a given area of medium and for constant dollars, the amount of data that can be stored has doubled approximately every twelve months [Raymond 1991]. This means that over the years, it has become easier and easier to store and use larger and larger data sets. The result is that the disadvantages of raster-based models outlined above can largely be addressed by using a finer grid, and hence recording that much more data for the DTM. However, even coarse DTMs use much storage! For example, the National Digital Elevation Model (see below), which is a coarse DTM of the whole of South Africa, occupies about 60 Megabytes in a binary form.

3.1.2 Triangulated irregular networks

Given a set of points distributed irregularly across a plane, a *Thiessen polygon* (also known as a *Voronoi polygon* or a *Dirichlet cell* [Burrough 1986]) surrounds each point such that all places within that polygon are nearer to the controlling point than any other. *Delaunay triangles* are formed by the lines that are perpendicularly bisected by the sides of the polygons [Dale & McLaughlin 1988]. The Delaunay triangles connect points in the original set to their neighbouring points.

To address the problems of DTMs cited above, an alternative to raster-based DTMs was developed, namely the *triangulated irregular network (TIN)*. A TIN consists of a set of continuous, connected triangles based on a Delaunay triangulation of irregularly spaced nodes or observation points. The specific attribute being modelled is then recorded at each of the nodes.

The TIN allows extra data to be gathered in areas of complex relief without needing much redundant data to be gathered from areas of simple relief [Burrough 1986]. Hence, one could use finely digitised topographical features, such as ridge lines, stream courses, cliffs, pits and peaks, to ensure that the TIN is an accurate model of the terrain.

A TIN, in fact, has a topological structure similar to that of a network of polygons. For each node, one need record its position, attribute value (be it elevation or whatever) and the other nodes to which it is connected. Then, for some applications one uses the nodes, while for others, one uses the triangles. Figure 3.1 is an illustration of part of a TIN, and it shows the nodes that make up the TIN together with the Delaunay triangles.

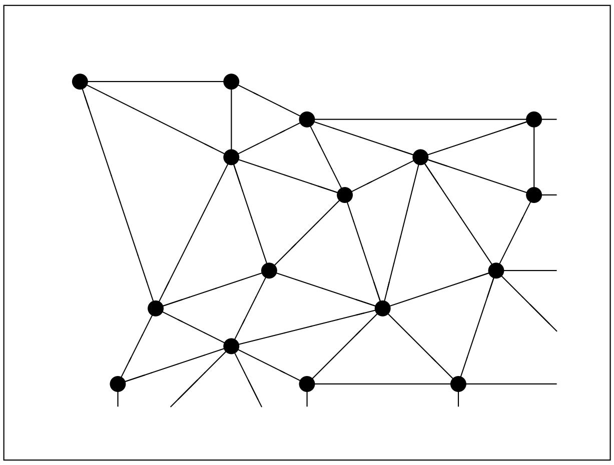


Figure 3.1: The North West corner of a TIN

The main disadvantages of a TIN structure are:

- All products derived from a TIN retain the imprint of the Delaunay triangulation [Burrough 1986], which reduce the "naturalness" of the images. For example, hill shaded images show flat triangular facets rather than smooth variations in the shading, and contours are very angular rather than smooth. Such problems can be addressed by post-processing of the images, though this then adds to the complexity of the process. Hill shaded images produced from raster DEMs are more realistic, though the finer the grid the better the hill shaded image [Cooper 1988a].

- The author would suggest that a TIN is a significantly more complex model than a DEM. This makes TINs more difficult to understand, and makes them more difficult to use as a basis for writing software to perform analysis.

- The structure of a TIN breaks down around the edges of the data set, as it is not possible to build meaningful triangles outside the outermost nodes. This is shown in Figure 3.1, which shows a corner of a TIN. As can be seen, the only way to "fill out" the triangulation around the edges would be to use long, thin triangles along the edges, which distort the data. By comparison, a DEM has valid data along all four of its edges.

Many elevation data sets are available from national mapping agencies in the form of DEMs rather than TINs. For example, in South Africa, the National Digital Elevation Model (NDEM) provides a DEM of the whole of South Africa at a resolution of 200 metres in the more interesting areas and at a resolution of 400 metres in the flatter areas. This is being supplemented by a DEM at a resolution of 50 metres, which currently provides coverage of the South Western part of the Cape.

In practice, DEMs and TINs are both used for the same applications by different people, depending on their preferences, or possibly their experience.

3.1.3 Applications of digital terrain models

Burrough [1986] cites the following as the most important uses of digital elevation models (DEMs) [1]:

- Storage of elevation data for digital topographical maps in national data bases.

- Cut-and-fill problems in road design and other civil and military engineering problems.

- Three-dimensional display of landforms for military purposes (weapon guidance systems, pilot training) and for landscape design and planning (landscape architecture).

- For analysis of cross-country visibility (for military and forestry lookouts and for landscape planning).

- For planning the routes of roads, the locations of dams, and so on.

- For statistical analysis and comparison of different kinds of terrain.

- For computing slope maps, aspect maps and slope profiles that can be used to prepare shaded relief maps, assist in geomorphological studies, or estimate erosion and run-off.

[1] While the terms DEM and DTM are used here, a TIN could also be used for these applications.

- As a background for displaying thematic information or for combining relief data with thematic data such as soils, land-use or vegetation.
- Provide data for image simulation models of landscapes and landscape processes.

He then cites other continuously varying attributes that could be modelled by a digital terrain model (DTM), such as surfaces of travel time, cost, population, indices of visual beauty, levels of pollution and groundwater levels [Burrough 1986].

Another application is to determine the propagation of radio waves across the earth's surface. This allows one to determine the reception areas for TV and radio transmitters, as well as providing a tool to regulatory authorities for allocating the frequency spectrum to users [2] [Jordan 1987].

Perhaps the most spectacular use of DEMs is to create synthetic but realistic views of the world. Hill shading is performed on a DEM to produce the effect of the sun's illumination [3]. Normally, the sun's position is assumed to be in the North East, though sometimes temporal terrain shading is used, whereby for a given time on a given day, the position of the sun (or, indeed the moon) is calculated first [Cooper 1988a]. A perspective view of the area is then created from the DEM, and it is draped by the hill-shaded DTM. Other features could be added from the GIS, or one could drape the perspective view with a satellite image. For even more realism, an anaglyph or a full-colour stereo pair could be created. Figure 3.2 shows a perspective view of a DEM draped with some vector data digitised off maps and satellite imagery.

3.2 Alternate spatial attributes

A feature has *alternate spatial attributes* when it is represented by a number of different sets of spatial attributes, where each set defines fully the location of the feature. An *alternate spatial attribute scheme* determines the manner in which the different alternate spatial attributes are related to their features. There are three main reasons as to why a feature would have alternate spatial attributes, namely:

- to cater for the conflict between the data needed for display purposes and the data needed for analysis;
- to cater for data used at different scales;
- to cater for temporal data.

[2] These telecommunication applications of DEMs actually drove the creation of South Africa's National Digital Elevation Model (NDEM).

[3] Hill shading is usually performed using Lambert's cosine rule for reflection off matte surfaces, which assumes tht the reflection off the surface is independent of the viewer's position. The reflection is $r \cos \theta$, where θ is the angle between the incoming light ray and the normal of the surface, and r is the reflectivity of the surface, usually 1.

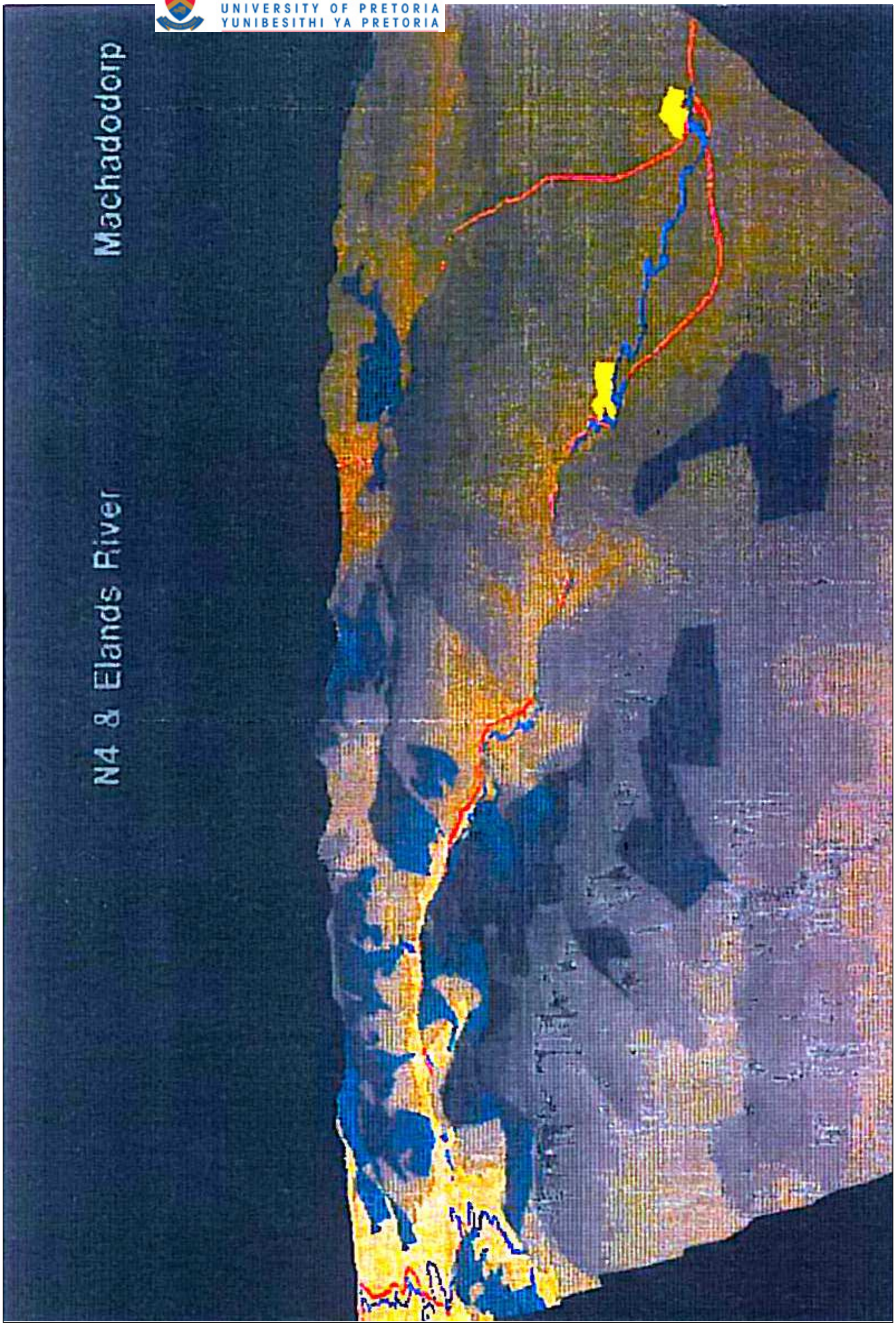


Figure 3.2: A synthetic perspective view of the Ngodwana region of the Eastern Transvaal, viewed from the North West.

3.2.1 Data for display *vs* data for analysis

Firstly, in an area with a high density of features, the graphical representation of the area (be it on a computer screen or hard copy) would be cluttered and difficult to interpret, unless the display of some of the features is suppressed, or unless some of them are represented in a simplified manner. However, for analysis on the spatial attributes of the features, one would prefer to retain as much detail as possible of the spatial attributes of all the features. Alternate spatial attributes allow one to keep different versions of the spatial attributes for the features to solve this problem — at one level, the alternate spatial attributes are for display, while at another level they are for analysis.

For example, Figure 3.3 shows the same set of buildings recorded using two different sets of alternate spatial attributes. Figure 3.3(a) shows the alternate spatial attributes that would be used for performing analysis on the data, together with labels identifying the buildings, and as can be seen, the picture is too cluttered too make a pleasing display. In Figure 3.3(b), the buildings have been aggregated into built-up areas, which allow one to see the road network more clearly, for example.

3.2.2 Storing data at several scales

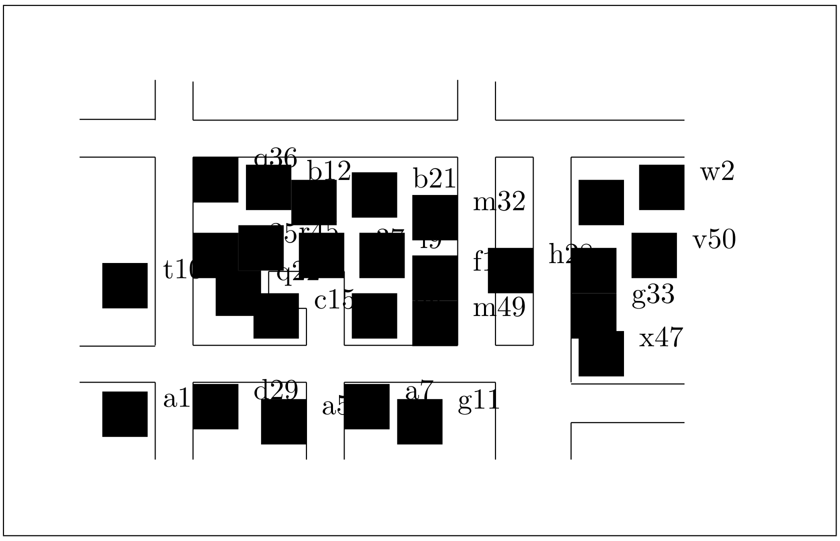
Secondly, if one deals with data at greatly disparate scales, one would like to retain different, scale dependent versions of the spatial attributes of those features which appear at both small and large scales — automatic generalization of spatial data from a large scale to a small scale is still an interesting research area. It is also not possible to create large scale spatial data from small scale data, though in the author's experience, some inexperienced users attempt to do just that. Small scale data contain less spatial information than large scale data. For example, a coastline at a small scale is smoother (that is, missing more details or "kinks") and, indeed, shorter, than the same coastline at a large scale [4]. When one "zooms in" on small scale data to use them at a large scale, the lines are rather jagged, and won't match any of the large scale data (unless one is very lucky!). In addition, scale determines how to characterise the topological dimensionality of spatial objects [Gatrell 1991]. For example, in Figure 2.10 above, at a small scale the airport is a point feature, while at a large scale, it is a compound feature.

Alternate spatial attributes allow one to keep more than one set of spatial attributes for a feature, or for a set of features. This is also how a compound feature could be given its own spatial attributes and symbology, for example.

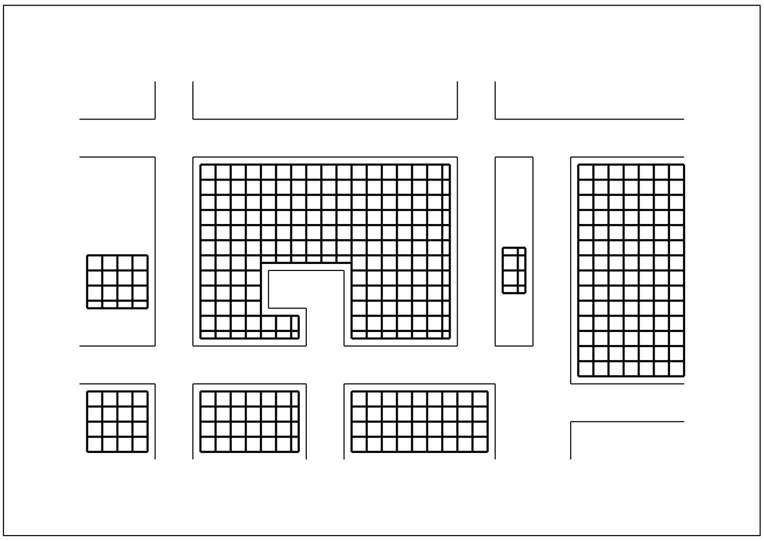
3.2.3 Alternate spatial attributes for temporal data

Thirdly, alternate spatial attributes could be used for temporal data. In the same way that different versions of a feature would be recorded for use at different scales, different versions of the feature could be kept as alternate spatial attributes as the feature changed with time. However, this use of alternate spatial attributes has not yet been tested.

[4] Studying these scale-dependent differences with respect to the length of the British coastline led Benoit Mandelbrot to the discovery of fractals [Mandelbrot 1967].



(a) The version for analysis



(b) The version for display

Figure 3.3: An example of alternate spatial attributes

3.3 Data quality

Data are only of value to a user when that user has information that will allow them to determine the *quality* of the data. Surprisingly, there is a tendency for users to be unaware of the inaccuracies inherent in the data — they assume blindly that the data are totally accurate and reliable (see Section 1.4.2 on cartographic licence, for example). The core of the problem is that for different uses, significantly different levels of quality for the same data are necessary or acceptable. For example, a digitised street network used in a vehicle navigation system has to be very accurate, to ensure that it does not direct the driver the wrong way down a one-way street, for example. However, the same network can be far less accurate when used as the background for a small, quick-reference tourist map where much of the network would be hidden behind tourist information.

The concept of data quality is an important and contentious issue in the field of spatial data handling, especially for the purpose of data exchange. Ever-increasing volumes of geo-referenced data generated by different sources, such as remote sensing, digital cartography and global positioning systems (GPS), are becoming available in digital form and are exchanged and disseminated amongst different geographical information systems (GISs) developed by different disciplines with different tasks requiring different quality levels. For such data to be exchanged effectively and used optimally some measure of the level of data quality is of primary importance. Users can only determine whether data are suitable for their purpose if producers give an indication of the quality of the relevant data [Clarke *et al* 1987b].

In developing their exchange standard, the American National Committee for Digital Cartographic Data Standards (NCDCDS) did much to highlight data quality issues [Moellering 1986, Moellering 1987a]. They coined the terms *truth in labelling* and *fitness for use*.

- **truth in labelling:** the producer of the data must verify the quality of the data, and must furnish the prospective user with this information on the quality of the data. That is, the producer must be truthful in identifying the quality of the data.

- **fitness for use:** the prospective user must evaluate the quality of the information on data quality provided, and then decide whether or not the data is of a sufficient quality to be included in his data base. That is, the recipient of the data must determine whether or not the data are fit for their use.

Truth in labelling should alter the operation of producers and consumers of digital geo-referenced data. Although it will not prevent producers distributing whatever data are obtained, they will be more likely to upgrade the quality of their product when they have to report all the detail to the professional community. Consumers, on the other hand, will have to become aware of the issues of data quality and ensure that they do not acquire data that do not fulfil their needs [Chrisman 1986].

Other terms that have been used to describe data quality itself include "meeting an expectation", "degree of excellence" and "conformance to a standard" [Chrisman 1986].

The essence is the same, though — such metadata must let the recipient of the data know exactly what they are receiving.

As is the case in South Africa, most mapping agencies are involved in setting certain map standards and in evaluating the maps they produce to ensure that these standards are met. Computerized cartography, however, is but one part of a GIS, and the potential uses of spatial information stored in a GIS are so diverse that specifying a standard that sets fixed quality levels for geo-referenced data on a national basis would be impractical. The actual properties of the data should rather be communicated in such a way that users can make their own informed decisions on the quality of the data. Hence, statements on data quality should be regarded as a *contractual* matter between the user and the supplier [Haywood 1986].

Unfortunately, the problem of how to quantify data quality is not yet well understood, and hence it is not possible to specify data quality as a single number. Thus, information on data quality is normally given in a textual form, describing *lineage*, *positional accuracy*, *attribute accuracy*, *logical consistency*, *currency* and *completeness*. These terms, and what would be suitable data quality statements for them, are assessed below.

Nevertheless, data quality is an elusive concept [Clarke *et al* 1987b].

3.3.1 Lineage

The lineage of a data set is basically its history. It consists of a statement describing to the user the origin of the data set, or its components, as well as all the processes and transformations leading to the final product — the data that the user has. It is a pedigree report required by the prospective user to evaluate the quality of the data and to decide whether the stated quality levels are appropriate for the intended use. The lineage report provides information such as the following:

- Date and scale of the source material.
- Organization of the data, for example, into map sheets or administrative units.
- Data capture method, for example, photogrammetry, field survey or map digitizing.
- Projection transformations that have been performed on the data.
- Accuracy of the capture method(s). In the case of an air survey this would include the aerial photography specifications and the calibration record, for example.
- Competency of the people who identified the data.
- Objectives behind the capturing of the data, such as completeness and maintenance policies.

3.3.2 Positional accuracy

Unfortunately, there is a tendency to confuse the terms *accuracy*, *resolution* and *precision*.

- **accuracy:** is the closeness of observations, computations or estimates to the true values or the values that are accepted as being true [Moellering 1985]. Higher accuracy therefore implies that a measurement is nearer the truth, with the truth being either absolute or relative. Accuracy is the final measure of the worth of the data [Clarke *et al* 1987b].

- **resolution:** is the smallest unit that can be detected. Resolution provides a limit to precision and accuracy [Moellering 1985]. *Spectral* resolution is the number of different bands of the electromagnetic spectrum in which a multi-scanner operates. The *spatial* resolution of digitizing equipment is the minimum distance that the equipment can detect between any two points, while the spatial resolution of a plotter is the minimum increment with which the pen can be moved in the X or Y directions [Clarke *et al* 1987b].

- **precision:** is a statistical measure of repeatability. It is usually expressed as variance or standard deviation of repeated measurements [ICA 1980]. In computing, the precision of a number is determined by the number of bits allocated for the number [Clarke *et al* 1987b].

The positional accuracy of geo-referenced data has two components, namely *planimetric* accuracy, which is defined with reference to a standard reference surface, and *vertical* accuracy, which is defined with reference to a geoid. Ideally, positional accuracy should be calculated on the basis of standard error or circular error, and be expressed in terms of metres in the real world, to make it independent of the scale of the data [Clarke *et al* 1987b].

3.3.2.1 Planimetric accuracy

The planimetric accuracy of coordinates can be quantified by using standard statistical procedures to compare the coordinates of a sample of points in the data base to the coordinates for the same points as provided by a survey of higher accuracy. The preferred method is to use the National Circular Map Accuracy Standard, which specifies that 90% of the sample points should be within a certain distance (such as 20 m) from their correct planimetric position [Clarke *et al* 1987b].

3.3.2.2 Vertical accuracy

The vertical accuracy of elevations or depths can be quantified by using standard statistical procedures to compare the values for a sample of points to the values for the same points as provided by a survey of higher accuracy. The preferred method is to use the National Linear Map Accuracy Standard, which specifies that 90% of the sample points should be within a certain vertical distance from their true elevation. In cartographic applications this distance is usually taken as half the contour interval [Clarke *et al* 1987b].

3.3.3 Attribute accuracy

Each of Stevens' measuring scales [Stevens 1946] (see Section 2.2 above) determines the appropriate mathematical operations that can be applied to the data in that class, and the limitation of each level of measurement must be recognized in any technique used to determine quality. For example, for two nominal measurements, only equivalence can be determined as distinctions are based only on qualitative considerations without any quantitative relationship being implied.

Ordinal scales involve nominal classification, but also differentiate within a class of data on the basis of rank. The numbers therefore have some associated implications of magnitude, and one can tell that a certain number is larger or smaller than another, even though one does not know by how much.

Like the ordinal scale, the interval scale is a relative measure, but here the distances between all successive numbers are of the same size so that one has the added feature of uniformity of difference. Because interval scales lack true zero points, they can never be used to measure absolute magnitudes.

The ratio scale provides the maximum information in that it possesses a true zero point indicating the least possible amount of whatever is being measured. Precise differences can be calculated, and all the measurements retain the same ratio to one another, no matter what units are employed. In statistical methodology, it is common to group nominal and ordinal scales under the general title of discrete or categorical measures, and interval and ratio scales under that of continuous measures [Clarke *et al* 1987b].

3.3.3.1 Discrete or categorical attribute accuracy

Whether the classification of discrete attributes is correct or wrong can be checked by comparing a sample in the data base with the original source or a source of higher accuracy. The ultimate source is *ground truth*, which is the real world. The attribute accuracy can then be expressed as a percentage of the sample points found to be correct [Clarke *et al* 1987b].

In statistics the allocation of individual features to existing groups is known as discrimination, and the accuracy of the classification can be quantified as a statistical measure of the probability of correct classification by means of techniques such as discriminant analysis [Mather 1976].

3.3.3.2 Numeric variable accuracy

Some attributes are continuous or measured values, and apart from measurement errors, they are also subject to the inaccuracies of the measuring device. As in the case of position, the accuracy of these attributes can be quantified as a statistical measure of the probability of being within a specified tolerance of the stated value [Clarke *et al* 1987b].

3.3.4 Logical consistency

Logical consistency basically describes whether or not the data make sense. A report on logical consistency should describe the fidelity of relationships encoded in the data structure of the digital geo-referenced information. That is, the topology used should be mentioned explicitly. The report should also detail the editing tests performed and the results of these tests. This information is important for the user of the data as retaining node-chain-region relationships in the GIS must be positionally and qualitatively accurate if the data set is to be found useful. Chains should begin and end at nodes; no chains should intersect without the presence of a node; and no chain should have its internal coordinates recorded twice. In the case of digital cartography, map sheet borders should match satisfactorily, and the data should be properly integrated across the borders of the source documents.

Logical consistency concerns errors of commission [Clarke *et al* 1987b].

3.3.5 Currency

As discussed above in Section 2.7, time is an important component of digital geo-referenced information. It also affects the assessment of the quality of the data. Data might be either too old or too new for a particular use and some aspects of data quality such as positional or attribute accuracy might change with time. Examples of data that change with time are the planimetric and vertical accuracy of points in areas subject to seismic activity, and the status of a road or the population of a city [Clarke *et al* 1987b].

3.3.6 Completeness

There is a link between currency and completeness in that a data set that is out of date is unlikely to be regarded as complete. However, it is also possible for a data set to be current and yet incomplete. Examples would be a photogrammetric survey that has not been field completed, and a map being digitised where only part of the capture specification has been achieved.

Completeness therefore covers errors of omission and raises questions about how exhaustively a data set reflects all the features it is meant to reflect. Provided that the user is aware that a data set is incomplete, and is aware of the extent to which the data set is incomplete, the data may still be of considerable value. Completeness is a common concern in analytical applications, and it is imperative that the supplier of the data should provide some indication of completeness in the quality report and of the tests conducted, to enable the user to ascertain whether or not the data are complete [Clarke *et al* 1987b].

3.3.7 The assessment of data quality

The final quality of a data set can be assessed in two ways [Haywood 1986]:

- **Tested against other data:** a sample of the digital geo- referenced data can be tested against an independent source of higher accuracy. In the case of digital cartographic data the graphic plot could be compared to a map that complies with the national mapping standard for positional accuracy. For topographic data, this testing procedure would involve a visit to the relevant area and some further survey activities.

- **Determining introduced error:** the influence of equipment and processes used at various stages of the production of the digital geo- referenced data is determined and used to estimate the final accuracy of the data. This is less reliable than the previous method, but is often the only practical solution.

The use of either method is in itself subject to quality considerations. A numerical expression of data quality is of no value without knowledge of how it was derived. This problem is particularly relevant in the case of data derived from different data collection methods and processes over a period of time. Some points might have been fixed by instrumental survey and the remainder graphically, and some features might have resulted from photogrammetric plotting, or field survey, or both. Although these data might not be subjected to different accuracy tests, variations in the overall expected accuracy are to be expected. One data set that is supposed to be 99% correct is not necessarily comparable to another that is 99% correct [Haywood 1986].

Knowledge of how the individual items of data were collected is therefore useful, especially if the method or process has a stated implication in terms of accuracy. As assessing the quality of digital geo-referenced data by means of quantifiable methods is as yet not well understood, the National Exchange Standard refrains from establishing rules as to how this should be done. Instead, the producer of the data should supply to the user the six fundamental categories of information on quality mentioned above.

3.3.8 Exchanging information on data quality

Information on the quality of a data set being transferred from the producer of the data to the user can be supplied in three ways:

- In the form of a separate printed document. The disadvantage of this method is that the documentation might become separated from the data set. In addition, in a networked environment with distributed data bases, which is becoming the typical GIS setup, the end user of the data set is unlikely to be able to readily access any printed documentation on the data.

- In a separate file on the exchange medium being used to exchange the data set. Such a file could be made available for end users to browse online.

- Incorporated directly into the data structures of the data set being exchanged.

The National Exchange Standard (NES) allows information on data quality to be exchanged in the form of free text within the exchange format. No attempt was made to provide a means for quantifying data quality as the subject is not yet well understood — such a facility will be added when required. The contents of the Global Information Section, a part of NES (see Section 6.5), may be regarded as part of the report on the quality of the data, in that they provide information essential for interpreting correctly the data being exchanged [Clarke *et al* 1987b].

CH-3-2

3.4 Integration

3.4.1 Introduction

Traditional map series are designed, drafted and published as a collection of individual map sheets that are intended to stand alone as single entities, rather than as small parts of a massive, seamless map. This gives the individual paper map an internal coherence and a pleasing appearance. Unfortunately, there is no guarantee of conformity across the seam of the maps [Fisher 1991]. The problems of creating a seamless continuous map from a set of not necessarily homogeneous map sheets is peculiar to GIS applications [Jackson & Woodsford 1991].

The integration of digital geo-referenced information is the process of combining two or more different data sets together to form a new, homogeneous, continuous and corrected data set. It is "the process of combining the relevant data with regard to their classes, types, spatial position and topology into a synergistic whole" [Jobson 1986]. The original data sets might be coincident (describing the same area on the earth's surface), or adjacent (describing adjacent areas on the earth's surface), or even overlapping, and they might contain the same or different features.

In addition, the original data sets might come from different sources (either different organisations or different compilers within the same organisation) and/or have been published at different dates. These situations cause enormous problems when integrating data sets as they invariably cause many mismatches. For example, the dates of publication of the map sheets comprising the South African 1:50 000 national mapping series range from 1972 to 1992. It will be appreciated that in the intervening 20 years much development has taken place in South Africa, and such development would not be reflected on the older maps.

3.4.2 Types of integration

Typical integration problems are those of *edge matching* or *horizontal integration* [5], and those of reconciling the different digital versions from each data set for the same feature (*vertical integration*). Integration problems are symptomatic of the varying quality of the data sets being combined and of a lack of awareness about quality issues. When

[5] While the term "edge matching" is more commonly used than "integration", the former does not convey the full meaning of integration, as the concepts of topological and vertical integration are absent [Jobson 1986].

integrating, one has to match up both the *topology* and the *spatial attributes*, as well as the *non-spatial attributes*. When integration of spatial data is performed, it will be a combination of horizontal or vertical integration with topological or spatial integration, or a combination of three or all four types of integration.

- **Horizontal integration:** Traditionally known as edge matching, from the process of matching data across the edge between two map sheets, horizontal integration is the process whereby data sets representing adjacent areas on the earth's surface are combined to form a new, continuous data set. Typical horizontal integration problems are recreating an area feature that lies across the edge between the two data sets, reconciling the chains from the two data sets that form the same line feature but that don't meet properly at the edge, and dealing with data sets of different ages (for example, where the newer data set shows features that do not continue across the edge into the older data set, or where different units (for example, feet and metres) were used for the contours, which do not then match up across the edge).

- **Vertical integration:** This is the process whereby different coincident data sets are combined to form a new, integrated data set. The most common vertical integration problem occurs when the same feature has different representations in each of the data sets being combined — the best version has to be selected, or a new, better version determined, which might necessitate the adjustment of other features. Another problem concerns logical consistency — the position of a feature from one data set (for example, a bridge) might be inconsistent with the positions of features from the other data set (for example, a river the bridge purports to cross). Another common example would be where an administrative boundary from one data set is meant to lie along a river that is in a different data set and where the two sets of coordinates do not match.

- **Topological integration:** This is the process of combining features from adjacent or coincident data sets so that the topology of the data is maintained. Typical topological integration problems are that features might not be consistent across data set boundaries (for example, a tar road from one data set becoming a dirt track when it crosses a boundary into an adjacent data set), and that features might not be consistent with their surrounding features (for example, a river crossing the same contour line several times). Topological integration has to be combined with *spatial integration*, because while the corrected data set might be topologically correct, it might not look correct.

- **Spatial integration:** This is the process of combining data from adjacent or coincident data sets, and rectifying the coordinates in the data sets so that the positions of the spatial attributes match up. Hence each point, line or area should have only one representation, straight lines should run straight across the boundaries of the data sets (that is, they should not kink at the boundary), lines should not simply end at the boundaries of data sets, and the boundary lines of the data sets should be removed. Spatial integration has to be combined with *topological integration*, because while the corrected data set might look correct, it might not be logically correct. One should first perform topological integration, to identify and match up the features, and then one should do the spatial integration.

- **Non-spatial attribute integration:** This is the process of combining the non-spatial attributes of features where different non-spatial attributes were derived from the various original data sets. The most common problem concerns the classification of features. For example, in one data set a road might be classified as *road/main/unsurfaced*, while in another, newer, data set, the road might be classified as *road/main/surfaced*. One then has the option of updating the classification of that part of the road derived from the older data set. However, this is a non-trivial process as one probably cannot determine how far the surfacing of the road has progressed.

To summarise, horizontal and vertical integration determine where the data sets lie relative to each other, while spatial and topological integration determine what operations have to be performed on the data. Data could be spatially integrated (for example, the coordinates of a road could be rectified to make the road straight across the edge between two map sheets) but not topologically integrated (for example, the two parts of the road from the two sheets might not be identified as being the same road), which is quite common with primitive GISs, or vice versa.

3.4.3 Benefits of integration

The following are the benefits of proper integration (taken from Jobson [1986]):

- Redundancy are duplication of information are reduced;
- The information is continuous;
- The information is more complete;
- The information is more reliable, as the process of integration will reveal inconsistencies and errors;
- The topology of the information will be maintained, and even extended, as features are integrated with features with which they had not previously been integrated.

3.5 Symbology

Symbology refers to the graphical representation of geo-referenced information, which includes placement of labels on maps, symbols used to represent features on maps, and shading of maps. The following are some of the issues which have to be considered when creating symbology:

1. combinations of colour, density, style, etc,

2. label placement, compass roses, scale bars, grid lines, legends, text and other allied information,
3. scale-dependent and -independent symbols,
4. point, line, area and solid (three-dimensional) symbols, followers, fills, hatches, etc,
5. both vector and raster based symbols,
6. topological relationships within the symbology (such as symbols overlapping and symbols composed of a combination of other symbols),
7. capabilities and limitations of the various output devices, and
8. ensure ease of use, versatility and completeness.

Much work has been performed on cartographic communication, that is, how symbols on maps are perceived by users [Medyckyi-Scott & Board 1991]. However, to date, little work has been done on developing generic models of symbology within GISs (though see Scheepers & Van Biljon [1985], and Scheepers [1987a and 1988]), and almost none on developing mechanisms for exchanging symbology between GISs. As current techniques for creating symbology are system-dependent, having been developed along with their output devices, there is a need for a generic model of symbology. Such a generic model would address problems such as maintaining consistent symbology across different output devices and providing a hierarchy of symbology to match a hierarchical feature classification scheme, and would facilitate the development of a mechanism for exchanging symbology [Scheepers 1987b, Scheepers 1989].

When inexperienced users see a map and then get a copy of the data set from which the map was created, they often anticipate that they will also get all the symbology used to create the map. They anticipate that they will be able to re-create immediately an exact copy the original map. Their initial perception is that the symbology is the actual geo-referenced information, rather than merely a representation of the geo-referenced information [Moellering 1991b]. A generic mechanism for exchanging symbology would help provide such users with what they want.

The only symbology for which NES makes provision is annotation. Initially, NES did not cater for any symbology at all, as it is not a part of digital geo-referenced information, but a capability for annotation was added to Version 2 [Standards Committee 1991], because of demand for such a facility. NES allows one to position each letter of annotation (currently any printable character in ISO 646) at any orientation and at any size, which allows the annotation to follow any curvilinear feature.

3.6 Abstract concepts made concrete

As outlined earlier, abstract concepts describing the fundamental nature of digital geo-referenced information have to be made concrete in a GIS so that they can be rendered to data structures and code. Such information is also not yet fully understood, so GISs have changed to reflect the maturing of our understanding of the information.

In this section, an analysis is provided of some of the peculiarities that occur in GISs due to the changing understanding of the fundamental nature of the information, and due to the need to make abstract concepts concrete. Similarly, today's state-of-the-art GISs are based on our current understanding of the fundamental nature of digital geo-referenced information. In the years to come, deficiencies will be found in our understanding, and in the future, new GISs built on current technology will also be perceived to have made outdated abstract concepts concrete!

3.6.1 Polygon centroids

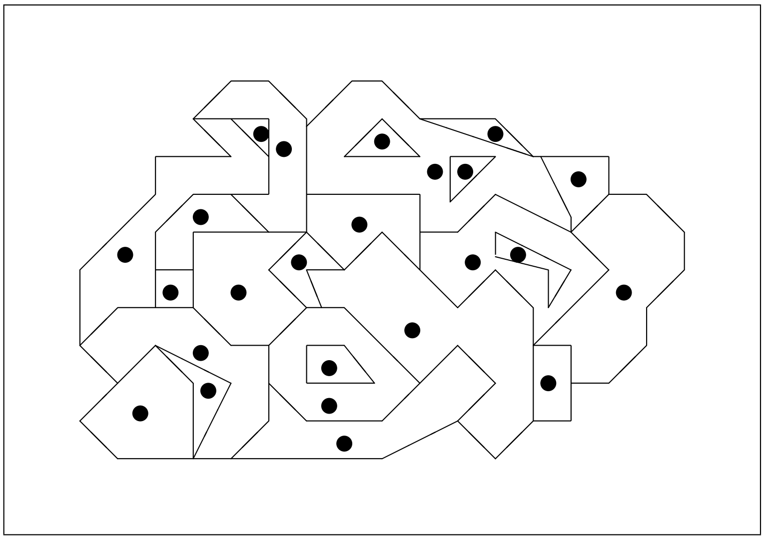


Figure 3.4: Polygons with centroids

A classic example concerns attaching non-spatial attributes to area features. Before the concept of a feature was used, the need was to attach the non-spatial information to the region (or polygon, as they were then generally known) representing the area feature. The original approach taken was to assign to each region a centroid, that is, a point that lies wholly within the boundary of the region. Then, the descriptive information for the region would be attached to the centroid, in a manner similar to attaching information to point features. Here, the abstract concept of a polygon centroid is imposed on a GIS, where it has to be taken into consideration when developing models that use polygons. Centroids are illustrated in Figure 3.4.

Centroids are normally at the centre of gravity of a polygon (computationally, the easiest position to calculate for a centroid is the centre of the min-max box[6] of the polygon),

[6]The min-max box of a polygon is that smallest box, orientated orthogonally to the coordinate axes,

though when assigning them, one has to ensure that they actually lie within the polygon — if they lie outside the polygon, then the relationships between centroids and polygons would be ambiguous. Such problems with assigning centroids occur with concave polygons that are either convoluted or are long and narrow. A problem also occurs when the polygon has an island that overlaps the selected position for the centroid. Figure 3.4 includes a few examples of such problem polygons.

Under rare circumstances, it is possible for the centroid of a polygon to be moved outside the polygon when the data undergo a projection transformation. This could occur when the centroid lies close to a boundary of the polygon that consists of a long straight line between two points. The projection transformation could so alter the position of the centroid and the two points that the centroid would lie outside the straight line.

Fortunately, as users of geo-referenced information became more literate in the fundamental concepts of digital geo-referenced information, it was realised that the centroid was redundant, and in some cases could even lead to erroneous interpretation of the data. It was realised that the information could be attached directly to the region (more correctly, to the area feature whose spatial attribute was that particular region). The new concept of area features was an abstraction of the original concept of a region, which was the boundary itself of the area feature. It was realised that to this abstract concept of an area feature, one could attach the non-spatial information and the spatial information (the boundary), and hence form the link between the two types of information.

Centroids are not entirely without value! Centroids, or more correctly, the centres of gravity of regions, can be used when performing analysis where the distances between regions is significant. The distances between the centroids is then used to ascertain the strength of the spatial influence of neighbouring regions on a particular region [Gatrell 1991]. However, one only needs to allocate centroids if one intends doing such analysis.

3.6.2 Islands

Islands are areas that are wholly contained within other areas, but that do not form a part of the larger area. The obvious example is that of an island within a lake or dam. In 1985, it was stated: "It seems that holes in cartographic objects constitute a gap in our knowledge" [Moellering 1985, pg 150]!

As mentioned above, islands could interfere with the positioning of centroids. In addition, before the topology of regions was better understood, it was common practice to add a line connecting an island to the outer boundary of the area containing the island. This connecting line then meant that the island region was now no longer an island as it was no longer completely surrounded by one polygon. Sometimes, in fact, the connecting line would be digitised twice — once as one went from the outer boundary to the island, and once as one went back. This "abstract" line meant that islands could be handled without having to cater for them explicitly. However, it created problems when plotting the data (the line had to be hidden, and it occasionally interfered with the hatching of

that contains all the points of the polygon. It can be determined by taking the smallest and largest x and y coordinates of all the points defining the boundary of the polygon.

the outer area) and with modelling.

In modern GISs, islands are modelled simply through the topology of regions, which eliminates the problem of islands as special cases. In addition, the problem of shading a complex polygon with islands is now well understood [Scheepers 1987b].

3.6.3 Continuous map vs map-sheet bound

Historically, analogue geo-referenced information was gathered, processed, displayed and analysed according to map sheets, and this process was carried through to the early GISs, in which the data were stored in sheets. While this made them efficient in terms managing the data base and performing spatial-based searches, it created problems when one's area of interest overlapped several sheets. There is a "law" of spatial analysis which states that one's area of interest is always at the intersection of four map sheets! Often, sheets overlap, or gaps are left between them, creating slivers. Some slivers are due to the nature of map projections.

In a GIS that has a continuous data base as opposed to one that is map-sheet bound, all the data sets for each map sheet are integrated to form one seamless data set. One can then extract one's area of interest from the data base without having to be concerned about incompatibilities across map-sheet boundaries. To speed up spatial-based searches, such continuous GISs are often *tiled*, that is, a regular grid (a pattern of tiles) is placed over the continuous data base and the data are separated into each of the tiles. The difference between a data base that has been tiled and one that is map-sheet bound is that in the former, the data should match up perfectly across the edges of the tiles.

Unfortunately, there is one major problem with continuous data bases. At a large scale, the significance of the curvature of the earth is such that one uses ellipsoids rather than spheres for the reference surface, and one has to use several projections to map the whole of a country. For example, South Africa extends from approximately 16°30′E to approximately 33°E. The South African Coordinate System is based on the Gauss Conformal projection, which is accurate within two degrees on either side of a central meridian. Hence, South Africa is covered by the nine Lo[7] "bands", Lo 17°E, Lo 19°E, Lo 21°E and so on through to Lo 33°E, inclusive. Maps along the edges of Lo bands (such as those that border on 28°E, which runs through Johannesburg), will not match up across the edge without correction.

Conventionally, this problem is addressed by storing all the coordinates in geographical coordinates (that is, in latitude and longitude), which are projection-independent. Unfortunately, this means that whenever data are entered into, or withdrawn from, the data base, they have to be converted between geographical coordinates and the projection, which adds a significant computational overhead and which reduces the accuracy of the coordinates. Nevertheless, a continuous data base is significantly better suited for all forms of analysis than one that is map-sheet bound. It is also generally easier to use.

Two disadvantages of tiling are that clipping features into tiles can create an unexpect-

[7] *Lo* is an abbreviation for *longitude of origin*, and is the term used in South Africa to differentiate on which of the nine Gauss Conformal projections the data lie.

edly large storage overhead, and the use of tiles could result in incorrect answers to queries (for example, selecting areas greater than or smaller than a certain size), unless the data are reconstituted across tile boundaries before the query is processed [Chrisman 1990].

3.6.4 Layers

Electronic components, such as microprocessors, tend to consist of layers of circuits. As a result, computer-aided design (CAD) systems used for designing electronic components provided the facility of *layers*. On each layer in the CAD, one would record the circuitry for a different layer on the component. This concept was used in many early GISs, and is still used in some of the leading commercial GISs. On each layer, one would record a separate class of features, and the classification would be allocated to the layer, and not to the features themselves. Again, an old concept is made concrete in a GIS in a manner that affects the use of the GIS. Some such GISs are actually a hybrid between a layer-based system and a feature-based system, in that the layer is used for a higher-level class (for example, Roads), and within the layer, features are assigned more refined classes (for example, Main Road, Secondary Road, or Track).

The real disadvantage of a layer-based GIS is the problem of providing topology across layers. Invariably, chains are duplicated across layers, and whenever changes are made to the data base, a process is run on the data base to ensure that the coordinates match up across layers. Hence, in addition to the redundant storage of coordinates (which can be significant), and the less rigid topology, layer-based GISs require additional post-processing whenever changes are made.

A well-structured GIS based on layers could speed up the input and output of classes of features, in the same way that tiling speeds up the spatial searching of features.

3.6.5 Separation of raster and vector

Currently, there are very few GISs that cater for both vector and raster data, and even then, the raster and vector data are not truly integrated. Presumably, in the not too distant future GISs will be available in which raster and vector data are truly integrated.

3.7 Summary

In this chapter, DTMs, DEMs and TINs, which are well understood models, have been reviewed. Alternate spatial attributes, a concept that the author helped pioneer, have been introduced. Much research still needs to be done on alternate spatial attributes, especially on determining how they could be used to model temporal information.

The nature and importance of information on the quality of data, an area where much research is being done internationally, especially on how to model data quality and how to encode information on data quality (for storage or exchange purposes), and the topics of data integration and symbology have been analysed.

Finally, several outdated abstract concepts that have been made concrete in GISs, and that affect the way such GISs are used, have been assessed in this chapter.

Chapter 4

Standards

In previous chapters, the nature of geo-referenced information has been analysed. In this chapter, standards and languages are assessed, and it will be argued that an exchange standard can be construed as a language.

4.1 Introduction to the standards process

4.1.1 Standards in general

Standards are a necessary evil. They affect most aspects of our daily lives. Good standards facilitate use and integration, and they reduce costs in the long run. Some standards promote safety as well. However, standards can be expensive to implement before they have a critical mass of users, and if the standards are badly designed, they can lock people into poor, dangerous or outdated technology.

> [Standards] are costly to develop; much voluntary and sponsored time is involved in their development, and the inevitable delay before they are in place can be serious. However, the benefits of standards are considerable. They:
>
> - provide a common language
> - identify good practice
> - save time and cost once developed and accepted [AGI 1989].

Standards have to reflect the technology as it exists when they are designed, but they must also facilitate adaption as technology matures. There is often a conflict as a standard must be backwardly compatible to outdated technology but it must be at the forefront of current technology to be useful in the future. Often, standards take a long time from first being mooted until they are finally accepted, as many people and organisations have to be solicited for input to the design of the standard and for approval of the final standard (for example, witness the ISO's procedure for standards, as outlined below) . After all, to be successful, a standard must be accepted by its user community. These delays can mean that by the time a standard is complete it is out of date.

Standards can be *de facto* or approved. *De facto* standards (or industry standards) occur when one company produces a product that is so successful that other companies produce products that reinforce features of the original product, such as the way it works or the way it is combined with other products. These other products are either clones (products that duplicate most or all of the features of the original product at a lower cost or with better performance) or complementary products (products that are added to the original product to provide more features), or both.

In computing, *de facto* standards tend to be entrenched by both clones and complementary products. Examples are the IBM PC/AT and its ISA bus, Hayes modems and Hewlett Packard laser printers.

De facto standards reinforce the position of the original manufacturer in the market. They reflect the idiosyncrasies of the original manufacturer, and unfortunately, are often not well thought out, as features are added in the rush to market the product. *De facto* standards can lock users into outdated technology. They can also suppress the emergence of new technology.

For example, the latest Intel microprocessor used in PC-compatible computers, the just-released *Pentium*, is backwardly compatible to all the other Intel processors in the range, namely the 80486, 80386, 80286, 8086, 8088 and 8008. That is, it contains the instructions of the older processors. The 8008 was developed in the mid 1970s, originally to drive computer terminals, and had an 8-bit architecture. The Pentium retains the functionality of the 8008 and the other processors in the range, and includes different ways to perform the same instructions — new ones were added as the range moved into 16- and 32-bit architectures, without the old 8-bit instructions being dropped [Barr 1993] . Hence, the Pentium incorporates ideas about microprocessor technology dating back nearly 20 years, despite significant developments in the interim, such as RISC (reduced instruction set computers), data flow architectures and parallel architectures.

Another example is the operating system UNIX, developed in the late 1960s at Bell Laboratories as a multi-purpose environment offering multi-user, multitasking and communications features. It began to be used extensively in universities during the 1970s, and now in the 1990s it is the "hottest new" operating system for use in the commercial sector. UNIX was developed before interactive computing was common place, and before graphical user interfaces, microkernels with message passing, CSP (communicating sequential processes) and parallel operating systems such as SIMD (single instruction, multiple data) and MIMD (multiple instruction, multiple data) were developed. In fact, the group that originally developed UNIX have gone on to develop a new operating system, *Plan 9* [Ritchie 1992].

Approved standards are developed by standards authorities in various countries, though sometimes they adopt an existing *de facto* standard as an approved standard. Standards authorities include the National Institute of Standards and Technology (NIST) and the

American National Standards Institute (ANSI) [1], both in the United States, the British Standards Institution (BSI) in the United Kingdom, the Deutsches Institut für Normung (DIN) in Germany, the Association Française de Normalisation (AFNOR) in France, and the South African Bureau of Standards (SABS) in South Africa. There are a number of international standards organisations, with the most important being the International Organization for Standardization (ISO).

ISO is a worldwide federation of national bodies (such as ANSI, BSI, DIN, AFNOR and SABS), one member organisation from each country, and in 1990 it comprised 87 members.

> The scope of ISO covers standardization in all fields except electrical and electronic engineering standards, which are the responsibility of IEC, the International Electrotechnical Commission. Together, ISO and IEC form the specialized system for worldwide standardization — the world's largest non-governmental system for voluntary industrial and technical collaboration at the international level.
>
> The result of ISO technical work is published in the form of international standards [...] ISO work is decentralized, being carried out by 169 technical committees and 645 sub-committees which are organized and supported by technical secretariats in 31 countries. The Central Secretariat in Geneva assists in coordinating ISO operations, administers voting and approval procedures, and publishes the international standards.
>
> The people who develop International Standards are an estimated 20 000 engineers, scientists and administrators. They are nominated by ISO members to participate in the committee meetings and to represent the consolidated views and interests of industry, government, labour and individual consumers in the standards development process [ISO 1990].

The following are the ISO's procedures for managing the work of a technical committee drafting a standard or a revision to a standard (taken largely from Smith [1992]):

- **The Proposal Stage:** The Proposal stage begins with a suggestion for a new area of standardization which is documented on an ISO *New Work Item* proposal form. This is circulated to voting members who ballot on the creation of a new standards project (A three-month voting period is prescribed). Approval requires a simple majority vote and a commitment by at least five national bodies to participate actively in the development of the standard. Projects can be placed within an existing Working Group (WG), or a new WG can be created to act as a focus for the technical development work related to the proposed standard.

[1] NIST is empowered to develop Federal standards only in areas where there is no commercial standards activity, and it selects other standards that suit its mission of facilitating government procurements [Cline 1992]. ANSI is the United States representative on ISO, but is one of several private institutions that develops standards [Bierman 1992].

- **The Preparatory Stage:** The work on developing a *Working Draft* of the ultimate standard is performed by experts from participating countries, organized into working groups and advisory groups under the guidance of a convenor, and further subdivided into project areas, each under the direction of a project leader.
- **The Committee Stage:** The Committee stage begins with the circulation of the document in the form of a *Committee Draft* (CD) for formal balloting. Voting members are asked to vote on the acceptance of the CD for registration as a *Draft International Standard* (DIS) (A three month voting period is prescribed). Ballot comments are collected and summarized by the Secretariat, and the CD is then either revised or registered as a DIS. A DIS has to be published in both English and French.
- **The Approval Stage:** The English and French versions of the DIS are then circulated for formal ballotting, for which a six-month voting period is prescribed. Again, ballot comments are collected by the ISO. If approved, the standard is either published without change or with an amendment reflecting persuasive technical comments received. If an amendment is drafted, it requires a two-month vote as above. If the DIS is not approved, either a new DIS is prepared, also for a two-month vote, or it is referred back to the committee stage for further work.
- **The Publication Stage:** The ISO Chief Executive Officer does the final preparation of the Foreword for the standard and sends the proof back to the Secretariat for review. Further editorial or technical amendments to the standard are unacceptable at this stage. The Publication stage ends with the release of the document as an *International Standard*.

As can be seen, if the development of an ISO standard runs smoothly, then in addition to 12 months being required for voting at the various stages, there is also the time taken to prepare all the documents, the time taken to translate the DIS into French or English, and the time taken to publish the final standard, before it is available to the public. In addition, of course, the actual technical work on developing the standard will take many months, if not years.

4.1.2 Computer-related standards in South Africa

4.1.2.1 Computer-related standards approved by the SABS

While the SABS is very active in many fields, it is almost completely inactive when it comes to computer-related standards. Currently, the only computer-related international standards that the SABS has approved are those that relate to the safety of computer equipment. In November 1988 the SABS indicated that:

> there are no national standards in South Africa for computers. Standards of the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO) are used when required as are the national standards of other countries [Herbert 1988].

In fact, South Africa is only an observer-member of JTC 1, the joint technical committee of the ISO and the IEC that develops and maintains computer standards.

4.1.2.2 Problems with standards for character sets

The SABS policy is that if one wishes to know which standard to use when there is not an approved South African standard, then one must use the approved international standard. Unfortunately, there are times when more than one ISO standard could be used, and they are incompatible with each other. For example, ISO has the following standards for character sets for data processing [ISO 1990]:

- **ISO 646:1983** "Information processing — ISO 7-bit coded character set for information interchange"
- **ISO 2022:1986** "Information processing — ISO 7-bit and 8-bit coded character sets — code extension techniques"
- **ISO 4873:1986** "Information processing — ISO 8-bit code for information interchange — Structure and rule for implementation"
- **ISO 8859-1:1987** "Information processing — 8-bit single-byte coded graphic character sets — Part 1: Latin alphabet No. 1"
- **ISO 8859-2:1987** "Information processing — 8-bit single-byte coded graphic character sets — Part 2: Latin alphabet No. 2"
- **ISO 8859-3:1988** "Information processing — 8-bit single-byte coded graphic character sets — Part 3: Latin alphabet No. 3"
- **ISO 8859-4:1988** "Information processing — 8-bit single-byte coded graphic character sets — Part 4: Latin alphabet No. 4"
- **ISO 8859-5:1988** "Information processing — 8-bit single-byte coded graphic character sets — Part 5: Latin/Cyrillic alphabet"
- **ISO 8859-6:1987** "Information processing — 8-bit single-byte coded graphic character sets — Part 6: Latin/Arabic alphabet"
- **ISO 8859-7:1987** "Information processing — 8-bit single-byte coded graphic character sets — Part 7: Latin/Greek alphabet"
- **ISO 8859-8:1988** "Information processing — 8-bit single-byte coded graphic character sets — Part 8: Latin/Hebrew alphabet"
- **ISO/IEC 8859-9:1989** "Information processing — 8-bit single-byte coded graphic character sets — Part 9: Latin alphabet No. 5"
- **ISO 9036:1987** "Information processing — Arabic 7-bit coded character set for information interchange"

There are a number of other related standards for graphical characters and so on.

Now, it is reasonable to assume that for 7-bit character sets, ISO 646 should be used (the character set traditionally known as 7-bit ASCII). However, given the diacritical marks used in Afrikaans, for example, it would be desirable to use one of the standards for 8-bit character sets, but which one? The choice could be reduced to one of the five Latin alphabets (ISO 8859-1, 8859-2, 8859-3, 8859-4 and ISO/IEC 8859-9), but one of the other alphabets might be more appropriate for the other languages used in South Africa. Unfortunately, until the SABS specifies which is the character standard for South Africa, the National Exchange Standard (NES) [Standards Committee 1991] is restricted to 7-bit character sets.

The situation is actually worse, because some ISO standards provide options that national standardization bodies (such as the SABS) are required to exercise.

For example, ISO 646 [ISO 1983] does not specify unique graphic character allocations for 12 of the 128 characters. National standardization bodies are responsible for defining national versions for these characters. However, ISO 646 defines International Reference Versions (IRVs) for these characters which are assumed if none of them are explicitly defined by the national standardization body. The problem is that the IRV for the character with the hexadecimal value 24 is defined as the currency sign (that is: ¤) but in South Africa in common usage that character is generally defined as the dollar sign (that is: $), as is defined in ANSI X3.4-1986 [ANSI 1986]. The other difference between ISO 646 and ANSI X3.4-1986 concerns the character with the hexadecimal value 7E, which in ISO 646 is defined as a tilde or overline (that is: ˜), and in ANSI X3.4-1986 as a tilde (that is: ∼). Confusingly, they have different interpretations of the nature of the symbol for a tilde.

The Standards Committee for NES selected ANSI X3.4-1986 as the standard character set to be used for NES as it conforms with general usage, even though a strict interpretation of the SABS's policy would indicate that ISO 646 should be used.

With the recent approval of ISO 10646 in May 1992, this problem should disappear after a few years. ISO 10646 makes provision for every single character used in every script known to man, including ancient scripts. Unfortunately, as it is based on 32-bit characters, which makes it incompatible with the current standard for the language C, for example, and as it is complex, it will be some time before it is in common usage.

4.1.2.3 NES as an approved standard

The development of the original version of NES was funded mainly by the National Programme for Remote Sensing (NPRS [2]), who realised that there was a need for such standards to stimulate the use of digital geo-referenced information, especially products

[2] Founded in 1975, the NPRS was one of several National Programmes of the Foundation for Research Development (FRD) that funded scientific and engineering research in South Africa during the 1980s. During 1989, with the re-organisation of the FRD, all the National Programmes were phased out, and the FRD introduced new Special Programmes. The main difference between the National Programmes and the Special Programmes is that the latter are narrower in focus and are initiated for specific periods in order to achieve specific aims [Arndt 1988]. The National Programmes provided a framework for

derived from remote sensing. The NPRS intended *ab initio* that the standard be administered by some other body once it had been developed. The State Inter-departmental Coordinating Committee for the National Land Information System (CCNLIS[3]) agreed to assume responsibility for NES in 1987, and early in 1988 it established a sub-committee, the Standards Committee, which was made responsible for NES and other standards related to the National Land Information System (NLIS[4]).

The Standards Committee approached the SABS about recognising NES as an SABS (and hence official South African) standard. Unfortunately, the SABS felt that they were not competent to evaluate the standard, and as the CCNLIS had some authority over the use of GIS and related standards in Government Departments, it was considered sufficient to leave NES in the care of CCNLIS. A more serious problem has been the reluctance of the SABS to designate which international computing standards should be used in South Africa, as outlined above.

However, once NES is established and stable, and the SABS is more geared towards computing standards, the Standards Committee will probably resubmit NES for consideration as an SABS standard.

Acceptance of NES by the South African user community has been slow, as one would expect, due to the inherent difficulties of implementing an interface to an exchange standard, and the lack of available data for exchange. However, all the leading GIS vendors in South Africa[5] have implemented, or are implementing, interfaces to NES for their GISs. In addition, with the increasing availability of base data sets (such as the 1:500 000 and 1:50 000 national mapping series from the Chief Directorate of Surveys and Land Information), it is reasonable to anticipate a significant increase in the use of NES.

4.2 Standards for exchanging geo-referenced information

4.2.1 The purpose of such standards

Digital geo-referenced information consists of more than just graphics and text. Key components are the relationships between features, and the relationships between the graphics and the text. In addition, ancillary information (such as the reference surface and projection used) and information on the quality of the data are essential for the data to be meaningful to the recipient.

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proposals for research projects in specific fields.

[3]The CCNLIS is responsible for the National Land Information System (NLIS), which effectively means that it is responsible for coordinating GIS and related activities in government departments. The CCNLIS is chaired by the Chief Surveyor General, whose Directorate provides the secretarial functions for the CCNLIS.

[4]The intention of NLIS is that it should pool all digital geo-referenced information available from government departments, and indeed, available from other sources. Initially, NLIS will be merely an inventory of available information and how to get it, but ultimately, NLIS will be a mechanism for ordering and obtaining information in real time over computer networks.

[5]These would include, in alphabetical order, Computer Foundation (for their GIS, ReGIS), GIMS (Arc/Info), ICL/Genamap (Genamap), Intertech (Intergraph) and Siemens Nixdorf (SICAD).

Exchange standards suitable for digital geo-referenced information aim at exchanging all of this information, without losing or altering any of the information. They aim to transfer the information between any GISs, no matter the level of sophistication of the GISs or the applications for which they are used. They also aim to be as independent as possible of the hardware, software and data structures used in commercial GISs.

4.2.2 *De facto* standards

There are several *de facto* standards that are used for exchanging digital geo-referenced information. Unfortunately, most are standards for CAD (computer-aided design) drawings, and are incapable of exchanging topology or non-spatial attributes. For example, Autocad's *.DXF* format is becoming widely used. However, it does not cater for projection systems, geographical coordinates, feature classes, topology, raster data or data quality [Lee & Coleman 1990]. In the author's experience, the injudicious use of CAD standards to exchange digital geo-referenced information can waste a remarkable amount of time for the recipient, as they might have to classify the data, add topology, and assign non-spatial attributes from scratch. Use of a standard designed specifically for digital geo-referenced information would obviate this waste.

Needless to say, a CAD standard does not make provision for reference surfaces or projections, and the recipient would have to guess at which were used (assuming, of course, that the recipient understood about reference surfaces and projections). The differences between various reference surfaces and projections can result in errors of several hundred metres on the ground. For example, the European Commission's CORINE (CO-ordinated INformation on the European environment) Programme is a multinational environmental monitoring and assessment tool. A major problem that was experienced by the developers of CORINE was the integration of data sets whose projections were unclear, unknown or even incorrectly specified [Mounsey 1991].

4.2.3 National and international standards

National and international standards for the exchange of digital geo-referenced information are generally purpose-designed to cater for all forms of digital geo-referenced information, and to be independent of all GISs and data models. The intention is that they provide a neutral format for translation between the various GISs being used.

Unfortunately, they have tended to be complex and they have taken a long time before they are implemented, which is why the use of *de facto* standards such as the CAD exchange standards has proliferated. National and international standards for digital geo-referenced information are discussed in more detail below in Chapter 5.

4.3 The need for exchange standards

Digital geo-referenced data sets tend to be large, and potentially very large. Data capture is usually laborious and expensive. Hence, mechanisms for exchanging data between organizations have always been important. The exchange of data often requires conversion of data from one format to another, and any such conversion may be complicated because of the enormous diversity of digital geo-referenced information. The range of data types and data structures used can be expected to increase [Pascoe & Penny 1990].

> Spatial data exchange and standardization are important in GIS because they are key elements in the data integration process, that is, bringing together disparate data sets. Standards must be established before spatial data exchange can proceed freely [Guptill 1991].

4.3.1 The advantages of exchange standards

The transfer of data between two GISs requires a sequence of one or more interfaces, and at each interface the data are converted from one data structure to another [Pascoe & Penny 1990]. The reason that there might be more than one interface is that one might need to use intermediate formats, because the actual data structures in a GIS might be proprietary information. One can either handle the problem through writing *ad hoc* programs to convert between each of the interfaces, or one could adopt a standard format for data interchange [Pascoe & Penny 1990]. The advantages of the standard format are:

- The standard will (hopefully) be well designed and comprehensive, ensuring that one will not lose information during the transfer. With an *ad hoc* solution, one would have to invest much effort up front to ensure that one designs a comprehensive conversion program.
- The standard tools available with GISs for reading and writing data to and from their data bases might differ in their capabilities to the extent that information gets lost in an *ad hoc* transfer.
- The number of converters that need to be written are significantly less for a standard than they are for *ad hoc* solutions [Pascoe & Penny 1990].
- One's GIS vendor or a third-party software company will (hopefully) provide the conversion programs to a standard interface.
- There will be a body of expertise that one could call upon when interfacing to a standard.
- Standards often require that the creator of the data set provide some information on the quality of the data, and metadata such as the projection and reference surface used.

4.3.2 The disadvantages of exchange standards

The disadvantages of using an exchange standard are:

- For occasional one-off transfers or transfers between very limited GISs, implementing the interface to the standard might be too expensive for the users' requirements. However, it is quite likely that the users will be involved in transfers more and more frequently, and that their GISs will become more and more sophisticated, either as their GISs are upgraded, or as they migrate to other GISs.

- The standard might not provide sufficient functionality for sophisticated users, resulting in information being lost during the transfer. If a standard is not designed and maintained properly, then this is likely to happen.

- The standard might be difficult to understand. To create a standard, one has to codify the data in a rigorous manner, which means that one might need to use formalisms that are difficult for the average user to understand — for example, with GISs, few users have a computer science background. This can only be counteracted through well-written user manuals and workshops for users.

- The standard might require the user to be more honest about their data than they would chose to be — this would be because of the requirement to provide information on data quality, or metadata (such as the projection used) that the user does not know.

4.3.3 Evaluating their implementation

There are two aspects to evaluating the implementation of an exchange standard by its intended user community, namely the pervasiveness of interfaces, and the quality of interfaces. The pervasiveness could be determined by counting how many GISs have interfaces to the exchange standard, and how many users of those GISs have acquired the interfaces for their own systems.

The quality of interfaces can only be evaluated through rigorous testing. Such testing would be centred on a standard suite of benchmark data sets that test as many aspects of the interface as possible. Care would have to be taken that the benchmark data sets test all the functions of the exchange standard, test as many as possible of all the different combinations of functions, test that the interface can deal with very large and very small data sets, test for fencepost [6] and off-by-one [7] errors, and test that the interface can handle error conditions. Some of the data sets would be passed several times in succession through interfaces to and from the exchange standard and then tested against the original data set to see whether they differ materially. Generally, the test data sets would be in the format of the exchange standard.

At this stage, there is no official standard suite of test data sets for NES, though the author has compiled a few small ones. However, it is envisioned that an official standard

[6] A fencepost error is the discrete equivalent of a boundary condition, and usually occurs when one counts things rather than the spaces between them, or vice versa, or by neglecting to consider whether one should count one or both ends of a row [Raymond 1991].

[7] An off-by-one error often occurs when one starts a counter at 0 and not 1, or vice versa, or when one uses the incorrect relational operator when testing for the end of a loop.

suite will be developed shortly, as various national data sets become available from the Chief Directorate of Surveys and Land Information, who provide secretarial services to the CCNLIS, and who's head, the Chief Surveyor General, chairs the CCNLIS (see Section 7.4.1).

4.3.4 Evaluating their acceptance

The acceptance of an exchange standard by a user community would be reflected by their willingness to use the exchange standard ahead of other alternatives, such as a graphics standard, or an *ad hoc* conversion. Such willingness would be reflected in the availability of data in the exchange standard, as opposed to other formats, and the extent to which buyers of data specify usage of the exchange standard. A key component is also the awareness within the intended user community of existing standards for the exchange of digital geo-referenced information, and their pros and cons *vis-à-vis* the alternatives.

4.4 Exchange standards as languages

4.4.1 Introduction

Unfortunately, from a software development point of view, the world of GIS is dominated by the users of GISs, who generally do not have much training in formal computer science (their computer-related training is generally restricted to programming). Hence, the difficulty of implementing complex GIS-related programs, such as interfaces to exchange standards, is underestimated. In addition, because such users have not had exposure to formal software development techniques and tools, implementations of such software are often not designed properly. For example, in the author's experience, there are very few people working with GISs in South Africa who have heard of a grammar such as the Backus Naur Form (BNF), let alone who understand BNF.

It is common for GIS users without a computer science background to berate computer scientists for poorly designed code that does not work properly, when in fact there probably were no computer scientists involved in either the design or the implementation of the code[8]. These users would probably not try to use the formal definitions included here.

However, there are some computer scientists working in the field of GIS and these formal definitions should help them understand NES and hence help them implement it.

4.4.2 Grammars, syntax and semantics

A language is a set of strings of symbols. More formally:

- An *alphabet* $\mathcal{T}$ is a finite set of symbols.

[8]For example, such complaints were voiced during the discussion sessions at the SAGIS'89 conference held in Pietermaritzburg during July 1989.

- A sequence $s = t_1 t_2 \ldots t_n$ of symbols from some alphabet $\mathcal{T}$ is called a *string* or a *word* over the alphabet $\mathcal{T}$. The *length* of a string is the number of symbols in the word.
- If $u = a_1 a_2 \ldots a_m$ and $v = b_1 b_2 \ldots b_n$ are strings, the *concatenation* of u with v is the string $uv = a_1 a_2 \ldots a_m b_1 b_2 \ldots b_n$.
- The *empty word*, denoted by Λ, is an empty sequence. It has length 0 and has the property that any word u concatenated with Λ is equal to u, and Λ concatenated with any word u is equal to u. That is: $u\Lambda = u = \Lambda u$.
- $\mathcal{T}^*$ is the set of all strings of symbols over the alphabet $\mathcal{T}$, including the empty word[9].
- A *language* $\mathcal{L}$ over the alphabet $\mathcal{T}$ is a subset of $\mathcal{T}^*$ [Backhouse 1979].

Languages include the natural languages spoken by people, as well as computer languages (languages used for programming computers). In addition, as will be argued below in Section 4.4.4, exchange standards are also languages.

The *syntax* of a language characterises the structure of a language. The *semantics* of a language characterise the meaning of a language. That is, they determine the effect of a valid implementation of the language, or the values produced by the language.

One can define the syntax of a language that consists of a finite number of strings by listing all the strings. However, one could not use such a method to define the syntax of a language that consists of an infinite number of strings, such as a computer language. One then uses a *grammar* to define the syntax. A grammar defines how symbols may be combined to form strings, and how the strings may be combined to form valid *sentences* (defined below) of the language — the language is generated by the grammar. A computer program is a valid sentence of a computer language, for example. A grammar consists of four parts:

1. A finite set $\mathcal{N}$ of *non-terminal symbols*.
2. A finite set $\mathcal{T}$ of *terminal symbols*, where $\mathcal{N} \cap \mathcal{T} = \phi$.
3. A distinguished symbol $\mathcal{S} \in \mathcal{N}$ called the *start* or *sentence* symbol.
4. A set $\mathcal{P}$ of *productions* each of which has the form $u \to v$ where $u \in \mathcal{N} \cup (\mathcal{N} \cup \mathcal{T})^*$ and $v \in (\mathcal{N} \cup \mathcal{T})^*$. u is called the *left-hand side (LHS)* and v the *right-hand side (RHS)* of the production [Backhouse 1979].

That is, the set of all the terminal symbols of a language is the alphabet of the language. The LHS of any production must contain at least one symbol, while the RHS could contain zero (that is, the empty word) or more symbols. If there is only one symbol on the LHS, then it must be a non-terminal symbol. Backhouse's original definition of the

[9]The notation x^* means an iteration of zero or more times of x, while the notation x^+ means an iteration of one or more times of x.

LHS in the fourth part above was $u \in (\mathcal{N} \cup \mathcal{T})^+$ [Backhouse 1979], though this would allow the LHS to consist of a single terminal symbol.

A *sentence* is defined as follows:

- Let $\mathcal{G} = (\mathcal{N}, \mathcal{T}, \mathcal{P}, \mathcal{S})$ be a grammar. A string w' is *immediately generated* by a string w if and only if $w = sut, w' = svt$ and $u \to v$ is a production of $\mathcal{G}$, where s and t are arbitrary strings.
- A string w' is *generated* by w if either $w' = w$ or there is a sequence of strings $w_0, w_1, \ldots, w_n$ such that $w = w_0, w' = w_n$ and w_i immediately generates w_{i+1} for each $i, 0 \leq i < n$. We now write $w \Rightarrow^* w'$ if w' is generated by w.
- The language generated by $\mathcal{G}$, denoted $\mathcal{L}(\mathcal{G})$, is the set of all strings $w \in \mathcal{T}^*$ such that $\mathcal{S} \Rightarrow^* w$.
- A word $w \in (\mathcal{N} \cup \mathcal{T})^*$ is a *sentenial form* of $\mathcal{G}$ if and only if $\mathcal{S} \Rightarrow^* \sqsupseteq$, and is a *sentence* of $\mathcal{G}$ if and only if $\mathcal{S} \Rightarrow^* w$ and $w \in \mathcal{T}^*$ [Backhouse 1979].

That is, a valid sentence is a string of terminal symbols that can be generated from the start symbol. A sentence cannot include any non-terminal symbols, and the sentence must include all the terminal symbols that were generated in the formation of the sentence.

Chomsky classified grammars into four types by imposing increasingly severe restrictions on the form of productions, namely:

Type 0 : No restriction on the productions.

Type 1 or *context-sensitive*: All productions have the form $u \to v$ where $length(u) \leq length(v)$ and $u, v \in (\mathcal{N} \cup \mathcal{T})^+$.

Type 2 or *context-free*: All productions have the form $\mathcal{A} \to v$ where $\mathcal{A} \in \mathcal{N}$ (it is a non-terminal symbol) and $v \in (\mathcal{N} \cup \mathcal{T})^*$.

Type 3 or *regular*: Either all productions have the form $\mathcal{A} \to t\mathcal{B}$ or $\mathcal{A} \to t$, or all productions have the form $\mathcal{A} \to \mathcal{B}t$ or $\mathcal{A} \to t$, where $t \in \mathcal{T}^*$ and $\mathcal{A}, \mathcal{B} \in \mathcal{N}$ [Backhouse 1979].

However, Backhouse [1979] points out that in terms of these definitions, the production $u \to \Lambda$ is not allowed in a context-sensitive grammar, while it is allowed in a context-free grammar. He adds that the context-free grammar could be rewritten without using the empty word, and that the empty word is used for convenience. For example, it is common to use recursion in a context-free grammar, as follows:

Given $\mathcal{A} \in \mathcal{N}$ and $a \in T$,
$\mathcal{A} \to \mathcal{A}a$
$\mathcal{A} \to \Lambda$

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This could be rewritten as:

$$\mathcal{A} \rightarrow \mathcal{A}a$$
$$\mathcal{A} \rightarrow a$$

In contrast to the above definition, another definition of the restriction for a context-free grammar is:

$\mathcal{A} \rightarrow a$ where $\mathcal{A} \in \mathcal{N}$ and $a \in (\mathcal{N} \cup \mathcal{T})^+$ [Brady 1977] [10].

A regular grammar then satisfies the requirements of a context-free grammar, though the converse is generally not true, and a context-free grammar satisfies the requirements of a context-sensitive grammar, though the converse is generally not true.

To define the grammar for a language, one needs a formal notation to specify the notation of the language. This higher-level formal notation is a *metalanguage*, that is, a language used to specify other languages. A metalanguage commonly used to specify computer languages is the Backus-Naur Form (BNF), first used in the definition of Algol-60. One could extend this idea to a meta-grammar, which would be used to generate grammars used to specify languages [Gazdar *et al* 1985].

A context-free grammar (which uses the empty word) specifying the language which is the National Exchange Standard (NES) is provided in Appendix A. It utilises the metalanguage EBNF (Extended Backus-Naur Form), which incorporates extensions to BNF that make it simpler to use.

4.4.3 Formal specification methods

Formal specifications are based in mathematics, which provides them with precision and helps to eliminate unintended ambiguities in the grammar being described. However, they are not meant to replace informal natural language descriptions of the grammars as the formal and informal descriptions complement each other. It would be easier for a beginner to learn the grammar using the natural language version, while it would be easier to use the formal specification to determine the exact and correct usage of the grammar in a particular situation. The one text is used for learning and the other for reference.

Meyer [1990] cites the example of the original report on Algol 68 which used a clever but difficult new formalism. Readers of the report gained the impression that they had to master the formalism before they could understand Algol 68. The case has probably been similar with the first version of NES [Clarke *et al* 1987b]. Although over 40% of the document contains introductory material to help the reader understand NES, and although every definition is described using natural language, it is the author's experience that most readers gave up fairly quickly on understanding NES, once they had started to read the document.

[10] Brady actually uses the notation $\mathcal{V}^*$ ($\mathcal{V}$ = vocabulary), where $\mathcal{V} = \mathcal{N} \cup \mathcal{T}$, and $\mathcal{V}^*$ is the set of finite strings of members of $\mathcal{V}$, excluding the empty word.

As a result, the second edition of NES [Standards Committee 1991] includes a comprehensive user manual. The user manual explains the fundamental concepts of digital geo-referenced information and it explains how to use NES. It uses a number of graphical illustrations to help the reader understand the concepts.

Meyer [1990] also points out that formal specifications are not a panacea against the evils of programming (or in our case, implementing an interface between one's GIS and NES). They are not easy to learn or understand when being used to specify a language, especially if one does not have a certain level of mathematical ability and a minimum amount of computer science education.

4.4.4 Exchange standards and programming languages

Exchange standards generally specify hardware requirements, such as the exchange media to be used, as well as the syntax and semantics of a data set being exchanged. The syntax and semantics of the exchange standard describe how to put the data together and what the data mean. Pascoe & Penny [1990] point out that converting digital geo-referenced information from one format to another is similar to translating computer programs from one language to another, and that an interface to an exchange standard is analogous to a compiler for a programming language. However, they did not take the analogy further.

The definitions of both an exchange standard and of a computer language specify the syntax and semantics of a data set. In the first case it is the data set to be exchanged, and in the second case it is the "data set" that constitutes the program to be compiled. Hence, a program written to convert data to or from an exchange standard, that is, an implementation of an interface to an exchange standard, is functionally the same as a compiler for a programming language. Both translate a data set from one well-defined specification to another.

The author suggests that an exchange standard is, in fact, a language. The alphabet of an exchange standard consists of the numbers, letters and symbols that make up the coordinates, non-spatial attribute values, data quality statements and so on of the digital geo-referenced information, as well as the tags, delimiters and so on that provide structure to the exchange standard. Strings in the exchange standard would include coordinate tuples, non-spatial attribute values and relations, for example.

To paraphrase the generic definition of a language, the formal definition of an *exchange standard* is as follows:

- Let $\mathcal{G}$ be the alphabet of digital geo-referenced information.
- Let $\mathcal{S}$ be the alphabet of control symbols (such as delimiters and tags) that provide structure to an exchange standard.
- $(\mathcal{G} \cup \mathcal{S})^*$ is the set of all strings of symbols over the alphabets $\mathcal{G}$ and $\mathcal{S}$, including the empty word.
- An *exchange standard* $\mathcal{E}$ over the alphabet $(\mathcal{G} \cup \mathcal{S})$ is a subset of $(\mathcal{G} \cup \mathcal{S})^*$.

Thus, when working with exchange standards one may use the tools of language designers and compiler writers to facilitate designing, specifying and implementing an exchange standard. Like a programming language, an exchange standard can be defined by a grammar, and one can use formal language theory to define it.

Pascoe & Penny [1990] also recommend the use of the query languages of relational data base management systems (DBMS) to facilitate the process of exchanging digital geo-referenced information. They suggest that compiler tools could be used to convert the data into a relational form, and then the DBMS query language would be used to convert the data from one relational form to another. They point out that the use of these query languages is computationally very inefficient, especially when one considers the volumes of digital geo-referenced information that would normally be exchanged, but that this does not represent a major problem as the conversion would only have to be done once for each data set one receives.

4.4.5 Formal specification of exchange standards

A formal definition of NES is provided in Appendix A. It gives a precise definition of the syntax of NES, which will be especially useful for those who have to implement interfaces to and from NES. The context-free grammar EBNF (Extended Backus-Naur Form) is used. It provides an elegant and universally accepted syntax description mechanism [Meyer 1990]. The advantages of EBNF are that it facilitates the systematic construction of a compiler (or interface program), it facilitates the detection of errors in the design of the language, and it facilitates the addition of new constructs to the language [Backhouse 1979, Aho *et al* 1986]. The advantage of EBNF over BNF is that it improves the clarity of the definition of the language and it removes unnecessary recursion through the use of metasymbols to indicate repetition and option [Backhouse 1979].

The disadvantage of both BNF and EBNF is that they are concrete syntaxes. That is, they describe the external appearance of a program, not the program's structure. When attempting to understand the deep structure of a language, a concrete syntax provides much irrelevant detail such as keywords and other external syntactic conventions, that is, "concrete icing on the abstract cake — sometimes called 'syntactic sugar' [11] " [Meyer 1990].

For the purposes of NES, a concrete syntax will suffice now. As has been mentioned above, the world of GIS is dominated by users without a background in formal computer science theory, and an overuse of formalisms could discourage users from attempting to understand NES. In the future, a definition of NES using an abstract syntax will probably be beneficial — in the same way that compiler construction has become easier over the years, so too will the construction of interfaces to exchange standards, but the range of digital geo-referenced information will increase, making exchange standards progressively more complex [Pascoe & Penny 1990]. An abstract syntax will then become more useful.

[11] Syntactic sugar consists of "features added to a language or formalism to make it 'sweeter' for humans, that do not affect the expressiveness of the formalism" [Raymond 1991].

4.4.6 Using *Lex* and *yacc* to implement NES

Under the UNIX operating system, tools such as *Lex* and *yacc* are available to help with writing compilers and similar programs.

Lex is a pattern-action language for specifying lexical analysers [Aho *et al* 1986]. A lexical analyser reads through an input stream sequentially and breaks it up into tokens. A token is a sequence of characters that together have a collective meaning in terms of the grammar being used. A lexical analyser performs pattern matching, and lexical analysers have been used in pattern recognition problems where the patterns can be expressed in terms of grammars.

yacc (an acronym for "yet another compiler-compiler")is an LALR parser generator [Aho *et al* 1986]. A parser generator produces a syntax analyser, which is then used to analyse the syntax of an input stream in terms of some grammar being used. LALR stands for "look ahead left-right" which is the manner in which the syntax analyser will analyse the syntax of the input stream — that is, the input stream is processed sequentially from the beginning to the end (from left to right) with no back-tracking, and symbols that follow the current symbol are examined to determine how to parse the current symbol.

Syntax analysers produced using *yacc* often use a lexical analyser produced by *Lex* to convert the input stream into tokens.

Samples of *Lex* and *yacc* code used to produce a lexical and a syntax analyser for NES are included in Appendix B. The complete code listings are not included for the sake of brevity, and because the code, especially for *yacc*, is largely similar to the EBNF definition given in Appendix A.

4.5 Summary

In this chapter, standards in general, the processes they go through to adoption, and exchange standards in particular, have been discussed.

Languages, grammars and formal specifications have been reviewed. How one can use a formal specification such as EBNF to specify an exchange standard, and how one can use compiler tools such as *Lex* and *yacc* to implement the interface to an exchange standard (such an interface is conceptually similar to a compiler), have been assessed.

Finally, the main contribution of this chapter has been to recognise that an exchange standard is a language, and to develop a formal definition of exchange standards in general.

Chapter 5

Other standards

In this chapter, we review several exchange standards for digital geo-referenced information produced in other countries, and assess some of the international activities related to such exchange standards.

5.1 Overview of exchange standards

Exchanging digital geo-referenced information is complex, due to the divergent nature of geo-referenced information (such as topographical, cadastral, hydrographical, geological and demographic information), the various forms of digital data (vector, raster and non-spatial, as well as the topological and other relationships within the data), the disparity with which different users and systems view the data, and the sheer volume of data involved.

A data set in the format of an exchange standard is not a data base — it is merely a set of data that has been extracted from one data base with the purpose of being incorporated into another data base. To be successful, an exchange standard must be independent of the data bases that might be interfaced to it [Cooper 1989b].

Just because data sets exist in the format of a particular exchange standard does not automatically guarantee that they will be used. Their existence and content need to be advertised to the broader user community, to ensure that they are used to reduce the duplication of data capture. The key is to have an index of all such available data sets, which should include metadata. Such metadata would describe the spatial domain of each data set, describe restrictions on their use, and provide information on data quality, for example [Langen 1990].

To assist with remembering all the acronyms used in this chapter, Table 5.1 lists them with the expanded names for which they are acronyms.

Acronym	**Full name**
ACSM	American Congress on Surveying and Mapping
AGI	Association for Geographic Information
CCNLIS	Coordinating Committee for the National Land Information System
CEDD	Committee on the Exchange of Digital Data
CERCO	Comité Europeen des Responsables de la Cartographie Officielle
DCDSTF	Digital Cartographic Data Standards Task Force
DGIWG	Digital Geographic Information Working Group
EDIGEO	Echange de Données Informatisées Geographiques
ETF	European Transfer Format
FACS	Feature Attribute Coding Standard
FGEF	Federal Geographic Exchange Format
FICCDC	Federal Interagency Coordinating Committee for Digital Cartography
FIPS	Federal Information Processing Standard
ICA	International Cartographic Organisation
IHO	International Hydrographic Organisation
ISO	International Organisation for Standardization
NAWG	North American Working Group
NBS	National Bureau of Standards
NCDCDS	National Committee for Digital Cartographic Data Exchange Standards
NES	National Exchange Standard
NIST	National Institute of Standards and Technology
NTF	National Transfer Format
OS	Ordnance Survey
SAA	Standards Association of Australia
SDES	Spatial Data Exchange Standard
SDTS	Spatial Data Transfer System
USGS	United States Geological Survey

Table 5.1: Some acronyms used with various exchange standards

5.1.1 The American standard

This chapter contains reviews of a number of exchange standards drafted in other countries. It contains in Section 5.2 a detailed review of Report #6 of the American National Committee for Digital Cartographic Data Exchange Standards (NCDCDS [1]) [Moellering 1985]. This was the latest report available from the NCDCDS when the NES project began, at the end of 1985. The NCDCDS's Report #7 [Moellering 1986] described some testing of the standard and contained examples of quality reports (see section 3.3), and Report #9 [Moellering 1987b] is a bibliography on exchange standards.

The NCDCDS's Report #8 [Moellering 1987a] superceeded Report #6, and was subsequently superceded by the standard proposed by the Digital Cartographic Data Standards Task Force (DCDSTF [2]) [DCDSTF 1988]. The latest version is the final draft version submitted to the National Institute of Standards and Technology (NIST [3]) for approval as a Federal Information Processing Standard (FIPS [4]), namely Version 12/90 [DCDSTF 1991]. SDTS was approved as FIPS 173 on 29 July 1992. The DCDSTF version and the version in the NCDCDS's Report #6 are essentially the same, and the differences are summarised below in Section 5.3.

The American standard has been the most influential on the development of standards and on the development of the underlying theory, which is why it is reviewed in the most detail.

5.1.2 Other standards

The Australian standard [SAA 1981] was the first national standard to be developed, and it is reviewed below in Section 5.4.

Development of the British standard, the National Transfer Standard (NTF) [Haywood 1986], took place basically in parallel with that of the South African standard, so the author did not review it in depth. However, the author did prepare a brief commentary on NTF for the authors of NTF [Cooper 1986d], which is summarised below in Section 5.5.

[1] The NCDCDS was formed under the American Congress on Surveying and Mapping (ACSM), and was supported by a grant from the United States Geological Survey (USGS), who, in terms of a memorandum of understanding signed with the US National Bureau of Standards (now the National Institute of Standards and Technology), assumed leadership in developing, defining and maintaining earth science data elements and their representation standards used by US Government agencies. [Rossmeissl & Rugg 1991].

[2] The DCDSTF was established by the USGS to meld NCDCDS's proposed standard with the "Federal Geographic Exchange Format" developed by the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC). The FICCDC had been set up by the USGS, under a directive from the Office of Management and Budget, to eliminate duplication and waste in the development of Federal digital cartographic data bases and to serve as a focal point for coordination of digital cartographic activities [Rossmeissl & Rugg 1991].

[3] Formerly the National Bureau of Standards (NBS), NIST is responsible for Federal standards in the USA.

[4] Standards developed with NIST assistance become the basis for FIPS that are approved by the US Secretary of Commerce and issued for use by the US Government in its information technology activities [Radack 1992].

The commentary was prepared to further our understanding of exchanging digital geo-referenced information, as well as in the spirit of scientific cooperation.

Other early standards development was performed by the International Hydrographic Organisation (IHO), whose work is assessed below in Section 5.6.

Canadians were very influential in the development of both the American standard and the IHO standard. Several European nations have also developed standards, for example, France, Germany, Norway, Sweden, Denmark and Switzerland. Unfortunately, these standards are written in the various official languages of these countries, and the author is not fluent in any of them!

Surprisingly, there has been almost no effort at developing a national standard in Japan, though there have been a few, small efforts based on a narrow range of data, such as the Road Administration Information Centre (ROADIC) of the Department of Roads in the Ministry of Construction [Kubo 1991, Akuyama & Yauchi 1991].

5.1.3 Towards one, unified standard

Currently, there are a number of efforts focussed at multi-national standards for exchanging digital geo-referenced information. Examples are:

- **The International Hydrographic Organisation (IHO)** — The IHO provides a forum for cooperation among its member hydrographic offices, and it facilitates the exchange of charting information between chart-producing nations. It has also done much to standardise the nautical chart and ensure that it is readily available throughout the world. With the move to automated chart production, electronic charts and electronic display devices, there was a need for the IHO to have an exchange standard, which is assessed below (see Section 5.6) [CEDD 1986a]. The trend in the IHO's standards activities is towards facilitating the real-time transmission of information on hazards and other navigational information to ships at sea.

- **Digital Geographic Information Working Group (DGIWG)** — DGIWG is a part of NATO (North Atlantic Treaty Organisation), and was established to set up standards for the military use of GIS in NATO. Standards developed by DGIWG are freely available outside of the military, and DGIWG is trying to get them accepted by civilian organisations. DGWIG developed an exchange standard known as DIGEST [5], which has also been adopted provisionally by France as their national exchange standard. The French version will be known as EDIGEO [6], and will have to be adapted for civilian use [Salgé 1991].

- **Comité Europeen des Responsables de la Cartographie Officielle (CERCO)** — CERCO is a committee at which the heads of the national agencies responsible for official cartography in Western Europe meet to consider issues of mutual concern. CERCO is developing the European Transfer Format (ETF), which will be

[5] DIGEST is an acronym for the Digital Geographic Information Exchange Standard.

[6] EDIGEO is an acronym for Echange de Données Informatisées Geographiques.

based on ISO 8211. The intention is that European countries could either adopt ETF as their exchange standard, or they could implement the interface between their national standard and ETF [Sowton 1991b].

- **Australia, New Zealand and USA** — Both Australia and New Zealand have decided to adopt the American SDTF as their own national standards, with minor modifications to account for their own unique situations (such as the reference surface and coordinate system used).

However, these are competing rather than complementary efforts.

In 1989 the Standing Commission on Advanced Technology of the International Cartographic Association (ICA) founded the ICA Working Group on Digital Cartographic Database Exchange Standards. Its main purpose was to disseminate information on exchange standards to ICA member countries — it has also deliberately stood clear of trying to develop one international standard, which is probably why it has been successful. All significant national and international standards have been represented on the Working Group, and in 1991 the Working Group published its first book, "Spatial database transfer standards: current international status" [Moellering 1991a]. The book describes standards activities in 16 countries and in two international organisations. The author is the South African representative on the Working Group and co-authored the chapter on activities in South Africa [Cooper & Clarke 1991].

At the ICA meeting in Bournemouth in 1991, the Working Group was upgraded to the ICA Commission on Standards for the Transfer of Spatial Data. The Commission has already begun working on its next publication, a monograph outlining criteria for evaluating exchange standards, due to be published by May 1993. This monograph should make a significant impact on the GIS world in general, and not just on those working on exchange standards, as it will be the first publication with input from many countries to give a clear and technical description of the fundamental nature of digital geo-referenced information. It will also highlight those areas where research is needed to improve our understanding of such information.

The Commission has identified twelve categories of the technical characteristics of exchange standards, as follows:

- **Administrative information:** This includes the name of the standard, responsible institutions, the history of the standard and its status.

- **Transfer context:** This provides more details on the logical and technical environment in which the standard exists, such as concepts and data types supported, languages defined, and other standards used.

- **Transfer specification method:** This describes how the standard is specified, and whether or not a glossary is included.

- **Conceptual data model and schema:** This describes the data model of the data being exchanged.

- **Transfer machinery:** This describes the structure and organization of an implementation of the exchange standard, including mechanisms used and the extent to which the standard is self-describing.
- **Transfer elements:** This describes the nature of the data elements which may be exchanged using the standard, such as the spatial primitives, the aggregated spatial data types, non-spatial primitives, data structures (topological, object-oriented, etc), graphic elements (annotation and symbology) and spatial referencing (reference surfaces and coordinate systems).
- **Update information:** This describes the extent to which the standard provides for update information, as opposed to merely retransmitting the entire data set.
- **Quality information:** This describes how information on data quality is exchanged.
- **Feature/object information:** This describes how features are classified and how classes are encoded in the standard.
- **Attribute information:** This describes how non-spatial attributes and their values are defined, structured and encoded in the standard.
- **Relationship information:** This describes how relationships between features are defined and transferred.
- **Metadata information:** This describes the metadata capabilities of the standard [ICA 1992].

The characteristics will be published in the form of a questionnaire, that the developers of a standard could answer with respect to their standard.

The Commission plans to follow up this monograph with a second edition of the book reviewing standards activities, due to be published early in 1995. This book might also include a comparison of the various standards against the criteria outlined in the monograph. A significant motivation for a second edition is that the standards field is evolving rapidly and some of the chapters in the survey [Moellering 1991a] were already out of date by the time the book was published.

5.2 The American standard — NCDCDS version

The following is a summary of the American standard, as published in Report #6 of the NCDCDS [Moellering 1985]. The original summary was completed on 24 March 1986, and it has been lsightly updated.

5.2.1 Outline of Report #6

The report is divided into two parts, the first being the proposed standard and the second being supporting documentation. Each part consists of five chapters, the first about the standard in general and the remaining being the reports of the four working groups, namely:

- **WG 1:** Digital Cartographic Data Organisation
- **WG 2:** Digital Cartographic Data Quality
- **WG 3:** Digital Cartographic Features
- **WG 4:** Terms and Definitions

The working groups were given the following set of basic goals:

1. To assess the state of current knowledge and understanding in the technical area.
2. To define any gaps in such knowledge and understanding necessary to specify digital cartographic standards in that area.
3. To invite presentations and opinions from all interested parties relating to the standards area.
4. To prepare technical working papers of their deliberations and discussions.

Within this set of basic goals, the working groups were given general tasks which will be outlined in the relevant sections below.

5.2.2 WG1: Digital cartographic data organization

WG 1 (Data Organisation) was given the following general tasks:

1. Examine cartographic data models.
2. Examine cartographic data structures.
3. Examine cartographic data interchange.

The Working Group (WG) drew up what they considered to be a suitable set of objectives for a general digital cartographic data interchange format. To quote them:

> “
>
> 1. Provide an interchange format which is documented within the transfer media which will allow the recipient to read the data set to determine the basic logical and physical organisation with minimal specific external information.
> 2. Provide a format which will allow the inclusion of all necessary data such as: feature information, data quality, spatial and other data types, locational definitions, spatial and other relationships, ancillary data and map symbology.

> 3. Adopt industry-accepted standards to handle the various information [items] required.
> 4. Provide an interchange format applicable to present distribution formats and [to] present and future media. The format should be media independent.
> 5. Provide an interchange format that is computer-independent to allow maximum transportability of data and [that] permits flexibility in trade-offs among transportability, storage overhead and processing efficiency.
> 6. Provide an interchange format that will allow transfer of logically different data sets on one physical medium or in one equivalent electronic transmission. It must be possible to add incrementally onto the medium.
>
> These objectives for data interchange are to be accomplished by using an approach to data definition as proposed in the International Standards Organisation (ISO) Draft International Standard (DIS) 8211. This standard follows a general Tag-Length-Sequence convention for defining data structures and the data formats specifying the storage of data within the structures" [Moellering 1985].

The above are a comprehensive set of objectives. However, the first objective could be expanded to include fully automatic acceptance of data, so that without any operator or programmer interference the recipient data base management system could include all the data received (or just that which is relevant) into its data base.

The actual data organisation standards are not clearly defined in the report and appear to be unnecessarily complex. There are a number of different ways in which one can set up the data for transfer, and while this may help the producer by providing a structure similar to his own internal structure, it makes it difficult for the recipient who has to cater for all the variations, some of which require a large amount of operator intervention.

"A data interchange shall consist of one or more files. A file is a collection of related records. A record is a collection of related data fields. Each data field stores an item of data. Each of these is treated as a logical unit" [Moellering 1985]. Additionally, it appears that fields can be grouped into field sets within the records.

"The first record of a file must contain at least a record CORE section, and optionally a CORE EXTENSION section and a DATA section" [Moellering 1985]. It appears that CORE and CORE EXTENSION sections may appear in other records in the file. Each occurence changes the data definitions for subsequent DATA sections.

The CORE section defines the parameters for the file while the CORE EXTENSION section defines the structure of the data in the DATA sections.

Each field set in the CORE and CORE EXTENSION sections consists of a size field (two-character decimal integer), a data field (an optional tag subfield, an optional ASCII group separator and other data) and an ASCII unit separator. An ASCII record separator shall replace the unit separator in the last field set in a record. The presence of the tag subfield is determined by the presence of the group separator, which is a round-about way of doing it.

The hexadecimal values of the ASCII separators are as follows:

- Group separator (GS): 0D
- Record separator (RS): 0E
- Unit separator (US): 0F

As these are unprintable characters, in the text of the proposed standard, ';' is used for RS and '&' is used for US.

5.2.2.1 CORE FIELDS

The first two field sets must be the maintenance authority and the format identification respectively. The remaining field sets can be in any order and can be identified by their tags, or the tags can be omitted and a field set called the tag list can be added immediately after the format identification. This tag list will then identify the order of the rest of the field sets. Alternatively, all tags may be omitted and the order of the field sets determined by reference to external documentation.

The following are the core field sets:

1. MAINTENANCE AUTHORITY The authority under which the format (not the data) is defined and maintained.
2. FORMAT IDENTIFICATION (FORMAT ID) The specific format identification, including revisions as defined by the maintenance authority. It is not clear who will be responsible for ensuring the uniqueness of the format ID's or how they will be created and allocated.
3. DATA START POSITION The byte position of the data in the record, relative to the first byte of the record.
4. RECORD TYPE AND SUBTYPE A four byte code using ASCII characters. The report does not specify for what purpose this field set is to be used.
5. DATA DEFINITION INDICATOR (DDI) Defines the style and location of the Data Definition (DD) information pertaining to the data fields in the CORE EXTENSION, which is explained in more detail in Section 5.2.2.3 below.
6. RECORD NUMBER The records in a file shall be numbered from '1'.
7. RECORD LENGTH The total logical record length in bytes.
8. EXTERNAL AUTHORITY (EXTAUTH) Defines the source of known external documents which determine the structure and meaning of the data fields. The scope of the application of the External Authority is not clearly stated.
9. EXTERNAL FORMAT (EXTFMT) The document identification version as defined by the External Authority.

10. PACKING FACTOR The division of physical records into logical records.

11. RECORD REPETITION INDICATOR The number of subsequent data records without a CORE or CORE EXTENSION.

From the examples given in Report #6, such as those included below, it appears that an ENTRY MAP FIELD should be included between the EXTERNAL FORMAT and the PACKING FIELD. The purpose and format of the ENTRY MAP FIELD are not clearly defined in the proposed standard, although a lot of reference is made to it in the CORE EXTENSION. Additionally, at the end of the CORE section there is an ERROR CORRECTING CODE, to which no reference is made in the standard.

5.2.2.2 Core extension fields

The Core Extension section occurs in Data Definition Records (DDR) and Data Records (DR). The type of record is determined by the first component (presumably a collection of fields) in the section, namely the Leader component. The components of the Core Extension and their functions are described in Table 5.2.

Record	Component	Function
DDR	Leader	Identifies the DDR. Contains the entry map.
	Directory	Gives tag, length & position of each Data Definition (DD) field in the record.
	Data Description	Structure of each corresponding Data Field in the DR.
DR	Leader	Identifies the DR. Contains the entry map.
	Directory	Gives tag, length & position of each DD field in the record.
	Data Fields	These fields have the format described in the corresponding DD component in the DDR.

Table 5.2: The components of the Core Extension section [Moellering 1985]

The entry maps contain the sizes of the tag (t), length (m) and position (n) fields of the corresponding directory entries in the record. The tags relate the DDR directory entries to the corresponding DR directory entries, which implicitly links the data fields to their respective data descriptive fields. No tags appear in the DDR data descriptions or the DR data fields.

When the optional DDR (Data Definition Record) components are included in the record, the fields will appear in the following order:

1. DDR LEADER Identifies a DDR. Contains an entry map and certain format information.

2. DIRECTORY Multiple entries, one for each identified data field in the Data Description section, as follows:

Data Description Field Tag	ASCII chars	t length
Data Description Field Length	ASCII integer	m digits
Data Description Field Position	ASCII integer	n digits

3. DATA DESCRIPTION section of the DDR Defines the structure of the DR (Data Record) data fields, and has a structure for each entry:

Field Control	— Type of field (integer, complex, etc)
Separator	— RS or US
Field Name	— Optional user supplied name
Label	— Optional labels for subfields
Format Control	— Optional FORTRAN style formats

5.2.2.3 Inline structure

There are two shorter forms of the entire DDR/DR (Data Definition Record/Data Record) structure for Data Definitions (DD), namely the INLINE DD LONG FORM (with an entry map) and the INLINE DD SHORT FORM (without an entry map). The Long Form's structure will contain the Tag, Length and Position of the Data Directory as well as the FORTRAN Style Format Designation. The Short Form only uses the FORTRAN Style Format Designation for its structure.

Finally, it is possible to have no Data Definition at all. This form requires the CORE as introductory information, but does not require any other information for definition.

The following are the four forms that the DATA DEFINITION INDICATOR (DDI) can take:

	DDI	**Entry map**
No definition	0	0
Inline DD, Long	terminator	non-zero integer
Inline DD, Short	terminator	0
DDR/DR Groups	grouping code	non-zero integer

Where *terminator* is any ASCII printable symbol, excluding ')', '(' and '*', and *grouping code* is any ASCII alphanumeric character, excluding '0'.

The DDR (DATA DEFINITION RECORD) and the DR (DATA RECORD) are explained in the CORE EXTENSION description, above. The Inline DD structures are used when a shorter form of the entire DDR/DR structure is desired.

5.2.2.4 Ancillary records

"In the concept of a complete transmission, there may be a group of records ancillary to the primary data which carry related information. Some examples may be calibration, release/security, mapping conversions, accuracy, data set history, audit trails, and others. These will be located as DATA records by the system, and need to be identified by the Type-Subtype coding" [Moellering 1985].

This is actually inconsistent, because much this information is DATA QUALITY information, especially lineage, and thus should appear in the data quality report!

5.2.2.5 Illustration of record forms

TRANSACTION RECORD

A Transaction Record will normally be the first record of a transmission. It will be illustrated as a record containing a single undifferentiated data field.

A Transaction Record with 360 bytes total length, M=5, N=4, m=2, n=3, t=3 and one text field might be coded with the full INLINE STRUCTURE data definition as shown in Tables 5.3 – 5.5 (taken from [Moellering 1985]).

5.2.3 WG2: Digital cartographic data quality

WG 2 (Data Set Quality) was given the following general tasks:

1. Examine the fidelity of graphical data: metric and topological.
2. Examine coding reliability.
3. Examine updates and other temporal information.
4. Examine the lineage of a data set.
5. Examine the checking procedures used by the producer to verify the quality of the data.

The working group considered that the quality report that accompanies all digital cartographic data should have five sections, namely lineage, positional accuracy, attribute accuracy, logical consistency and completeness. These sections should also refer to temporal information and currency — that is, the age of the data and it's relevance.

The purpose of a quality report is to allow recipients to determine subjectively the value of the data. Rather than fixing arbitrary numerical thresholds, the producer must provide detailed subjective information, which the WG calls 'truth in labelling'. The quality report is then a human-readable text file printed on paper or encoded on computer-compatible media. The disadvantage of this is that one needs human intervention to determine whether the data has any value to the user while the advantage is that one has a data quality reporting system that is completely flexible and can cover all types of digitised cartographic data being exchanged.

Field	**Rel Pos'n**		**Format**	**Contents**
DCDS CORE				
Size of Maintenance Auth Field	M'	0 - 1	I2	05
Maintenance Authority		2 - 5	A4	DCDS
Unit Separator		6	A1	&
Size of Format ID Field	N'	7 - 8	I2	05
Format ID		9 - 12	A4	5BR3
Unit Separator		13	A1	&
Size of Data Start Position	S	14 - 15	I2	04
Data Start Position		16 - 18	I3	097
Unit Separator		19	A1	&
Size of Record Type/Subtype	T	20 - 21	I2	05
Record Type and Subtype		22 - 25	A4	STbb
Unit Separator		26	A1	&
Size of Data Definition Indicator	D	27 - 28	I2	02
Data Definition Indicator (DDI)		29	A1	!
Unit Separator		30	A1	&
Size of Record Number Field	L	31 - 32	I2	02
Record Number		33	I1	1
Unit Separator		34	A1	&
Size of Record Length Field	K	35 - 36	I2	04
Record Length		37 - 39	I3	360
Unit Separator		40	A1	&
Size of EXAUTH Field	A	41 - 42	I2	01
Unit Separator		43	A1	&
Size of EXTFMT Field	F	44 - 45	I2	01
Unit Separator		46	A1	&
Size of Entry Map Field	E = 0 or 4	47 - 48	I2	05
Entry Map		49 - 52	4I1	2303
Unit Separator		53	A1	&
Size of Packing Field	P	54 - 55	I2	01
Unit Separator		56	A1	&
Size of Record Repetition Factor	R	57 - 58	I2	01
Record Separator		59	A1	;
Error Correcting Code (Example only)		60 - 63	A4	AAAA
Record Separator		64	A1	;

Table 5.3: The CORE section of the NCDCDS standard [Moellering 1985]

Field	**Rel Pos'n**	**Format**	**Contents**
CORE EXTENSION			
Size of Directory Field	65 – 66	I2	09
Tag (size = t)	67 – 69	A3	TXT
Length (size = m)	70 – 71	I2	20
Position (size = n)	72 – 74	I3	086
Field Terminator (Unit Separator)	75	A1	&
Size of Inline Structure Field	76 – 77	I2	19
Tag	78 – 81	A4	TXT&
Length	82 – 85	A4	262&
Relative Position	86 – 89	A4	000&
Format Control	90 – 95	A6	A(262)
Terminator (Record Separator)	96	A1	;

Table 5.4: The CORE EXTENSION section [Moellering 1985]

Field	**Rel Pos'n**	**Format**	**Contents**
DATA FIELD			
Text	97 – 358	A262	ttt . . . ttt
Terminator (Record Separator)	359	A1	;

Table 5.5: The DATA FIELD section [Moellering 1985]

5.2.3.1 Levels of testing

The WG defined four categories of testing that could be used by producers and recipients of data to determine the quality of data. These tests fall roughly along a continuum of rigor as follows:

1. Deduction: Detailed tests can be conducted on sample areas and deductive logic can be used to extrapolate the tests to the rest of the data.

2. Internal Evidence: This requires some redundancy in the data and while it might be a weak test for aspects of the data such as positional accuracy, it is the most rigorous test for issues of data structure and logical consistency.

3. Comparison to Source: This verifies the fidelity of the processes performed, but cannot discover faults in the source information.

4. Independent Source of Higher Accuracy: A comprehensive test of overall quality can only be obtained by comparing the data to an independent source of higher accuracy. Well designed statistical samples are selected and compared against the source of higher accuracy whose measures can be considered to be the 'true values' because they are that much more accurate.

5.2.3.2 Components of a quality report

The WG regarded the following five components of a quality report as being necessary:

1. **LINEAGE:** The WG considered that the basis of any quality report is a narrative of the lineage of the data, including the original source material and all the processes and transformations leading to the final product. The user needs this information to assess the value of the data and the producer needs it to maintain and update the data. The narrative would cover:

   (a) Description of source material, such as survey data, aerial photography, remote sensing, map sheets or whatever.

   (b) Methods of derivation (including transformations).

   (c) Dates of source material. Preferably the date that the information corresponded to the ground, but if it is not known, then the date of publication can be used and it should be declared as such.

   (d) Dates of ancillary information used for update.

   (e) Control information used. This should specify whether benchmarks, triangulation stations or any other method was used. The user should be able extract the control points [7] used from the data.

   (f) Mathematical coordinate transformations. This should describe all the transformations used in all the steps from the source material to the final product. The locations of control points for these transformations should be given. The methods used should be documented (One can refer to separate documentation for the algorithms used). One should also specify the nature of the computational steps taken to avoid loss of accuracy through roundoff and one should include a set of sample computations, including numerical values, to confirm the equivalence of the transformations.

   Any data base created by merging information obtained from distinct sources should be described in sufficient detail so that the source of each element in the file might be identified. This can be done by a lineage code assigned to each element in the file or by a reliability overlay, which is a collection of points, lines and areas organised to represent quality information for another set of map information. As updates and modifications occur, the reliability overlay should be modified accordingly.

2. **POSITIONAL ACCURACY:** All coordinates used for the transfer of digital cartographic data should have a known and expressed relationship to latitude and longitude. This is implemented by using recognised standard reference ellipsoids (for horizontal measurements) and standards geoids (for vertical measurements). The dates of the geodetic standards and of the datum must be given and the

[7] These control points fix the coordinates for the rest of the data They are points that are easily identifiable in the data, and that have known coordinates, such as trignometric beacons or the corners of a map.

quality of control surveys must be reported. Temporal information is necessary to help distinguish between positional errors and changes that have occurred.

The working group recommends that existing standards be used and that these be maintained by existing standards bodies, such as the Federal Geodetic Control Committee (FGCC) which sets standards for geodetic control. When these standards are changed, the standards for digital cartographic data should be adjusted accordingly. The WG considers that digital data bases should be continually converted to reflect improved control in the horizontal datum.

Two standards used in conventional cartography are the National Map Accuracy Standards (NMAS) and Koppe's formula. The WG considers that NMAS does not yield acceptable measures of the distributions of errors and because it is strongly tied to the graphic scale (resulting in fixed tolerances translating to variable ground distances), it is not appropriate for digital data bases, which have scale-free characteristics. Koppe's formula splits errors into two parameters controlling planimetric and slope-related errors. The WG wishes to encourage testing, but they are unsure as to whether Koppe's formula provides the best means to report the results. Alternative standards, more germane to digital cartographic data standards, have been developed by the ASCE and the ASP for large scale maps. The WG considers that these concepts of testing could be extended to small scale maps.

Finally, the WG briefly considered Raster Registration and Rectification, noting that while their cartographic data standards could apply to raster sources without much difficulty, a geometric standard should be developed within the remote sensing community. Achievement of 'sub-pixel' accuracy in registration must not be confused with a statement of the total error in positions, due to the roundoff implicit in cellular representation.

3. **ATTRIBUTE ACCURACY:** Accuracy assessment of measures on a continuous scale should be done in a similar manner to that for Positional Accuracy. Accuracy assessment for categorical attributes can be performed by one of the following methods:

   (a) Deductive Estimate: Any estimate, even an educated guess, is permitted. The basis of the deduction and statements such as 'good' and 'poor' should be explained.

   (b) Tests Based on Independent Point Samples: The misclassification matrix should be reported as counts of sample points cross-tabulated by the categories of the sample and of the tested material. The sampling procedures and the locations of the sample points should be described.

   (c) Tests Based on a Polygon Overlay: The misclassification matrix should be reported as areas and the relationships between the two maps should be explained. As far as possible, the two sources should be independent and one should have a higher accuracy.

For categorical data, tolerable error rates will be lower than they are for continuous data — incorrect feature codes will result in the selection of the wrong features.

4. **LOGICAL CONSISTENCY:** This report should describe the fidelity of the relationships encoded in the data structure of the digital cartographic data and it should detail the tests performed and the results of the tests. General tests for data bases containing cartographic lines are:

   (a) Do lines intersect only where intended?
   (b) Are any lines entered twice?
   (c) Are all areas completely described?
   (d) Are there any overshoots or undershoots?
   (e) Are any polygons too small, or any lines too close?

   The report should state whether any inconsistencies were corrected or give details of any remaining errors, it should state the date of the testing and any modifications and corrections and should indicate how the new information was tested.

5. **COMPLETENESS:** This report should include information about selection criteria, definitions used and other mapping rules. It should describe the relationships between the objects represented and the abstract universe of all such objects, and the exhaustiveness of a set of features.

   Completeness has two specific concerns:

   (a) Geocodes: There are a wide variety of standards for features, such as the FIPS codes for states, counties and places in the USA, and these should be used where appropriate. A further quality issue is the meaning of geocodes over time — areas are split up and merged. Parallel creation of conflicting codes should be avoided and historical consistency should be maintained.
   (b) Relationships to a Universe: While Logical Consistency covers errors of commission, Completeness covers errors of omission. Scale-dependent, non-local decisions that result in features which are not consistently recognised (such as buildings which in rural areas are individually represented while in built-up areas they are collectively represented) must be explained to the potential user so that the digital data base might be properly used. Features should be included for defensible and consistent reasons, and not just because nothing else appears in that region.

5.2.4 WG3: Digital cartographic features

WG 3 (Cartographic Features) was given the following general tasks:

1. Examine feature classes.
2. Examine the structure and levels of classes.
3. Examine feature codes.

The WG decided on a classification scheme that has three required categories and two optional categories as follows:

- REQUIRED

  1. FEATURE: A defined entity of interest that is not further divided.
  2. ATTRIBUTE: A defined characteristic of a feature.
  3. ATTRIBUTE VALUE: A specific quality or quantity assigned to an attribute.

- OPTIONAL

  4. FEATURE CLASS: A specified group of features, such as culture, transportation or hydrography. Feature Class can be used for selection and plate separation of the relevant features.
  5. ATTRIBUTE CLASS: A specified group of attributes, such as those describing measure, seviceability, composition or structure.

The only attribute common to all features (and thus the only required attribute) is location. The two CLASS classifications were included and made optional even though the WG considered them to contain information that was redundant and that would vary amongst different users. The WG decided that their inclusion would be beneficial to some producers and users of cartographic data. In fact, their assertion that the CLASS classifications would contain information that would vary is only correct because they used a classification based on a linear list. Had they used a classification based on a hierarchy, the CLASS classifications would be pre-defined.

5.2.4.1 Relationships

Relationships between features and attributes are captured in four ways:

1. Topology in the data base. Features will be related by virtue of colocation of their coordinates.

2. The use of attributes and attribute values. Rather than the implicit relation of colocation, one could use attributes to relate features to each other.

3. The use of optional feature classes to group features. This method relates features that are logically connected together rather than those that are connected by virtue of their location.

4. Logical structure or coding of the data set. This is used for attribute to feature relationships — the attributes will be related to a feature by being included with it.

5.2.4.2 Cartographic feature definitions and codes

To support the work of the WG, five students at the Virginia Commonwealth University prepared a comprehensive list of feature and attribute definitions for the ACSM. When the definitions were completed, feature codes were assigned to the list. The codes do not impose a structure upon the features and attributes but are supplied for retrieval and updating.

The WG recommends that a National body be set up to maintain the standard list of features and attributes. The maintenance is necessary because it would be foolish to try to provide codes for all possible features and attributes at the outset — new types of features will come into use in the future. The maintenance will have to be done by a National body to ensure that new features and attributes requested by the users are properly defined. This body will allocate codes for them and will arbitrate when proposed new lists conflict with the existing list or other proposed lists. Sample feature and attribute definitions follow:

STREAM (Feature definition):

1. DEFINITION: A natural body of water flowing on the land surface.
2. SOURCE: Modified from USGS.
3. ATTRIBUTES: location, name, relationship to ground level, width, depth, volume, length, perennial/intermittent, salinity, direction of flow, branch/parent, force of flow, tidal.
4. INCLUDES: anabranch, awawa, bayou, beck, braided stream, branch, brook, creek, fork, glacial stream, kill, obsequent stream, pup, rio, river, tideway, torrent.

STREAM (Attribute defintion):

1. BRANCH/PARENT: Relationship between a main stream and one of its tributaries.
2. DIRECTION OF FLOW: The line or course of movement of water or lava shown by the position of one point relative to another without reference to the distance between them. The direction is usually indicated in terms of its angular distance from a reference direction.
3. FORCE OF FLOW: The strength or energy exerted by the movement of water or lava.
4. SALINITY: (salty/brackish/fresh) The proportion of dissolved salts in pure water. Brackish water is slightly saline with a salt content less than that of sea water, sometimes defined as 15–30 parts of salt per thousand.
5. PERENNIAL/INTERMITTENT: Present at all seasons of the year vs. occuring or appearing in interrupted sequence.

6. TIDAL: The alternating rise and fall of water level caused by the astronomic tide-producing forces.

5.2.4.3 Alternatives

The WG studied a number of issues for which there are alternatives:

1. Scale Independence vs. Scale Specific. Feature classification is an attempt to describe the real world where features are independent of graphic scale and cartographic representation, and thus it should be scale independent.

2. Hierarchical or Relational Data Organisation. Because data are not retrieved in the manner in which they are stored, in the data processing sense, data organisation is not relevant to the features. The WG decided that one needs a logical coding scheme for the features that is not tied to any formal existing hierachical or relational model.

3. Selected or Universal Basic Feature Set. The WG decided that the two basic feature sets would be derived from topographic maps and hydrographic charts.

4. Feature-Attribute Relationships. Each feature group must be a single class and must be explicitly defined. Any difference in the definition must be determined in the attributes, which must be multiple and appropriately describe the feature characteristics.

5. Relationships between Features. Common boundaries should be handled by the data structure (by using shared segments) rather than by attributes.

6. 'Standard Product' vs. 'Shopping List'. The WG felt that a potentially universal and open-ended list of features should be defined by the various producers and any interchange would then contain a sub-set of this 'shopping list'.

7. Minimum Set of Attributes. The only mandatory attribute should be location. However, for certain products, users may specify required attributes.

8. Completeness. Although an issue in data set quality, the WG felt that collection criteria might be included as a part of a feature's definition.

9. 'Pure Attributes'. These are attributes unrelated to any particular feature, such as bare earth, forest cover and gravity. They can be viewed as features themselves with location as an attribute, or the locations can be viewed as features with the 'pure attribute' as an attribute.

10. Uni- or Bi-Directional Interface. Because of the detail and universality of the proposed standard feature lists, the WG felt that the conversion to other coding schemes would be in one direction only, from the standard to the non-standard.

5.2.5 WG4: Terms and definitions

WG 4 (Terms and Definitions) was given the following general tasks:

1. Collect the new terms defined by the working groups.
2. Define cartographic objects.

The working group drew up a list of terms and definitions for about 40 terms, as well as for well understood objects, namely 0-, 1- and 2-dimensional objects. This list covers only a limited number of key words which are used in the other sections of the interim proposed standard.

The report points out that n-dimensional objects are defined using concepts from geometry, topology and graph theory and as a result, in the GIS/computerised cartography community there are a number of different definitions for the same object and sometimes the same term is used to define different objects.

5.2.5.1 0-Dimensional cartographic objects

"Punctiform cartographic objets are all primitive objects that cannot be subdivided" [Moellering 1985]. The WG proposed two classes to specify 0-dimensional cartographic objects, namely:

1. POINT Used for surface structure representations and non-topological substructure components in more complex cartographic objects.
2. NODE A punctiform topological object that explicitly recognises connectivity and can serve as a basic component of more elaborate compound objects. Normally the node will have coordinates, but if the application requires topology only, a truncated node is used where the coordinates are not defined.

5.2.5.2 1-Dimensional cartographic objects

"Linear objects are bounded by and defined by 0-dimensional objects. The generic term for a 1-dimensional object is that of a line" [Moellering 1985]. The six classes proposed are:

1. LINE SEGMENT A 1-dimensional object that is a direct line between two points.
2. LINK A 1-dimensional object that is a direct connection between two nodes.
3. DIRECTED LINK A link with a specified direction.
4. STRING A series of non-intersecting line segments strung together.
5. CHAIN A series of non-intersecting directed links strung together.

6. ARC A locus of points that forms a curve that is not closed.

Their LINE SEGMENT and LINK are the equivalent of NES's CHAIN without any internal coordinates, while their DIRECTED LINK, STRING and CHAIN are the equivalent of NES's CHAIN with internal coordinates. Their ARC is effectively the equivalent of NES's CHAIN through which a curve has been passed.

5.2.5.3 2-Dimensional cartographic objects

An areal object“ can be defined in two fundamental ways, one by building up a simple object from 0- and 1-dimensional objects. An alternative form is to define a separate primitive called a pixel” [Moellering 1985] The two classes are thus:

1. POLYGON A 2-dimensional object that can be formed on a plane or other simple curved surface in three ways:
   (a) area bounded by a sequence of line segments with closure.
   (b) area bounded by a sequence of links or directed links with closure.
   (c) area bounded by a chain(s) which has (have) closure.
2. PIXEL A picture element of an area on the ground in a non-divisible measurement. An array of pixels will form a nearly regular tessellation of a plane.

The WG noted that a problem occurs with holes in 2-dimensional objects. “Holes in cartographic objects constitute a gap in our knowledge” [Moellering 1985]. Holes are integral parts of the areal objects in which they appear. It is not a sufficient solution to have artificial cuts through the object to accommodate the holes, that is, a line that joins the boundary of the hole to the outer boundary of the areal object, which was a common method of dealing with holes in the past. At the time, the WG did not know of a better method for dealing with holes.

Three dimensional objects are not well understood and thus they are not catered for.

5.2.6 Conclusions

While the proposed standard has a lot of excellent ideas, especially concerning data quality, it is very much the product of a committee. As a result, it attempts to be all things to all men and it appears to be very unwieldy. The data organisation is not clearly explained, although a lot of reference is made to ISO DIS 8211, “Specification for a Data Descriptive File for Information Interchange”, on which the data organisation is largely based. It would also be desirable if operator or programmer intervention could be eliminated when assimilating into one's data base, data in the format defined by Report #6.

Langen implemented an interface between the .DXF format and SDTS, and reported that a full understanding of the standard requires time and assumes knowledge of many prerequisites, such as ISO 8211. However, he reports that "the standard offers great versatility for its implementation . . . [and] once the standard's concepts are understood, the transfer vehicle presents a very convenient and powerful tool" [Langen 1990].

5.3 The American standard — DCDSTF changes

Conceptually, the latest version of the American standard, namely SDTS Version 12/90 [DCDSTF 1991], is not that significantly different from that reviewed above, namely the version published in Report #6 of the NCDCDS [Moellering 1985]. Superficially, however, there appears to be little connection between the two! This is because Report #6 was more of a conceptual definition of SDES [8], rather than a formal definition. Since then, much work has been done on improving the presentation of SDTS to make it more intelligible to readers. Parts of SDTS have been modified and new modules added to improve SDTS, and small errors have been largely eliminated. In addition, some attempt has been made at simplifying SDTS. The driving force behind much of the changes has been the requirements specified by NIST for the acceptance of a standard as a FIPS, especially for complex standards, as SDTS is.

The first version of SDTS [DCDSTF 1988], which was published in a special issue of The American Cartographer, represented a merging of Report #6 and FGEF (the Federal Geographic Exchange Format). FGEF was developed by the Standards Working Group of the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC), in parallel with the development of Report #6. Ironically, the FICCDC had been formed "specifically to eliminate the duplication and waste in the development of Federal digital cartographic data bases" [DCDSTF 1988]. In practice, FGEF was significantly inferior to Report #6, and Report #6 was adopted as the basis for SDTS. It was then modified to incorporate the good ideas in FGEF.

Another significant development has been the definition of *profiles*, which are subsets of SDTS that are suitable for specific groups of users. For example, the Federal SDTS Profile, which is largely based on the requirements highlighted by FGEF, has been defined for use by Federal agencies.

Unfortunately, while the layout of SDTS Version 12/90 makes it much easier to read and understand the standard than Report #6 does, it does not mask the fact that SDTS is very complex! The author would suggest that even GIS experts well versed in exchange standards will struggle to implement interfaces to and from SDTS, and that most users will give up rather quickly on trying to understand it. The real problem with SDTS is that it tries to be all things to all GIS users, and that it has the appearance of being designed by a committee. The analogy with computer languages is that of the language PL/1.

For example, in Report #6, 12 cartographic objects were defined [Moellering 1985]. By the end of 1987, SDTS defined 17 cartographic objects (vector and raster) with a further 6 special cases, though it had codes for 25 vector objects and one raster object — some

[8] Spatial Data Exchange Standard, as the standard produced by the NCDCDS was known.

of the defined cartographic objects had no codes (such as the *rings*), while codes were assigned to several types of *arcs*, for example [DCDSTF 1988]. In SDTS Version 12/90, 30 vector objects are defined and given codes [DCDSTF 1991]. The author would suggest that some of the objects are of a more theoretical interest rather than of practical interest (and are not implemented in commercial GISs). Hence, they add to the complexity of SDTS. In addition, some of these objects constitute symbology rather than geo-referenced information. Their differences from the basic objects are related to the representation of the object, rather than the fundamental nature of the object. For example, there are several types of *arc* objects, such as the *nonuniform rational B-spline* and the *piecewise Bezier*. Further, the number of objects could be reduced without reducing the power of SDTS, as some of the objects are special cases of other objects.

5.4 The Australian standard

The following is a summary of the Australian standard [SAA 1981]. The original summary was completed on 12 December 1985, and it has been slightly updated.

5.4.1 Format of the data files

The exchange is based on individual records for each feature and makes no attempt to define structures within the data or relationships between the data. It is restricted to mapping and charting data and is not intended to deal with polygons (which they call area mosaics) and the associated problem of shared line segments.

With the data, essential information that must be provided are a task identifier, the horizontal and vertical coordinate systems and the length of coordinate-value fields. These can be supplied in an accompanying document or in definition records in the data files. These records can be used repeatedly to change the essential information at any stage as one processes the file sequentially.

Coordinates are given in latitude and longitude, eastings and northings on a UTM grid or in a donor-defined X and Y coordinate system. The donor must provide a written description of their coordinate system so that the recipient might write programs to translate them to what ever system they use. Provision is made for having both an offset and a scale factor for the X and Y coordinates, as well as a donor-determined fixed field-length for the values.

Heights or depths are given in metres relative to the Australian Height Datum (as defined by the National Mapping Council of Australia) or a donor-defined datum, or else as a Z as defined by the donor. Again, provision is made for an offset, scale factor and donor-determined fixed field length.

Further information which should be supplied includes an estimate of the standard error (horizontal and/or vertical), the type of source document, scale, dates of source material and digitising, details of aerial photography (where applicable), identity of original donor organization, a list of feature modifiers and other non-standard facilities used by the donor, and details of any symbol reference table that may have been used. This descriptive information is supplied in a document. It would be better to have it coded in the data so that the recipient could automatically evaluate the information and use it if it passes whatever criteria the recipient might have.

A file consists of a number of records. If definition records are being used, then the first record must be a definition record. All subsequent records are either feature records or further definition records which redefine the essential information.

A record consists of a header segment and one or more detail segments. A header segment contains the length of the whole record and the type of record. Additionally, a feature record header segment contains the feature code, feature modifier, the nature of the feature (point, line or area), the number of axes for coordinate values (1, 2 or 3) and the record sequence (which allows a feature to consist of a number of records).

There are four types of feature record detail segments: for lines (consisting of the coordinates); identification/names (consisting of the name or identification); point symbols (consisting of its coordinates, orientation and symbol reference number, which is defined in the descriptive information); and map annotation (consisting of the annotation, orientation and coordinates for the initial character of the annotation).

There are two types of definition record detail segments: for essential information and for descriptive information. The detail segment for essential information contains the coordinate systems and the field lengths, offsets and scales for the coordinates, given separately for all three axes. However, the detail segment for descriptive information merely contains strings of characters which must be printed out and interpreted by the recipient.

5.4.2 Medium of interchange

The Standards Association of Australia has standards for interchange which cover the medium of interchange (magnetic tape in various forms), tape labelling and file structures and a character set for interchange. The preferred and optional methods of interchange are drawn from these standards. This is an important part of the interchange standard because any recipient of data should be able to determine easily the manner in which the data were recorded on the medium used.

5.4.3 Classification of features

Features are classified by a four digit feature code (which is standardised) and a four digit feature modifier (which is defined by the donor). The feature code is basically a 3 level hierarchy. Code 0000 is for uncoded digitised data. After this, codes 0*nnn* to 3*nnn* are for cultural features, codes 4*nnn* are for hydrographic features, codes 5*nnn* are for relief features and codes 6*nnn* are for vegetation. The second digit is used for the next level of grouping and the last two digits are used to identify the type of feature. The drawbacks of the system are obvious and serious.

Firstly, the feature modifier is donor-defined (the default in the standard is zeroes) and if any values other than zero are used, a list of them and their meanings must be supplied. The standard does not specify whether the modifier's values are specific to a particular feature code, or whether they are generic to all feature codes (that is, a certain value for a modifier means the same for all feature codes). Also, if there are any modifiers, then the recipient's programs have to be changed manually to cater for them.

Secondly, the rigid standardised classifications go too far without going far enough — they attempt to have a feature code for every kind of feature (it is immediately obvious that features were only considered from a cartographic point of view), while restricting the details known about a feature. For example, they have the following codes for POPULATION CENTRES:

0002	General Population Centre	
0003	Capital City	
0004	Population:	500 000 and over
0005		100 000 – 499 999
0006		75 000 – 99 999
0007		50 000 – 74 999
0008		25 000 – 49 999
0009		20 000 – 24 999
0010		15 000 – 19 999
0011		10 000 – 14 999
0012		5 000 – 9 999
0013		2 500 – 4 999
0014		2 000 – 2 499
0015		1 000 – 1 999
0016		500 – 999
0017		200 – 499
0018		Under 200

It is noteworthy that they have a code for population centres of unknown size and status. However, there are three major flaws:

1. A Capital City cannot have a population size associated with it.

2. The distribution of codes is uneven — there are only two codes for centres with populations over 100 000, while there are seven codes for centres with populations under 10 000.

3. The classification list does not adequately cater for expansion, one of the stated objectives of the system. A new population range of 1 000 000 and over will have to be given the code 0019, and thus it will appear at the end of the list. Further, it will not be possible to determine whether centres currently with the code 0004 should retain that code or be changed to 0019.

The solution to this problem is obvious — the population of a centre should be an attribute of the feature rather than something hidden in the feature code.

A further example concerns RAILWAY LINES:

2301	Main line:	Commonwealth
2302		State
2303		Private
2304	Spur Line, Siding, Marshalling Yard	
2305	Light Railway or Tramway	
2306	Disused, Abandoned, Under Construction, Old Formation	
2307	Ski-lift, Chair-lift, Cable Car	
2308	Conveyor Belt	
2309	Turntable	
2310	Other Lines	
2311	Multiple Track Railway	
2312	Single Track Railway	

Here, there are two major flaws:

1. For a main line, one cannot specify the number of tracks, which in any case is restricted to one or many.
2. Lines under construction have been grouped with those that are disused, abandoned or old formations. The implication is that one should not expect the completion of lines under construction! Neither does the classification cater for proposed lines.

Both flaws also occur in the classification of ROADS, as follows:

2000	Road in general		
2001	Primary Road		
2002	Freeway, controlled access – Sealed		
2003	Highway	– Sealed	
2004		– Unsealed	
2005	Main Road	– Sealed	
2006		– Unsealed	
2007	Secondary Road		
2008	Sealed		
2009	Unsealed		
⋮	⋮ ⋮		
2019	Road abandoned or under consruction		
2030	Road, 2 or more lanes wide		– Sealed
2031			– Unsealed
2032	Road, 1 lane wide		– Sealed

2033		– Unsealed
⋮	⋮	⋮
2037	Divided Highway	
2038	Divided Distribution Road	
2039	Highway through Built-up Area	
2040	Distribution Road	
2041	Access Road	
2042	Proposed Road	

Thus, a road may be classified by the number of lanes (one or many, sealed or unsealed), or as a "primary road – highway" (sealed or unsealed), or as a divided highway (of indeterminate surface), but not as any combination thereof. How does one classify a divided, sealed highway which has three lanes, without loosing any information?

Although roads under construction are classified with those which have been abandoned, there is at least a classification for proposed roads. The implication is that the Australians are planning to build roads in the future, but not railways!

5.4.4 Conclusions

Although twenty different kinds of organisations, ranging from the Australian Banks Payment Systems Committee and the Life Insurance Federation of Australia to the CSIRO's Division of Computing Research and the Department of Defence, were represented on the committee, it was obviously dominated by the cartographers. As a result, while it may be an efficient system for the interchange of purely cartographic information, it is not a good system for the interchange of any other forms of spatially-related information.

Their standards for the medium of interchange are good — these are lacking in South Africa. However, because of their insistence of including all the information in the feature code and feature modification of the classification, the format of the data is deficient in that it does not cater for any other information being included with each feature. They do suggest using the feature modifier or the third coordinate to convey the height of the feature, which implies that some of the deficiencies had been pointed out to them and either they did not consider them important, they did not know how to solve them or they did not have the time to solve them.

To conclude, the author would suggest that as a GIS interchange standard this system has too many flaws to work at all, and as a purely cartographic interchange standard there are enough deficiencies to make it an irritating system to use. In fact, the old Australian standard is considered to be unsuitable for modern spatial data base and GIS applications by Standards Australia, who are considering replacing it with the American standard, SDTS [Clarke 1991].

5.5 The British standard

5.5.1 Background

A draft version of the British standard, the National Transfer Format (NTF), was released at Auto Carto London in September 1986 [Haywood 1986]. The first version of NTF [Sowton & Haywood 1987] was released in January 1987.

The Standards Committee of the Association for Geographic Information (AGI) is now responsible for NTF, and in addition to maintaining it, they are working on making NTF compliant with ISO 8211. They are also contributing to the development of a European Transfer Format (ETF) [Anon 1991].

In addition to being used in the United Kingdom, NTF has been adopted by the Republic of Ireland and Hungary [Sowton 1991a].

5.5.2 The structure of NTF

The following summary of NTF is drawn largely from Cooper [1986d], which was a commentary on NTF prepared by the author and submitted to the Working Party defining NTF.

NTF is designed to transfer digital map data, though the Standards Committee is expanding it to cater for all forms of digital geo-referenced information. NTF can be used at various levels, namely as raster data, unstructured data (with or without an unlimited number of attributes), topological data and data defined by a data dictionary. The levels make provision for users at varying degrees of sophistication. A data set being transferred may occupy more than one physical volume.

NTF has a fixed format throughout. Continuation records are provided to allow a logical record to span more than one physical record, though a field cannot be broken across physical records (presumably, this is to make the data more readable for people). Numeric records have to be right justified and alphanumeric records left justified. Dates are specified in the format year, month, day, but only two digits are allowed for the year, which is an inappropriate restriction, given that we are near the end of the 20th century, and given the importance of historical information for many users.

One useful feature is that the user may place comment records anywhere in the data set to annotate it. In addition, quality records may be placed anywhere in the data set. They allow information on data quality to be attached to a single character quality label, and the label may be attached to coordinate tuples in the data set. This allows information on data quality to be provided with a fine granularity, without greatly increasing the size of the data set.

NTF allows the Data Dictionary, Feature Classification and Data Quality sections of a data set being transferred to have unique names, so that in a subsequent transfer, the producer of the data set need only refer to them using their unique names, rather than having to retransmit them. Possibly, NTF's most significant contribution to the understanding of exchange standards has been with the provision for the exchange of update information. Instead of retransmitting the entire data set, one merely transmits information about what has been modified, added or deleted. The advantage of this is that if the recipient has added other data to the original data set, they do not have to sort out what should be deleted when the entire, updated, data set has been received. It also reduces the amount of data that have to be exchanged.

NTF allows for coordinate offsets and various coordinate resolutions, which helps to reduce the size of coordinates in the data set being exchanged.

In common with the American standard, NTF has quite a few different types of entities, which might confuse some users. The following are provided:

- **Cartographic names:** Provided through two record types, [**NAMPOSTN**] for annotation along a straight line at any orientation and [**CURVTEXT**] for curvilinear annotation.

- **Point geometry:** Provided through two record types, [**GEOMETRY1**] for two-dimensional coordinates for points and lines, and [**GEOMETRY2**] for three-dimensional coordinates. Collectively, these two records are referred to as [**GEOMETRY***].

- **Node:** Provided through the record [**NODEREC**], which relates a node to the links that start or end at that node, as well as to the coordinates for the node, through a [**GEOMETRY***] record.

- **Point feature/object:** Provided through the record [**POINTREC**], which is similar to [**NODEREC**], but which relates a point feature and its non-spatial attributes to its position.

- **Link (line geometry):** Provided through the two record types, [**GEOMETRY1**] and [**GEOMETRY2**], described above.

- **Line feature/object:** Provided through the record [**LINEREC**], which relates a line feature and its non-spatial attributes to its position through [**GEOMETRY***] records.

- **Complex line object:** Provided through the record [**CLINE**], which links several [**LINEREC**] records together and relates them to non-spatial attributes.

- **Polygon:** Provided through the record [**POLYGON**], which links together the [**LINEREC**] records that form its boundary, and which links the polygon to its non-spatial attributes. It also makes provision for a reference point, centroid or seed for the polygon.

- **Complex polygon:** Provided through the record [**CPOLY**], which includes or excludes [**POLYGON**] records to form a complex polygon. It also provides for non-spatial attributes and for a reference point, centroid or seed for the polygon.

- **Collection:** Provided through the record [**COLLECT**], it relates spatial entities and non-spatial attributes together to form a compound feature.

As can be seen, the differentiation between features and spatial attributes is not that clear.

5.6 The International Hydrographic Organization's standard

This assessment of the exchange standard developed by the International Hydrographic Organization (IHO) is taken from a survey of exchange standards published by the author [Cooper 1989b].

5.6.1 The development of the IHO standard

In 1983 the IHO created the Committee on the Exchange of Digital Data (CEDD). Its 15 member countries were Australia, Canada, Cuba, France, Germany, Greece, India, Italy, Japan, New Zealand, South Africa, Spain, United Kingdom, United States of America (as the chair) and Yugoslavia. The task of creating the standard was delegated to the North American Working Group (NAWG), which consisted of delegates from various organizations in Canada and the United States [CEDD 1986a].

The most critical problem that the CEDD had to face was the disparate levels of sophistication of the intended user countries. The most sophisticated required full topology and the ability to perform real-time updates of the electronic chart, while the most naïve required a graphics standard — they would merely reproduce the paper chart from the data, and not perform any analysis on the data.

During the third quarter of 1985, NAWG distributed a test data set of their proposed format. At the next CEDD meeting on 9 December 1985, only South Africa was able to produce a chart plotted from the data (one that had been produced at the CSIR's National Research Institute for Mathematical Sciences). This dispelled the doubts of the CEDD that the proposed format might be too complex for the smaller hydrographic offices to handle [CEDD 1986a].

The proposed format of the CEDD [CEDD 1986b] was released in November 1986.

5.6.2 The structure of the IHO standard

The IHO standard, known as the Format for the Exchange of Digital Hydrographic Data, is designed to cater for hydrographic information. It has a fixed format throughout. When a field has no value, blanks are inserted in the field. Attribute values have fixed positions (placements) within the attribute list of the features. However, the fixed placement is different for each feature class. Most of the attributes have enumerated values (numeric codes representing fixed textual descriptions). The values of numeric attributes are either restricted to 999 values, or have enumerated values representing ranges.

A fixed, three-level hierarchy is used for the classification. The standard has a comprehensive list of features, attributes and attribute values — the Feature Attribute Coding Standard (FACS). For obvious reasons, the classification is confined generally to those features found on nautical charts. No definitions of the features or attributes are given in the lists.

The standard allows for encoding information on the quality of the data, and for encoding global information.

The standard caters for both spaghetti data and "chain-node" data (data with topology), and chart-dependent and -independent data. The topology for which they cater is shared line segments. In the standard, there is an explanation of the advantages of using chain-node data. The standard caters for vector data but not raster data.

The standard does not cater for multi-reel volumes (data sets on more than one magnetic tape).

5.7 Summary

In this chapter, the exchange standards of the United States of America, Australia, the United Kingdom and the International Hydrographic Organization have been reviewed. In turn, each of these standards has flaws and each has good points. The project team that developed NES was influenced by these standards, and strove to develop a good standard that catered for the needs of the GIS community in South Africa. NES is described formally in Appendix A, and is assessed in the following chapter.

Multinational activities in the exchange standards field have been assessed in this chapter, with the development of the European Transfer Format promising to be the most interesting, while the activities of the ICA's Commission on Standards for the Transfer of Spatial Data hold the most promise for developing the understanding of standards for the exchange of digital geo-referenced information.

Chapter 6

The National Exchange Standard (NES)

6.1 Introduction

This chapter assesses the National Exchange Standard (NES) [Standards Committee 1991], which attempts to cater for all forms of digital geo-referenced data. The standard is based on a relational model, which makes it modular and thus flexible and relatively easy to use and update. A set of data being exchanged consists of a *File Identification*, a *Global Information Section* and a number of *Geo-referenced Information Relations*. This chapter should be read in conjunction with Appendix A, which provides a formal specification of NES. The assessment of NES below is based on that provided in Cooper [1989a]. All the entries in the Global Information Section and all the Geo-referenced Information Relations have tags of four and eight characters respectively, and these tags are used in the following assessment of NES.

Version 1.0 of NES was reviewed by Lane [1988].

6.2 The relational model of NES

The author designed much of the structure of NES. This includes the relational structure of NES, as well as the format of all the relations. The author also determined what entries and relations were needed, based on the functionality that the whole of the project team determined that NES should provide.

When the NES project began, it was decided to use a relational model, rather than a hierarchical or network model, because the relational model is inherently modular and more flexible than the other two. In a relational structure, the data are represented in a single uniform manner, and thus operations on the data are robust and simple to implement. In practice, the author found it easier to use a hierarchical structure at first, until the project team had clarified the exact nature of the digital geo-referenced data to be exchanged [1]. The author then found that it was a trivial process to convert the hierarchical model into the present relational model.

While ideally it might be preferable to use an object-oriented model for NES, at the time NES was developed, the technology of object-oriented data structures was not well understood outside of academia. In an object-oriented data base, an object is stored together with its attributes and the operations that it is capable of performing (known as *encapsulation*), and objects are arranged in a hierarchy of classes, and a class can *inherit* the attributes and operations of its parent class. Even now, although there might be much interest in “object-orientedness”, the use of object-oriented data bases in the commercial GIS world is rather limited.

When creating a data set in the format of NES, one merely omits those relations for which one has no data. It is easy to add new relations to NES. It is the intention of the CCNLIS [2] that each successive version of NES be backwardly compatible. That is, that data that can be exchanged through the relational structure of a particular version of NES should always be able to be exchanged through NES, no matter how many new relations are added to cater for new concepts or types of data [Cooper 1988b]. This is achieved by adding new relations and leaving the existing ones as they are, rather than modifying the existing relations. However, this has not been the case with the changes made between Versions 1.0 and 2.0 of NES, as inverse relations [3], which were included in Version 1.0, were omitted from Version 2.0. CCNLIS did not consider this to be a contravention of the principle, as very few people had attempted to implement NES at the time.

It is desirable to have a degree of normalisation in data in a relational form [Van Roessel 1987]. Normalisation eliminates or reduces redundancies in the data base, and anomalies when updating the data base. The dependencies in normalised data represent the relationships that will be stored in the data base [Ullman 1980]. The following are the normal forms for relational data:

- **First normal form:** The domain of each field must consist of primitives or indivisible elements, not arrays, vectors or sets of values.
- **Second normal form:** Every non-key field must be dependent on the complete primary key.
- **Third normal form:** No non-key field can be dependent on another non-key field [Van Roessel 1987, Ullman 1980].

There are some relations in NES for which normalization was not really feasible, due to

[1] A hierarchy is a natural way to view geo-referenced data, since features are composed of other features and features are composed of attributes, for example. Diagrams of the hierarchical structure enabled the project team to visualise the structure of the data and understand the relationships, but the diagrams became rather unwieldy.

[2] The Coordinating Committee for the National Land Information System (CCNLIS) is responsible for maintaining NES.

[3] For some relations, inverse relations were provided to make NES more complete. However, it was found that they caused confusion, so they were omitted.

the excessive storage and processing overheads that would be introduced. For example, the relation *CHAIDATA* contains the internal coordinates of chains. Each record in this relation has a variable numbers of fields as there is one field for each coordinate, and each chain contains a variable number of internal coordinate tuples. The following are the current format (which is not even in the first normal form) and the normalised format of the *CHAIDATA* relation in NES (For the purposes of such illustrations in this chapter, the symbol $\longrightarrow$ indicates derivation, and the symbol $\oplus$ indicates concatenation):

- *Chain data (current format — NES Version 2.0)*:
  Data ID $\longrightarrow$ *Coordinate tuples*
- *Chain data (normalised)*:
  Data ID $\longrightarrow$ *Sequence number* $\oplus$ *Coordinate tuple*

In practice, this means that with a normalised *CHAIDATA*, the *Data ID* field would have to be repeated for every coordinate tuple (the *Sequence number* field would not be included in the data set being exchanged, as analysed below). These differences are illustrated in Table 6.1.

Normalised	**Unnormalised**
`CHAIDATA4328,-102387,-7550;4328,-100137,-7275;4328,-99925,-7850;4328,-99625,-8675;4328,-99350,-10475;4328,-97375,-12300;4328,-97562,-12612;4328,-98900,-14825;4328,-99800,-14737;4328,-99862,-14762` ...	`CHAIDATA4328,-102387,-7550;-100137,-7275;-99925,-7850;-99625,-8675;-99350,-10475;-97375,-12300;-97562,-12612;-98900,-14825;-99800,-14737;-99862,-14762` ...

Table 6.1: Normalised and unnormalised versions of the relation *CHAIDATA*

For the rest of the relations in NES, an attempt was made to normalize the relations to the third normal form. This required the introduction of a *Sequence number* field to the keys of those relations where the keys were not unique. For example, the relation *REGICHAI* relates a region to the chains and/or arcs that constitute its boundary. The boundary may be formed by several chains and/or arcs. The sequence number ensures that there is a unique key for each instance of the relation relating a particular regions the the chains and/or arcs forming its boundary. However, the sequence number appears only in the documents describing or specifying NES, and not in the actual data being exchanged. As the data in the data set have an inherent ordering, the sequence number is implied by the record's position in the data set. For example:

Tag	**Region**	**Chain or Arc**	**Chain**	**Direction**
REGICHAI	11	C	5	F
	11	C	6	F

11	C	7	F
12	C	8	F
12	C	9	F
12	C	6	B
13	C	10	F . . .

Here, the key field is that labelled **Region**, which contains the unique identifier for regions in the data set. However, as can be seen, the key is not unique. There are three records for region 11, linking it to each of the chains 5, 6 and 7. Hence, it is necessary to introduce a sequence number to the key to normalise the relations, though in practice, it is omitted from the data as the records have unique positions within the data set, which provide the unique sequence number.

As an example of the relational model, the following are the relations which relate an area feature to its classification and its spatial attributes:

1. *Feature/classification* which relates:
   Feature ID $\longrightarrow$ *Classification*

2. *Feature/feature type* which relates:
   Feature ID $\longrightarrow$ *Feature type*

3. *Area feature/included regions* which relates:
   Feature ID $\longrightarrow$ *Region ID*

4. *Region/chains & arcs & direction* which relates:
   Region ID $\longrightarrow$ *Indication of chain or arc* $\oplus$ *Chain ID* $\oplus$ *Direction indicator*

5. *Chain/nodes & coordinate tuples* which relates:
   Chain ID $\longrightarrow$ *Node ID* $\oplus$ *Node ID* $\oplus$ *Length of chain* $\oplus$ *Data ID*

6. *Node/coordinate tuple* which relates:
   Node ID $\longrightarrow$ *Coordinate tuple*

7. *Chain data* which relates:
   Data ID $\longrightarrow$ *Coordinate tuples*

Relation 1 classifies the feature, relation 2 identifies the feature as an area feature, relation 3 connects the feature to its region spatial attribute, relation 4 performs the topological link between the region and the chains and arcs which form its boundary (specifying whether the chains and arcs are used forwards or backwards), relation 5 links the chains to their start and end nodes and to their internal coordinate tuples, relation 6 specifies the coordinate tuples identifying the locations of the nodes and relation 7 contains all the internal coordinate tuples for the chains.

6.3 Special features of NES

6.3.1 Alternate spatial attributes

As analysed above (see Section 3.2), alternate spatial attributes allow one to have several different versions of the spatial attributes of a feature. To the best of the author's knowledge, NES is the only exchange standard to provide such a facility.

In NES, in the Global Information Section, the entry *Alternate spatial attribute scheme* determines whether or not alternate spatial attributes are used in the data set being exchanged. If they are used, this entry and the entry *Alternate spatial attribute scheme release number* indicate which scheme is used.

If alternate spatial attributes are used, then in the Geo-referenced Information Relations, the field *Alternate spatial attribute* is used in every relation to differentiate between the various alternate spatial attributes of the features. This field follows immediately after the field *Feature ID*, as it qualifies this field. It is used in those relations relating a feature to its spatial attributes, as well as in the two relations which define the type of the feature (point, line, etc) and the feature's planimetric spatial domain.

If the entry *Alternate spatial attribute scheme* is not present in the Global Information Section, then alternate spatial attributes are not used at all in the data set being exchanged. If they are not used, then in the Geo-referenced Information Relations, the field *Alternate Spatial Attribute* is ignored completely. That is, it is not included in the data set being exchanged. It is important to note that the default is that alternate spatial attributes are not used. Hence, users who do not intend using alternate spatial attributes could ignore all mention of them completely, without impairing their understanding of NES, or of a data set in the NES format.

In the Geo-referenced Information Relations, the relation *EXCHASAS* (see Section 6.3.3 below) may be used for exchanging an alternate spatial attribute scheme with the data set being exchanged. Currently, no alternate spatial attribute scheme is defined for NES.

6.3.2 Information on the quality of the digital data

In NES, information on the quality of the data being exchanged may be included in the data set as free text only. The relation *DATAQUAL* is used to provide statements on data quality. The granularity of the information on quality can thus vary from coarse (referring to the whole data set) to fine (referring to a section containing only one instance of a particular relation) [Cooper 1987a].

Only when the quantification of information on the quality of digital geo- referenced data is well understood, will NES address the encoding of such meta-information.

6.3.3 Data dictionary capability

A data dictionary defines terms and structure. For example, in NES, data dictionary capabilities are provided in the Geo-referenced Information Relations for defining the classification scheme, the non-spatial attribute scheme, and the alternate spatial attribute scheme used in the data set being exchanged, as follows:

- **Classification:** The relation *EXCHCLAS* relates a *class path name* to a *classification code* and a *description*. The description enables the recipient to determine to which class in their GIS the class being exchanged should be mapped.
- **Non-spatial attributes:** The relation *EXCHNSAT* relates a *non-spatial attribute name* to a *non-spatial attribute ID*, the *units* used for the attribute (which could be text), and the *description* of the attribute. Again, the description enables the recipient to determine how to bring the attribute into their data base.
- **Alternate spatial attributes:** The relation *EXCHASAS* relates an *alternate spatial attribute* to its *description*, which will enable the recipient to determine how to incorporate the alternate spatial attributes into their GIS.

6.4 File Identification

The *File Identification* is a fixed format file for identifying the set of data being exchanged. It is 2048 bytes long and consists of standard 7-bit ASCII characters. The fixed format facilitates the extraction of the various fields, both by computers and humans! Most of the data in the File Identification is in a free text, human-readable form (for example, the *Data identification*, *Source* and *Maintenance organizations*, *Copyright statement* and *Comments*), while some is in a formatted, computer-readable form, yet still intelligible to a human (for example, the *Volume number*, *Time* and *Date stamps*, *Physical record size* and *Blocking factor*).

The purpose of the File Identification is to allow recipients of the data set to identify the data set, its currency and its relevance to their geographical information system, without having to do involved interpretation of the data set. The volumes of digital geo-referenced data that any user might receive, and thus the volumes of various physical media containing such data that might reside in the user's storage, are potentially enormous. The File Identification is there to provide identification of the data should the physical label on the media prove to be missing, illegible or cryptic.

In addition, the File Identification provides some information to the interface program attempting to interpret the data set — for example, the *Physical record size* and *Blocking factor* indicate the manner in which the data are stored on the physical exchange medium, and the *ASCII/Binary* and *Explicit lengths/Delimiters* flags indicate whether the data are stored using 7-bit ASCII characters or in binary, and whether the fields are separated by delimiters or whether the lengths of the fields are determined by explicit length fields appearing before each field.

The File Identification forms the *first physical file* of a data set being exchanged. The rest of the data forms the *second physical file*. On a magnetic tape, these two files are separated by two end-of-file markers. Version 2.0 of NES specifies the use of only magnetic tape and magnetic diskettes as the physical exchange medium, as few users in South Africa use anything else at this stage. This does not preclude the use of any other exchange medium, however.

6.5 Global Information Section

The *Global Information Section* provides details of the data being exchanged, such as the *Projection or coordinate system* and the *Reference surface* used. Such information is critical for the correct interpretation of the data being exchanged, though some people consider this information to be only information on the quality of the data being exchanged. However, if one does not know the reference surface, projection and standard meridians and parallels used in the creation of a data set, then one cannot confidently combine that data set with another.

The entries in the Global Information Section consist of variable length records, which in turn, consist of variable length fields. If one is using the ASCII version of NES with delimiters (as the author recommends), fields and records are delineated by delimiters between the fields and records. Alternatively, if one is using the binary version of NES with explicit lengths, then the fields and records are delineated by explicit lengths at the beginning of each field. The choice of ASCII and delimiters or binary and explicit lengths is indicated in the File Identification. The use of ASCII and delimiters is recommended as they are conceptually easier to understand and implement, both when creating and interpreting the data set.

Almost all of the entries have default values and are thus optional. Generally, those that do not have defaults are essential. For example, the *Standard meridians & parallels & scale factor* entry is essential for all projections where there are standard meridians and/or parallels. These then identify where on the earth's surface the data are. For example, the standard South African survey system is based on the Gauss Conformal projection, which is defined for 2°-degree wide strips running North-South, and each strip has a central meridian which identifies on which strip the data lie — one cannot determine from the coordinates alone as to which central meridian was used.

The *Bounding planimetric quadrilateral coordinate tuples* entries do not have default values, as they define the extent of the data set. They should be provided, as they will enable the recipient to determine the size of the area that must be allocated for the data set.

Other entries in the Global Information Section include the *Units* of the *Planimetric* and *Vertical coordinate resolutions*, which define the units for the coordinates (such as centimetres or metres). In addition, to allow one's coordinates to be in multiples of two metres, for example, the entries *Increment* of the *Planimetric* and *Vertical coordinate resolutions* define a factor by which the numeric values of the coordinates should be multiplied.

The entries *Data quality*, *Feature classification*, *Attribute* and *Alternate spatial attribute schemes* and *release numbers* define which schemes are used for recording information on data quality, and the classification, non-spatial attribute and alternate spatial attribute schemes used. Currently, the defaults are that information on data quality consists of free text, the feature classification and non-spatial attribute schemes distributed with Version 1.0 of NES are to be used, and that alternate spatial attributes are not used. However, the user could use the data dictionary capabilities of NES (see Section 6.3.3) to exchange their own definition for the last three.

6.6 Geo-referenced Information Relations

The *Geo-referenced Information Relations* contain the actual data being exchanged. Each section, which corresponds to a table in a relational data base, contains a sequence of instances of a particular relation.

As in the Global Information Section, the sections in the Geo-referenced Information Relations consist of variable length records and fields with either delimiters between the fields and records (and sections), or with explicit lengths at the beginning of each field, as indicated in the File Identification. The first relation must be that relation which lists all the relations used in the data set, which is the *RELALIST* relation when ASCII and delimiters are used, and the *TEMPLATE* relation when binary and explicit lengths are used. They allow the recipient of the data to determine what relations are used (to pre-empt any problems the recipient might have with certain relations), and to check that all data were received. In addition, *TEMPLATE* allows the creator of the data set to set up templates for the fields, and hence make the fields fixed length fields. The author would recommend the use of ASCII and delimiters as they are easier to understand and use (the data set is to an extent human-readable), and with the reducing costs for storing and transmitting data, the benefits of the binary version are not that significant any more.

The relation for exchanging information on the quality of the digital data, namely *DATAQUAL*, consists of free text which describes the quality of the data. In addition, the *Description* fields in the relations for exchanging the classification, namely *EXCHCLAS*, the non-spatial attribute scheme, namely *EXCHATTR*, and the alternate spatial attribute scheme, namely *EXCHASAS*, also contain free text. All other fields and relations contain data in a format encoded explicitly for automatic interpretation by the interface program of the recipient.

As analysed above, *EXCHCLAS* and *EXCHATTR* provide the user with a data dictionary facility for exchanging the definitions of the classification and attribute schemes with the data set.

The relation *FEATCLAS* relates a feature to its classification, *FEATTYPE* defines the type of feature (point, line, area, grid or compound) and *FEATNODE*, *FEATCHAI*, *FEATREGI* and *FEATMATR* relates point, line, area and grid features respectively to their spatial attributes (nodes, chains or arcs, regions and matrices respectively). *COMPFEAT* relates a compound feature to its constituent features.

The relations providing the topological relationships between spatial attributes are *REGICHAI* (relating a region to the chains and arcs that form its boundary), *CHAINODE* (relating a chain to its start and end nodes and its internal coordinates) and *REGIEXCL* (relating a region to its excluded regions).

There are the geometric data relations which contain the coordinate tuples and constitute the bulk of the data set — especially *CHAIDATA*, which contains the internal coordinate tuples of the chains. The others are *NODECOOR* (relating a node to its coordinate tuple), *ARCCDATA* (defining a circular arc), *ARCEDATA* (defining an elliptical arc), and *MATRDATA* and *RASTDATA*, which contain raster data being exchanged.

Simple non-spatial attributes are exchanged using *FEATNSAT*. More complex non-spatial attributes are exchanged using the relations *FEATTABL*, *DATADICT*, *FIELDICT* and *NSATnnnn* — the first three are used to define the name and format of the fourth, which contains the actual non-spatial attribute data.

Finally, annotation is catered for by *TEXTCHAR*.

6.7 The author's contribution to NES

As mentioned above, the author designed the relational structure for NES, including the design of all the individual relations and entries. In addition, the author normalised the relations in NES, to the extent that doing so improved NES. In this regard, the author recognised that while sequence numbers were essential to normalise relations in theory, in practice it was not necessary to include them in the actual data set being transferred. This is because the data set forms a sequential data stream, and each byte then has a unique address within the data stream, which could be used in the place of the sequence number. At that time, the developers of the American standard considered it necessary to include explicit sequence numbers in their model [Van Roessel 1987], though explicit sequence numbers are not used in SDTS [DCDSTF 1991].

The author was involved in the development of the concept of alternate spatial attributes prior to the development of NES (they were known as *detail levels* initially). The author then devised the technique for including them in NES, while ensuring that those users who did not use alternate spatial attributes could ignore them completely.

Finally, the author also helped to design the mechanism for exchanging complex non-spatial attributes.

6.8 Summary

In this chapter, NES has been assessed. It is to some extent the basis of this dissertation. NES has introduced several new concepts to the world of digital geo-referenced information, and the process of developing NES stimulated GIS in South Africa. NES is not perfect, and the process that has been established to maintain and improve NES is assessed in the next chapter.

Chapter 7

Conclusions

7.1 Summary

This dissertation analyses the fundamental nature of digital geo-referenced information, special types of digital geo-referenced data, and the application of such information. It has also analysed standards and the standards process, and includes reviews of several standards for the exchange of digital geo-referenced information. It has analysed languages and argued that an exchange standard is a language. A comprehensive glossary of terms covering all these fields is included in this dissertation.

Finally, this dissertation analyses the South African National Exchange Standard (NES), which is at the core of this dissertation, providing a full, formal specification of NES.

7.2 Future research topics

Moellering [1991] has identified a long list of topics in the field of standards for exchanging digital geo-referenced information. The following are a selection of those that he mentions and that have been highlighted in this dissertation:

- The search for more comprehensive hybrid data structures must be continued.
- Object-oriented data base concepts are in their infancy in cartography and must be explored in depth.
- The question of the possibility of a unified theory of spatial data must be considered and examined.
- 3-D spatial object primitives *must* be developed more completely.
- Pictorial and image objects require further development.
- The notion of temporal aspects of spatial data structures is still in its infancy and presents many research opportunities.

- The idea of manipulating complex objects needs more work.
- More concise approaches to the reporting of quantitative data quality levels need development.
- Syntax/semantic transfer concepts need fuller development [Moellering 1991b].

As can be seen, there is much research that could be conducted in this field. However, in the near future, in the author's opinion, much energy will be focussed on implementing interfaces to exchange standards and on testing them, rather than on research.

7.3 The contributions made by NES

In the author's opinion, NES has made a number of significant contributions to the field of standards for the exchange of digital geo-referenced information. For example, NES was the first exchange standard designed to cater for all forms of digital geo-referenced information *ab initio* — other standards were generally targeted at either cartographic or hydrographic information when they were first developed. NES was also the first standard based entirely on a relational model, and is one of the few designed to be modular and expandable, and one of the few to allow the exchange of both vector and raster data in the same data set.

The author also believes that NES is one of the few exchange standards to combine full-functionality with a structure that is relatively easy to understand. For example, the American standard, SDTS, is based on ISO 8211 [ISO 1985], and the British standard, NTF, will be. ISO 8211 is so complicated that the British exchange standard *experts* found it necessary to hire the developer of ISO 8211 to help them understand ISO 8211 and implement NTF on ISO 8211 [Sowton 1991b].

NES's unique contributions are alternate spatial attributes (as analysed in Section 3.2) and the provision for complex non-spatial attributes(as analysed in Section 2.3.8.3).

It is gratifying that some of the terminology used in NES is starting to be used in other standards, for example, the term *non-spatial attribute*.

The process of developing this standard has made a significant contribution to creating more awareness among the South African GIS community of the fundamental concepts of geo-referenced information [Cooper 1988c]. For example, the project team held numerous, well-attended workshops around South Africa at which these concepts were discussed. The project team also stimulated GIS in general, for example by initiating one user group (the Transvaal Association for GIS (TAGIS)), and by providing a catalyst for another user group to become active (the Natal/KwaZulu Association for GIS (NAGIS)).

7.4 The future of NES

7.4.1 Maintenance committee

The NPRS [1] asked the chairman of the State Inter-departmental Coordinating Committee for the National Land Information System (CCNLIS) to assume responsibility for NES. A sub-committee of the CCNLIS, the Standards Committee (of which the author is a member), was established early in 1988 with the following functions:

1. To promote the use of NES.
2. To provide an advisory service to interested organizations in matters relating to the exchange of geo-referenced information.
3. To promote research in and investigate matters relating to the exchange of geo-referenced information and to keep abreast of developments in the computer and information industries and similar exchange standards in other countries.
4. To establish and maintain a directory of organizations with geo-referenced information and their conditions for exchanging this information.
5. To provide an information service on the availability of geo-referenced information.
6. To maintain NES by receiving and co-ordinating users' requests and comments and then issuing revisions of NES when deemed necessary.
7. To prepare and maintain a user manual for NES.

It has been suggested that the brief of the Maintenance Committee should go beyond these functions. For example, the committee should have an evaluative function to determine the quality of implementations of interfaces to NES, and the success of NES in the market place.

In addition to maintaining NES, the Standards Committee has produced a standard for data for the National Land Information System (NLIS) [Standards Committe 1990], that specifies requirements such as the reference surface and projection to be used for data to be incorporated into NLIS.

7.4.2 Questionnaire on data availability

The Standards Committee prepared and distributed a questionnaire [NESC 1988] on the availability of digital geo-referenced data in South Africa. The questionnaire asked respondents to specify what data were available, specifying the feature classes, geographical extent and non-spatial attributes, and to provide some data on the quality of the

[1] The National Programme for Remote Sensing (NPRS) funded the development of Version 1.0 of NES.

digital geo-referenced data. There were also a few questions on the conditions of supply. Further questionnaires on data availability were distributed during 1991 and 1992.

Unfortunately, the response from users to the questionnaires has been poor, probably largely due to the lack of data available in an organised and comprehensive form.

7.4.3 User manual

Version 1.0 of NES [Clarke *et al* 1987b] was intended to provide a precise definition of NES, albeit with a few introductory chapters. A user manual was therefore needed. This was borne out by those who first used NES [Greenwood 1988]. The user manual has been completed (largely by the author) and was distributed with Version 2.0 of NES [Standards Committee 1991]. It provides a step-by-step guide on how to develop interface programs for NES, using examples.

7.4.4 Improving NES

There are a number of errors in Version 1.0 of NES. While none are errors of logic (they are mainly typographical) they could cause problems for people reading that document. In addition, NES had to be improved in a number of areas. Version 2.0 of NES was completed and published late in 1991 [Standards Committee 1991]. It corrects errors in Version 1.0, tightens up some of the language, removes all inverse relations (which had confused people implementing NES, and which in any case were redundant), and includes improvements made to the relations that cater for non-spatial attributes and for raster data. In addition, a relation for exchanging map annotation was added — while this conflicts with the principle of NES of exchanging geo-referenced information and not graphics, there was much demand from the user community for such a relation.

Nevertheless, there are still improvements that can be made to NES. The classification scheme is incomplete, and probably always will be so (as new types of features are added). The exchange of information on the quality of the digital geo-referenced data must be improved, both by quantifying the information and by providing guidelines on what must be provided. These are problems that affect all such exchange standards.

Further updates and corrections of the published standard will be produced by the maintenance committee as and when appropriate. These updates will be driven by the need to correct errors (a minor update correcting a few typographic errors was released in May 1993), the need to complete the classification and attribute schemes (these will be updated later in 1993), and when called for by the user community (for example, the inclusion of annotation).

7.5 Final comments

While the community in South Africa supports NES in principle, not many attempts have been made to implement it. This is largely due to the lack of data to exchange.

However, the situation has changed during 1992, as significant data sets are starting to become available, such as the complete 1:500 000 national mapping series, and as vendors begin implementing interfaces to NES.

Concern has been expressed over the need for an exchange standard peculiar to South Africa. Unfortunately, there is not one, definitive international standard that could be used instead. In addition, the commercial GISs available in South Africa have been developed in several different countries, which means that they do not all have one common national standard that they all support. Implementation of exchange standards in other countries has also been a long process, so the situation in South Africa is not unique.

When the one, definitive international standard for the exchange of digital geo-referenced information is developed, who can say how much of it will be based on NES?

Appendix A

Using EBNF to define NES

A.1 Outline of EBNF

A.1.1 The background to EBNF

This Appendix contains a formal definition of the latest version of the National Exchange Standard (NES), namely Version 2.0. It has been defined using the Extended Bacus-Naur Form (EBNF)[Aho *et al* 1986, Gries 1981].

EBNF is a formal metalanguage that is frequently used for specifying the syntax of computer languages, for example in the ISO definition of Pascal. It is an extension of the Bacus-Naur Form (BNF), introduced in the definition of ALGOL60. EBNF is a context-free grammar, which means that the resolution of any symbol appearing on the left-hand side of a production is not dependent on the symbols that preceded or followed that symbol. See Section 4.4 for more details.

A.1.2 "Standard" EBNF

While BNF is defined concisely, there is no standard definition of the extensions to BNF that constitute EBNF. The following is a brief summary of what is generally accepted as the "standard" version of EBNF, that is, BNF and the minimum set of extensions that are usually used:

- EBNF is a notation for representing rules that can be used to derive sentences of a language. If a finite set of these rules can be used to derive all sentences of a language, then this set of rules constitutes a formal definition of the syntax of the language — that is, all syntactically correct programs, or in our case, all syntactically correct implementations of NES.
- A **non-terminal** symbol is one that can be expanded (by a rule) . Non-terminal symbols are delimited by angle brackets. For example,

  <Non-terminal symbol>

- a special non-terminal symbol is the **start symbol**. In the case of NES, it is:

  <NES>

- A **terminal** symbol is one that cannot be expanded — that is, it is part of the language being defined (part of NES). Terminal symbols are written normally. For example,

  Terminal symbol

- A **rule** or **production** consists of a left hand side (LHS) (which can only be a single non-terminal symbol) and a right hand side (RHS) (terminals and non-terminals that define the symbol on the LHS). The LHS is separated from the RHS by the symbol ::= meaning "may be composed of". If the length of the RHS warrants it, it may be spread over more than one line. For example,

  <LHS> ::= <RHS>
  a terminal too long to fit on the same line as the rest

- On the RHS, curly braces, that is, { and }, are used to indicate that the enclosed symbol(s) occur zero, one or many times. For example,

  <LHS> ::= { <this occurs 0, 1, or many times> }

- On the RHS, a vertical line, that is, |, separates symbols where only one of them may be selected. For example,

  <LHS> ::= <this> | <or that> | <or even this>

- The empty set, that is, $\emptyset$, is allowed. For example,

  <LHS> ::= $\emptyset$

A.1.3 Additions to EBNF

The following have been added to EBNF for the purpose of defining NES. They simplify using EBNF and should make reading the EBNF easier.

- On the RHS, round brackets, that is, (and), are used to group terminals and/or non-terminals together, especially a list of options. For example,

  <LHS> ::= (<this> | <or that>) <followed by this>

- On the RHS, curly braces used with a superscript on the right brace, are used to indicate that the enclosed symbol(s) occur a fixed number of times, being the number in the superscript. For example,

  <LHS> ::= { <this occurs exactly 5 times> } ^{5}

- To facilitate reading the EBNF form of NES, comments on the productions are included. Comments are lines that commence with the paragraph character, that is, ¶. For example,

  ¶This is a comment.

- Some of the characters that occur in data in the NES format are not printable, such as the delimiters, so their values are given in hexadecimal. Such hexadecimal values may be identified by a subscript *"H"*. For example,

  <LHS> ::= $1\mathrm{F}_H$

A.1.4 Precedence of operators in EBNF

The following is the order of the precedence of the operators in EBNF, from the highest precedence to the lowest:

1. The brackets around a non-terminal, that is: $<$ and $>$.
2. All other brackets, that is: (and), { and }, and { and } ^{n}.
3. The "or" operator, that is: |.
4. Concatenation, that is: a sequence terminals and non-terminals following each other on the RHS of a production.

A.1.5 Syntax vs semantics

EBNF defines only the *syntax* of the language (NES), that is, the grammatical rules that govern the use of the language — where in a sentence of the language the various symbols may be relative to each other.

EBNF does not define the *semantics* of the language, that is, the meaning of the symbols. Hence, a data set could conform to the EBNF of a language without actually meaning anything — it could contain pure garbage.

A.2 The EBNF for NES

NES is defined below using EBNF. Please note that the definition given in this section is for NES as used with ASCII characters [ISO 1983] and delimiters, which is the way most people will use NES.

It is assumed that the reader has access to a copy of NES v2.0 [Standards Committee 1991], in which the meaning of the NES terms used herein are explained. The definition below also appears in [Cooper 1993].

A.2.1 The overall structure of NES

<NES>	::=	<First physical file> <Second physical file>
<First physical file>	::=	<File Identification>
<Second physical file>	::=	<Global Information Section> <GS> <Geo-ref Info> <FS>

A.2.2 The File Identification

¶The File Identification is a fixed length, fixed format, ASCII file.

<File Identification>	::=	<Data ID> <Volume number> <Source org> <Maintenance org> <Copyright> <Access privileges> <Date stamp> <Time stamp> <North limit> <South limit> <West limit> <East limit> <ASCII/binary> <Lengths/delimiters> <Record size> <Blocking factor> <Comments>

<Data ID>	::=	{ <char> }^{128}
<Volume number>	::=	{ <digit> }^{8}
<Source org>	::=	{ <char> }^{256}
<Maintenance org>	::=	{ <char> }^{256}
<Copyright>	::=	{ <char> }^{256}
<Access priviledges>	::=	{ <char> }^{256}

<Date stamp>	::=	{ <digit> }^{8}
<Time stamp>	::=	{ <digit> }^{6}
<North limit>	::=	{ <digit> }^{7} (N | S)
<South limit>	::=	{ <digit> }^{7} (N | S)
<West limit>	::=	{ <digit> }^{7} (W | E)
<East limit>	::=	{ <digit> }^{7} (W | E)
<ASCII/binary>	::=	A | B
<Lengths/delimiters>	::=	<digit> | D
<Record size>	::=	{ <digit> }^{8}
<Blocking factor>	::=	{ <digit> }^{8}
<Comments>	::=	{ <char> }^{824}

A.2.3 The Global Information Section

¶The Global Information Section contains overall information about the data
¶set being exchanged. Defaults are normally used for most of the entries.

<Global Information Section>	::=	<projection> <PCRU> <PCRI> <FPCO> <SPCO> <DIMC> <VCRU> <VCRI> <A/RC> <HDTF> <HDAT> <BPQ1> <BPQ2> <BPQ3> <BPQ4> <QUAL> <QUNO> <CLAS> <CLNO> <ATTR> <ATNO> <ASAS> <ASNO>

¶The entries for the Projection System and Standard Meridians and Parallels
¶are treated differently from the other entries here, as one of these two entries
¶must be present in any Global Information Section.

¶Each entry begins with a four-character tag (which identifies the entry) which is
¶then followed by the actual data in the entry, defined below.

<projection>	::=	<P/CS> | <SM&P> | <P/CS> <RS> <SM&P> | <P/CS> <RS> <REFS> | <SM&P> <RS> <REFS> | <P/CS> <RS> <SM&P> <RS> <REFS>

<P/CS>	::=	P/CS <P/CS entry>
<SM&P>	::=	SM&P <SM&P entry>
<REFS>	::=	REFS <REFS entry>
<PCRU>	::=	$\not\phi$ | <RS> PCRU <PCRU entry>
<PCRI>	::=	$\not\phi$ | <RS> PCRI <PCRI entry>
<FPCO>	::=	$\not\phi$ | <RS> FPCO <FPCO entry>
<SPCO>	::=	$\not\phi$ | <RS> SPCO <SPCO entry>
<DIMC>	::=	$\not\phi$ | <RS> DIMC <DIMC entry>
<VCRU>	::=	$\not\phi$ | <RS> VCRU <VCRU entry>
<VCRI>	::=	$\not\phi$ | <RS> VCRI <VCRI entry>
<A/RC>	::=	$\not\phi$ | <RS> A/RC <A/RC entry>
<HDTF>	::=	$\not\phi$ | <RS> HDTF <HDTF entry>
<HDAT>	::=	$\not\phi$ | <RS> HDAT <HDAT entry>

<BPQ1>	::=	$\not\phi$ | <RS> BPQ1 <BPQ1 entry>
<BPQ2>	::=	$\not\phi$ | <RS> BPQ2 <BPQ2 entry>
<BPQ3>	::=	$\not\phi$ | <RS> BPQ3 <BPQ3 entry>
<BPQ4>	::=	$\not\phi$ | <RS> BPQ4 <BPQ4 entry>

<QUAL>	::=	$\not\phi$ | <RS> QUAL <QUAL entry>
<QUNO>	::=	$\not\phi$ | <RS> QUNO <QUNO entry>
<CLAS>	::=	$\not\phi$ | <RS> CLAS <CLAS entry>
<CLNO>	::=	$\not\phi$ | <RS> CLNO <CLNO entry>
<ATTR>	::=	$\not\phi$ | <RS> ATTR <ATTR entry>
<ATNO>	::=	$\not\phi$ | <RS> ATNO <ATNO entry>
<ASAS>	::=	$\not\phi$ | <RS> ASAS <ASAS entry> | <RS> ASAS <ASAS entry> <RS> ASNO <ASNO entry>

¶Here the actual data for the entries are defined.

<P/CS entry>	::=	GAUS | UTM | LAMB | ALBE | MERC | GNOM | POLA | AZIM | GEO | OTHE
<SM&P entry>	::=	<geo coord> <more SM&P>
<more SM&P>	::=	(<US> <geo coord> <more SM&P>) | (<US> <scale factor>) | ∅
<geo coord>	::=	<integer> <more geo> <NEWS>
<more geo>	::=	: <integer> : <integer> | : <integer> | ∅
<NEWS>	::=	N | E | W | S
<REFS entry>	::=	CLARKE | BESSEL | WGS72 | INTERNAT | { <digit> } ^{8}
<PCRU entry>	::=	<units>
<PCRI entry>	::=	<real number> | <integer>
<FPCO entry>	::=	<real number> | <integer>
<SPCO entry>	::=	<real number> | <integer>
<DIMC entry>	::=	2 | 3
<VCRU entry>	::=	<units>
<VCRI entry>	::=	<real number> | <integer>
<A/RC entry>	::=	A | R
<HDTF entry>	::=	{ <char> }
<HDAT entry>	::=	<real number> | <integer>
<BPQ1 entry>	::=	<coords>
<BPQ2 entry>	::=	<coords>
<BPQ3 entry>	::=	<coords>
<BPQ4 entry>	::=	<coords>
<QUAL entry>	::=	{ <char> }
<QUNO entry>	::=	<version number>
<CLAS entry>	::=	{ <char> }
<CLNO entry>	::=	<version number>
<ATTR entry>	::=	{ <char> }
<ATNO entry>	::=	<version number>
<ASAS entry>	::=	{ <char> }
<ASNO entry>	::=	<version number>

A.2.4 The geo-referenced information relations

¶The Geo-referenced Information Relations contain the actual data being exchanged.
¶The first relation differs from the others in that it lists all the relations used in
¶in the data set. This allows the recipient to determine rapidly what relations were
¶used, as well as providing a check that all relations were received. There must
¶be a one-to-one correspondence between the relations listed in the first relation
¶(RELALIST, in this case) and the remaining relations. Each relation begins with
¶an eight-character tag.

<Geo-ref Info>	::=	<list of relations> <EXCHCLAS> <EXCHATTR> <EXCHASAS> <DATAQUAL> <FEATCLAS> <FEATNSAT> <FEATTYPE> <FEATSDOM> <FEATNODE> <FEATCHAI> <FEATREGI> <FEATMATR> <COMPFEAT> <REGICHAI> <CHAINODE> <REGIEXCL> <NODECOOR> <CHAIDATA> <ARCCDATA> <ARCEDATA> <MATRDATA> <RASTDATA> <FEATTABL> <DATADICT> <FIELDICT> <NSATnnnn> <TEXTCHAR>

<list of relations>	::=	<RELALIST>
<RELALIST>	::=	RELALIST <relation> { <RS> <relation> }
<relation>	::=	EXCHCLAS | EXCHATTR | EXCHASAS | DATAQUAL | FEATCLAS | FEATNSAT | FEATTYPE | FEATSDOM | FEATNODE | FEATCHAI | FEATREGI | FEATMATR | COMPFEAT | REGICHAI | CHAINODE | REGIEXCL | NODECOOR | CHAIDATA | ARCCDATA | ARCEDATA | MATRDATA | RASTDATA | FEATTABL | DATADICT | FIELDICT | { NSAT <table> } | TEXTCHAR

¶All the remaining relations are optional, but if they appear, they must be in
¶the order specified.

<EXCHCLAS>	::=	$\not\emptyset$ | <GS> EXCHCLAS <EXCHCLAS entry> { <RS> <EXCHCLAS entry }
<EXCHATTR>	::=	$\not\emptyset$ | <GS> EXCHATTR <EXCHATTR entry> { <RS> <EXCHATTR entry> }
<EXCHASAS>	::=	$\not\emptyset$ | <GS> EXCHASAS <EXCHASAS entry> { <RS> <EXCHASAS entry> }
<DATAQUAL>	::=	$\not\emptyset$ | <GS> DATAQUAL <DATAQUAL entry> { <RS> <DATAQUAL entry> }
<FEATCLAS>	::=	$\not\emptyset$ | <GS> FEATCLAS <FEATCLAS entry> { <RS> <FEATCLAS entry> }
<FEATNSAT>	::=	$\not\emptyset$ | <GS> FEATNSAT <FEATNSAT entry> { <RS> <FEATNSAT entry> }
<FEATTYPE>	::=	$\not\emptyset$ | <GS> FEATTYPE <FEATTYPE entry> { <RS> <FEATTYPE entry> }
<FEATSDOM>	::=	$\not\emptyset$ | <GS> FEATSDOM <FEATSDOM entry> { <RS> <FEATSDOM entry> }

<FEATNODE>	::=	$\not\phi$ | <GS> FEATNODE <FEATNODE entry> { <RS> <FEATNODE entry> }
<FEATCHAI>	::=	$\not\phi$ | <GS> FEATCHAI <FEATCHAI entry> { <RS> <FEATCHAI entry> }
<FEATREGI>	::=	$\not\phi$ | <GS> FEATREGI <FEATREGI entry> { <RS> <FEATREGI entry> }
<FEATMATR>	::=	$\not\phi$ | <GS> FEATMATR <FEATMATR entry> { <RS> <FEATMATR entry> }
<COMPFEAT>	::=	$\not\phi$ | <GS> COMPFEAT <COMPFEAT entry> { <RS> <COMPFEAT entry> }
<REGICHAI>	::=	$\not\phi$ | <GS> REGICHAI <REGICHAI entry> { <RS> <REGICHAI entry> }
<CHAINODE>	::=	$\not\phi$ | <GS> CHAINODE <CHAINODE entry> { <RS> <CHAINODE entry> }
<REGIEXCL>	::=	$\not\phi$ | <GS> REGIEXCL <REGIEXCL entry> { <RS> <REGIEXCL entry> }
<NODECOOR>	::=	$\not\phi$ | <GS> NODECOOR <NODECOOR entry> { <RS> <NODECOOR entry> }
<CHAIDATA>	::=	$\not\phi$ | <GS> CHAIDATA <CHAIDATA entry> { <RS> <CHAIDATA entry> }
<ARCCDATA>	::=	$\not\phi$ | <GS> ARCCDATA <ARCCDATA entry> { <RS> <ARCCDATA entry> }
<ARCEDATA>	::=	$\not\phi$ | <GS> ARCEDATA <ARCEDATA entry> { <RS> <ARCEDATA entry> }
<MATRDATA>	::=	$\not\phi$ | <GS> MATRDATA <MATRDATA entry> { <RS> <MATRDATA entry> }
<RASTDATA>	::=	$\not\phi$ | <GS> RASTDATA <RASTDATA entry> { <RS> <RASTDATA entry> }
<FEATTABL>	::=	$\not\phi$ | <GS> FEATTABL <FEATTABL entry> { <RS> <FEATTABL entry> }
<DATADICT>	::=	$\not\phi$ | <GS> DATADICT <DATADICT entry> { <RS> <DATADICT entry> }
<FIELDICT>	::=	$\not\phi$ | <GS> FIELDICT <FIELDICT entry> { <RS> <FIELDICT entry> }
<NSATnnnn>	::=	{ <GS> NSAT <table> <NSATnnnn entry> }

¶For the relation NSATnnnn, the tag consists of the four letters 'NSAT', followed
¶by 4 digits, which are defined by the relation FEATTABL.

<TEXTCHAR>	::=	$\not\phi$ | <GS> TEXTCHAR <TEXTCHAR entry> { <RS> <TEXTCHAR entry> }

<EXCHCLAS entry>	::=	<class path> <US> <classification> <US> <description>
<EXCHATTR entry>	::=	<attribute name> <US> <attribute>
		<US> <units> <US> <description>
<EXCHASAS entry>	::=	<alternate ID> <US> <description>
<DATAQUAL entry>	::=	<comment> <seq no>
<FEATCLAS entry>	::=	<feature> <US> <classification>
<FEATNSAT entry>	::=	<feature> <seq no> <US> <attribute> <US> <value>
<FEATTYPE entry>	::=	<feature> <alternate> <US> <feature type>
<FEATSDOM entry>	::=	<feature> <alternate> <US> <min 1st coord> <US>
		<max 1st coord> <US> <min 2nd coord> <US>
		<max 2nd coord>
<FEATNODE entry>	::=	<feature> <alternate> <US> <node>
<FEATCHAI entry>	::=	<feature> <alternate> <seq no> <US>
		<indicator> <US> <chain/arc> <US> <direction>
<FEATREGI entry>	::=	<feature> <alternate> <seq no> <US> <region>
<FEATMATR entry>	::=	<feature> <alternate> <seq no> <US> <matrix>
<COMPFEAT entry>	::=	<feature> <alternate> <seq no> <US> <feature>
<REGICHAI entry>	::=	<region> <seq no> <US> <indicator>
		<US> <chain/arc> <US> <direction>
<CHAINODE entry>	::=	<chain/arc> <US> <node> <US> <node> <US>
		<length> <US> <chaindata>
<REGIEXCL entry>	::=	<region> <seq no> <US> <region>
<NODECOOR entry>	::=	<node> <US> <coords>
<CHAIDATA entry>	::=	<chaindata> <US> <coords> { <US> <coords> }
		<more chaindata>
<more chaindata>	::=	$\not\phi$ | <RS> <chaindata> <US> <coords> { <US> <coords> }
		<more chaindata>

¶The CHAIDATA relation is not normalised, as it consists of a variable number
¶of coordinate tuples that follow the Data ID.

<ARCCDATA entry>	::=	<chain/arc> <US> <node> <US> <node> <US> <coords>
<ARCEDATA entry>	::=	<chain/arc> <US> <node> <US> <node> <US> <coords> <US> <coords>
<MATRDATA entry>	::=	<matrix> <seq no> <US> <coords> <US> <coords> <US> <coords> <US> <spacing> <US> <spacing> <US> <spacing> <US> <ordering> <US> <encoding> <US> <length> <US> <length> <US> <length> <US> <minimum> <US> <maximum> <US> <null> <US> <raster>
<RASTDATA entry>	::=	<raster> <US> <value> { <US> <value> }
<FEATTABL entry>	::=	<feature> <US> <table defn> <seq no> <US> <table> <US> <description>
<DATADICT entry>	::=	<table defn> <US> <fields>
<FIELDICT entry>	::=	<table defn> <US> <column> <US> <attribute>
<NSATnnnn entry>	::=	<seq no> <record> { <RS> <record> }
<record>	::=	<value> { <US> <value> }
<TEXTCHAR entry>	::=	<feature> <seq no> <US> <char> <US> <coords> <US> <world/map> <US> <units> <US> <char height> <US> <char width> <US> <orientation>

¶The sequence number is not actually used in a data set being exchanged, so it
¶is set to the null string here.

<seq no> ::= $\emptyset$

<description>	::=	<text>
<class path>	::=	<text>
<classification>	::=	<text>
<attribute name>	::=	<text>
<attribute>	::=	<text>
<alternate ID>	::=	<text>
<comment>	::=	<text>
<feature>	::=	<text>
<feature type>	::=	P | L | A | G | C | N
<node>	::=	<spatial attribute>
<indicator>	::=	C | A
<chain/arc>	::=	<spatial attribute>
<direction>	::=	F | B
<region>	::=	<spatial attribute>
<matrix>	::=	<spatial attribute>
<chaindata>	::=	<text>

<spatial attribute>	::=	<text>
<coords>	::=	<real number> | <integer>
<scale factor>	::=	<real number>

¶If alternate spatial attributes are used, then the Alternate ID and a Unit
¶Separator are added to the data set after each feature.
<alternate> ::= ∅ | <US> <text>

<spacing> ::= <real number> | <integer>
<ordering> ::= M | S
<encoding> ::= N
<minimum> ::= <real number> | <integer>
<maximum> ::= <real number> | <integer>
<null> ::= <real number> | <integer>
<value> ::= <real number> | <integer>
<raster> ::= <text>
<table defn> ::= <text>
<column> ::= <digits>
<table> ::= { <digit> } ^{4}
<world/map> ::= R | M
<char height> ::= <real number> | <integer>
<char width> ::= <real number> | <integer>
<orientation> ::= <real number> | <integer>
<real number> ::= <mantissa> [<fraction>] [<exponent>]
<mantissa> ::= [<sign>] <digits>
<fraction> ::= <decimal> <digits>
<exponent> ::= <expn mk> [< sign >] <digits>
<integer> ::= [<sign>] <digits>
<units> ::= mm | cm | m | km | deg | min | sec
<version number> ::= <digits> [<decimal> <digits> [<decimal> <digits>]] [<letter>]
<length> ::= <digits>
<fields> ::= <digits>
<text> ::= <char> [<char>]
<char> ::= <letter> | <digit> | <special>
<letter> ::= A | B | . . . | Z | a | b | . . . | z
<digits> ::= <digit> { <digit> }
<digit> ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
<sign> ::= + | -
<decimal> ::= .
<expn mk> ::= E

¶<special> can be any one of the printable characters in 7-bit ASCII,
¶which are listed here after the ::= without using the | symbol to separate
¶them, as it is itself a valid special character.
<special> ::= ! ” % & ’ ( ) * + , − . / : ; <=> ? _ # $ [\ ] ˆ ‘ { | } ˜

¶The following are the delimiters used in NES. They are the standard
¶delimiters defined in ASCII [ISO 1983].

<US> ::= $1F_H$
<RS> ::= $1E_H$
<GS> ::= $1D_H$
<FS> ::= $1C_H$

A.3 The EBNF for NES in binary

To the best of the author's knowledge, no one has attempted to implement the binary version of NES. In addition, given the significant decline in the costs of storage since NES was developed in 1987, and given the significant increase in bandwidth available on telecommunications, it is probable now that no one will attempt to implement the binary version of NES. The advantage of the compaction offered by the binary version is outweighed by the disadvantage of its greater complexity over the ASCII version. Hence, the formal definition of NES in binary has not been included here.

Appendix B

Using *Lex* and *yacc* to describe NES

B.1 Introduction

As shown in Chapter 4, an exchange standard is a language. A formal definition of the National Exchange Standard (NES) [Standards Committee 1991] is provided in Appendix A, using the context-free grammar, the Extended Bacus-Naur Form (EBNF). EBNF is similar in structure to the parser generator, *yacc*, which is available as an utility on the UNIX operating system. The pattern-action language, *Lex*, also available on UNIX, is often used in conjunction with *yacc* to parse the input stream into tokens [Aho *et al* 1986] (see Section 4.4.6 for more details).

Because of the similarities to the EBNF definition of NES provided in Appendix A, the full implementation of a syntax analyser for NES using *Lex* and *yacc* is not provided here, though examples of the implementation are provided to give the flavour of the implementation (See Levine *et al* [1992], Aho *et al* [1986], or a set of UNIX manuals for a description of the format of *Lex* and *yacc* code).

B.2 Examples of the *Lex* definition of NES

The full *declarations* part of the *Lex* code for NES is provided below. These declarations determine how the input stream will be divided up into tokens. Tokens in NES include delimiters, numbers and text strings.

```
US          \037
RS          \036
GS          \035
FS          \034
```

The four standard ASCII delimiters are defined using octal.

```
delimiter   [{US}{RS}{GS}{FS}]
```

```
letter              [A-Za-z]
digit               [0-9]
integer             [+\-]?[0-9]+
number              {integer}(\.[0-9]+)?(E{integer})?
special             [^A-Za-z0-9\037\036\035\034]
```

A special is then any character except a delimiter, letter or digit.

```
text                ({letter}|{number}|{special})
```

The following "start conditions" are set to indicate which part of a record is being processed:

```
%start _U _R _G
```

The following are examples of rules:

```
{US}                { BEGIN _U; return(US); }
^"P/CS"             { BEGIN _U; return(PCS_tag); }
<_R>"FPCO"          { BEGIN _U; expect_coords = 1; return(FPCO_tag); }
<_G,_R>"FEATCLAS"   { BEGIN _U; return(FEATCLAS_tag); }
{number}            { yylval.ly.numb1 = atof(yytext);
                          BEGIN _N;
                          yylval.ly.flag = 'N':
                          strcpy(yylval.ly.txt1, yytext);
                          return(text); }
```

The *yacc* code will then use this *Lex* code to identify the tokens in the input stream.

B.3 Examples of *yacc* definition of NES

The following is the *declarations* part of the *yacc* code for NES:

```
%{
#include <stdio.h>
#include <floatingpoint.h>
#include <string.h>
```

This is for including standard libraries used in the supporting code.

```
struct LY {  char flag; double numb1; char txt1[1024]; };
int _dimension = 2; in_relations = 0; expect_coords = 0;
%}
%token US
%token RS
%token GS
%token FS
%token PCS_tag
```

```
%token SMP_tag
%token FEATCLAS_tag
%token FEATREGI_tag
%token <ly> text
%type <ly> PCS_entry
%type <ly> classification
```

The following is the *translation rules* part of the *yacc* code. Only a selection of rules relevant for defining the standard meridian for a projection, and for exchanging an area feature, are included below. In addition, to show how these rules are used, code is included to write out (to standard output) the standard meridian in decimal degrees, and to call a routine to write a node's ID and coordinate tuple to a file. The code appears after a translation, between curly brackets ('{' and '}'), and consists of standard C code. In the C code, the special variable '$$' refers to the left hand side of each rule, while the variables '$1', '$2', ... refer to the first, second, and so on, tokens on the right hand side.

```
NES   : First_physical_file Second_physical_file _junk_
      ;
```

NES is then defined as consisting of the *First physical file* and the *Second physical file*. In turn, the *First physical file* contains the *File Identification*, and the *Second physical file* contains the actual data being exchanged, namely the *Global information section* and the *Geo-referenced information relations*, which are of interest to us in this example. The non-terminal _junk_ is used to process superfluous characters at the end of a NES file, to ensure that the parsing concludes as gracefully as possible.

```
Second_physical_file     : Global_Information_Section GS Georef_Info FS
                         ;

Global_Information_Section     : projection PCRU PCRI FPCO SPCO
                                 DIMC VCRU VCRI ARC HDTF HDAT BPQ1
                                 BPQ2 BPQ3 BPQ4 QUAL QUNO CLAS CLNO
                                 ATTR ATNO ASAS ASNO
                               ;

projection     : PCS
               : PCS RS
               | SMP
               | SMP RS
               | PCS RS SMP
               | PCS RS SMP RS
               | PCS RS REFS
               | PCS RS REFS RS
```

```
                    | SMP RS REFS
                    | SMP RS REFS RS
                    | PCS RS SMP RS REFS
                    | PCS RS SMP RS REFS RS
                    ;

SMP     : SMP_tag SMP_entry
        ;

SMP_entry       : geo_coord more_SMP
                ;
more_SMP        : US geo_coord more_SMP
                | US scale_factor
                  { printf("Scale factor:  %f \n", $2) ; }
                |
                ;
geo_coord       : text _COLON text _COLON text NEWS
                  { if (($6 == 'N') || ($6 == 'S')) ;
                        printf("Standard parallel:  ") ;
                  else
                        printf("Standard meridian:  ") ;
                  printf("%f %c \n", ($1 + $3 + $5), $6); }
                ;
```

Geographical coordinates are of the form *25:45S*.

```
NEWS            : 'N'
                | 'E'
                | 'W'
                | 'S'
                ;
scale_factor    : text
                ;
```

In the example of the description of an area feature that follows, the relations relating the feature to its classification or non-spatial attributes are omitted. In addition, the example below assumes that the boundary of the region(s) describing the position of the area feature contain only chains and not arcs.

```
Georef_Info     : list_of_relations EXCHCLAS EXCHATTR
                  EXCHASAS DATAQUAL FEATCLAS FEATNSAT FEATTYPE
                  FEATSDOM FEATNODE FEATCHAI FEATREGI FEATMATR
                  COMPFEAT REGICHAI CHAINODE REGIEXCL NODECOOR
                  CHAIDATA ARCCDATA ARCEDATA MATRDATA RASTDATA
                  FEATTABL DATADICT FIELDICT NSATnnnn TEXTCHAR
                ;
```

```
FEATREGI       : null
               | FEATREGI_tag FEATREGI_entry more_FEATREGI
               | FEATREGI_tag FEATREGI_entry more_FEATREGI GS
               ;
more_FEATREGI : RS FEATREGI_entry more_FEATREGI
               |
               ;
REGICHAI       : null
               | REGICHAI_tag REGICHAI_entry more_REGICHAI
               | REGICHAI_tag REGICHAI_entry more_REGICHAI GS
               ;
more_REGICHAI : RS REGICHAI_entry more_REGICHAI
               |
               ;
CHAINODE       : null
               | CHAINODE_tag CHAINODE_entry more_CHAINODE
               | CHAINODE_tag CHAINODE_entry more_CHAINODE GS
               ;
more_CHAINODE : RS CHAINODE_entry more_CHAINODE
               |
               ;
NODECOOR       : null
               | NODECOOR_tag NODECOOR_entry more_NODECOOR
               | NODECOOR_tag NODECOOR_entry more_NODECOOR GS
               ;
more_NODECOOR : RS NODECOOR_entry more_NODECOOR
               |
               ;
CHAIDATA       : null
               | CHAIDATA_tag CHAIDATA_entry more_CHAIDATA
               | CHAIDATA_tag CHAIDATA_entry more_CHAIDATA GS
               ;
more_CHAIDATA : RS CHAIDATA_entry more_CHAIDATA
               |
               ;

FEATREGI_entry   : feature alternate seq_no US region
                 ;
REGICHAI_entry   : region seq_no US indicator US chain_arc US direction
                 ;
CHAINODE_entry   : chain_arc US node US node US length US chaindata
                 ;
NODECOOR_entry   : node US {expect_coords = 1;} coords
                   { put_coor($1, tmp_coor1, tmp_coor2, tmp_coor3) ; }
                 ;
```

NODECOOR then contains the coordinates for the nodes.

```
CHAIDATA_entry    : chaindata US {expect_coords = 1;}
                    chain_coords more_chain_data
                  ;
more_chain_data   : RS chaindata US {expect_coords = 1;}
                    chain_coords more_chain_data
                  |
                  ;
chain_coords      : chain_coords US coords
                  | coords
                  ;
```

CHAIDATA then contains the internal coordinates of the chains.

```
feature         : text
                ;
node            : spatial_attribute
                ;
indicator       : 'C'
                | 'A'
                ;
```

This indicates whether the spatial attribute is a chain or an arc.

```
chain_arc       : spatial_attribute
                ;
direction       : 'F'
                | 'B'
                ;
```

This indicates whether the chain is used forwards or backwards.

```
region          : spatial_attribute
                ;
chaindata       : text
                ;

spatial_attribute   : text
                    ;

coords              : _number US _number
                    | geo_coord US geo_coord
                    | _number US _number US _number
                    | geo_coord US geo_coord US geo_coord
                    ;
alternate           : null
                    | text US
                    ;
null                :
                    ;
```

Finally, the *supporting C-routines* part includes code to link in the lexical analyser defined in the *Lex* code; as well as various support routines:

```
#include "lex.yy.c"
void yyerror(s)
     ⋮
main()
     ⋮
```

Appendix C

Glossary

C.1 Introduction

This glossary of terms pertaining to geo-referenced and related information was drawn up to clarify the terminology used in this document, to provide a comprehensive glossary of such terms as used in South Africa, as well as provide the Afrikaans equivalents for the English terms. It was beyond the scope of this dissertation to provide a full glossary in Afrikaans as well.

The initial basis for this glossary was the glossary distributed with Version 1.0 of the National Exchange Standard (NES) [1] [Clarke *et al* 1987b] in September 1987, which defined 126 terms. The glossary provided here is far more comprehensive than that original glossary. A wide range of diverse references has been used, and the glossary has been updated and extended substantially to cover a much broader range of terms.

The Afrikaans translations have been derived, where possible, from the *Opmeetwoordeboek / Survey dictionary* [Vaktaalkommissie 1965] and the *Tweetalige rekenaarwoordeboek / Bilingual computer dictionary* [Coetzee *et al* 1985], though many translations had to be derived *ab initio*, for which the *Tweetalige woordeboek / Bilingual dictionary* [Bosman *et al* 1984] proved invaluable. Some of the translations were sourced from NES Version 1.0 [Clarke *et al* 1987b], while others were suggested by Prof D Kourie and colleagues of the author. Individual translations have not been provided with citations, as this would make the text in this glossary difficult to use, especially when one is scanning it quickly for a particular translation.

Digital geo-referenced information terms are explained in greater detail in Chapters 1–3, and terms related to standards are explained in greater detail in Chapter 4.

[1]The NES glossary was based on the glossary [Clarke *et al* 1986b] developed early in 1986 by the project team that designed NES.

C.2 Glossary of terms in English

The following are definitions of some geo-referenced information related terms, given in English. The Afrikaans equivalent is given at the end of each entry. Cross references are supplied in some cases where the term that has been cross-referenced might not have an obvious link to the original term. As many of the terms consist of several words, most constituent words are listed and the reader is referred to the entry in the glossary where the term is defined. The terms have been placed in the glossary in alphabetical order.

ACCURACY The closeness of the results of observations, computations or estimates to the true values or the values that are accepted as being true [Moellering 1985]. Accuracy is the final measure of the worth of the data — how closely do they represent the real world?

Afrikaans equivalent: *akkuraatheid.*

ACQUISITION, DATA The process of gathering data. Data acquisition includes collating, cleaning, annotating and transcribing physical sources documents, as well as data capture.

Afrikaans equivalent: *data-insameling.*

AERIAL PHOTOGRAPH Any photograph taken from the air, for example, from an aeroplane, a balloon or an airship. Aerial photographs may be vertical, oblique or horizontal.

Afrikaans equivalent: *lugfoto.*

AGI — **see under:** *ASSOCIATION FOR GEOGRAPHIC INFORMATION.*

AIR PHOTO INTERPRETATION — **see under:** *PHOTO INTERPRETATION.*

ALBERS' EQUAL AREA PROJECTION This is the map projection commonly used in South Africa for scales of 1:2 500 000 and smaller. It is a conic projection in which the parallels are unequally spaced arcs of concentric circles, more closely spaced at the North and South edges of the map, and in which the meridians are equally spaced radii of the same circles, cutting the parallels at right angles [Snyder 1984].

Afrikaans equivalent: *Albers se vlaktroue projeksie.*

ALPHABET An alphabet is a finite set of symbols [Backhouse 1979].

Afrikaans equivalent: *alfabet.*

ALTERNATE SPATIAL ATTRIBUTE Alternate spatial attributes are multiple sets of spatial data for the same feature. Each set describes the feature with different amounts of detail. Generally, spatial alternates are scale dependent, but not necessarily so.

Afrikaans equivalent: *alternatiewe ruimtelike attribuut.*

AM/FM — **see under:** *AUTOMATED MAPPING/FACILITIES MANAGEMENT.*

ANAGLYPH An anaglyph is a composite stereoscopic picture printed in superimposed complimentary colours [Oxford 1983]. Typically, the view for one eye is printed in red and the view for the other eye is printed in green or cyan. One then uses a pair of glasses with one red lens and one green or cyan lens to view the anaglyph to obtain the stereo effect.

Afrikaans equivalent: *anaglief.*

ANALYSIS, DATA The methodical investigation of a problem, and the separation of the problem into smaller related units for further detailed study [Longley & Shain 1982]. Ultimately, data analysis is the process of extracting information from data.

Afrikaans equivalent: *data-ontleding.*

ANALYTICAL STEREOPLOTTER — **see under:** *STEREOPLOTTER.*

ARC An arc is any continuous part of the circumference of a circle or an ellipse with a node at each end. The circular arc is defined by giving the start and end nodes of the arc and either the centre of the circle or any other point on the arc. The elliptical arc is defined by giving the start and end nodes of the arc and the coordinates of the focii of the ellipse.

Afrikaans equivalent: *boog.*

AREA FEATURE — **see under:** *FEATURE, AREA.*

AREA OF OVERLAP — **see under:** *OVERLAP, AREA OF.*

AREA OF UNDERLAP — **see under:** *UNDERLAP, AREA OF.*

ASCII American Standard Code for Information Interchange, as defined in ANSI X3.4 published by the American National Standards Institute in 1977 [ANSI 1986]. It is the basis for, but not exactly the same as, ISO 646 [ISO 1983]. ASCII is a standard character set consisting of seven information bits and one parity bit used for exchanging computer data. This is the character set used in this exchange standard. See Section 4.1.2.2 for details.

Afrikaans equivalent: *ASCII.*

ASSOCIATION FOR GEOGRAPHIC INFORMATION The Association for Geographic Information (AGI) is the main umbrella organisation for users of geographical information in the United Kingdom. It was launched in January 1989, and has taken over responsibility for the British exchange standard (the National Transfer Format), amongst its other activities.

ATTRIBUTE A defined characteristic of an entity. In a GIS, attributes can be spatial (dependent on the entity's position in the n-dimensional space) or non-spatial (independent of the entity's position). Non-spatial attributes are also known as the *descriptive* attributes of an entity.

Afrikaans equivalent: *attribuut.*

ATTRIBUTE, ALTERNATE SPATIAL — see under: *ALTERNATE SPATIAL ATTRIBUTE.*

ATTRIBUTE VALUE A specific quality or quantity assigned to an attribute [Moellering 1985].

Afrikaans equivalent: *attribuutwaarde.*

AUTOMATED MAPPING/FACILITIES MANAGEMENT Automated Mapping/Facilities Management, now almost universally known by its acronym AM/FM, refers to using a GIS to manage utility networks, including both bulk supply and reticulation. Examples are electricity, water, sewerage and natural gas. Sometimes, the acronym AM/FM is taken to stand for "Asset Management/Facilities Management". Historically, AM/FM as a discipline was independent of GIS, but now they are acknowledged as being the same. In fact, the motto of AM/FM International is "AM/FM is GIS" [Morrison 1991].

BACKUS-NAUR FORM (BNF) A metalanguage, developed by John Backus and popularised by Peter Naur, used to specify or describe the syntax of a language in which each symbol in the metalanguage represents a set of symbols in the language being described. BNF is similar to the context-free grammars developed by Noam Chomsky to describe natural language. To facilitate its use, extra rules are often added to BNF to form the Extended Backus-Naur Form (EBNF).

Afrikaans equivalent: *Backus-Naur vorm.*

BAND, SPECTRAL — see under: *SPECTRAL BAND.*

BASE DATA Data which would appear on a base map. That is, fundamental or generic information used as a background for specialised data sets or as a base for compiling specialised data sets.

Afrikaans equivalent: *basisdata.*

BASE LINE A surveyed line established with more than usual care, to which surveys are referred for coordination and correlation [ASP 1980].

Afrikaans equivalent: *basislyn.*

BASE MAP A map showing certain fundamental information, used as a base on which additional data of a specialised nature are compiled. Also, a map containing all the information from which maps showing specialised information can be prepared: a source map [ASP 1980].

Afrikaans equivalent: *basiskaart.*

BATCH PROCESSING

1. The processing of data where a number of similar input items are grouped for processing during the same machine run, or
2. the technique of executing a set of computer programs such that each is completed before the next program is started [Longley & Shain 1982].

No interaction with the user takes place during program execution.

Afrikaans equivalent: *bondelverwerking.*

BESSEL 1841 The ellipsoid used as the reference surface in Namibia and in the Walvis Bay enclave. The equatorial radius (a) of the ellipsoid is defined as being 6 377 397.2 metres and the polar radius (b) as 6 356 079.0 metres. The flattening (f) of the ellipsoid is 1/299.15, which is derived from a and b [Snyder 1984].

Afrikaans equivalent: *Bessel 1841.*

BINARY A numbering system in which the digits can have one of only two values (or states or conditions), namely 0 or 1.

Afrikaans equivalent: *binêr.*

BINARY COMPATIBLE Computers are binary compatible when they will all run the same object code without recompiling the code. This is because their central processing units are from the same class of processor, either all manufactured by the same manufacturer or by different manufacturers under licence to the original developers of the class of processors. The most well known group of binary compatible computers are the IBM personal computer (PC) and the so called "PC-compatibles". Computers that are binary compatible with an original design are sometimes known as *clones,* especially if they are very similar to the original (perhaps being cheaper and/or more powerful) and produced to perform similar functions.

Afrikaans equivalent: *binêre bestaanbaar.*

BINARY LARGE/LINEAR OBJECT In relational data bases, *binary large objects* or *binary linear objects* (BLOBs) are often used to store multimedia information. Such BLOBs are binary data streams that can store any large, unstructured data object, such as pictures, sounds or object code programs [Shetler 1990]. BLOBs would be used to store photographs of houses (for an estate agent's data base) or digitised samples of bird calls (for an ornithological atlas), for example.

Afrikaans equivalent: *binêre lineêr objek.*

BINOCULAR VISION Simultaneous vision with both eyes [ASP 1980].

Afrikaans equivalent: *twee-oog-visie.*

BIT An abbreviation for *binary digit.* A bit is the smallest element used in computing, and can have the value of either 0 or 1.

Afrikaans equivalent: *bis.*

BLOB — **see under:** *BINARY LARGE/LINEAR OBJECT.*

BNF — **see under:** *BACKUS-NAUR FORM.*

BOUNDARY The boundary of a region consists of one or more chains and/or arcs that fully enclose the region. It is closed, that is, its initial and terminal nodes coincide.

Afrikaans equivalent: *grens.*

BYTE The smallest addressable unit of storage in a computer. Generally, a byte consists of 8 bits and can hold two hexadecimal digits, that is, a value between 0 and

255 inclusive. Normally, a byte holds one character from a character set, such as ASCII.

Afrikaans equivalent: *greep.*

CACHE In a computer, a buffer memory for storage that is significantly faster than the storage. A cache is used to contain those instructions and data that are accessed frequently, or those instructions and data that are anticipated to be accessed next, to ensure that they are retrieved more quickly. Caches are usually provided for main memory (especially for instructions) and for secondary storage (such as discs). If a cache is poorly designed, it can actually *slow* down the retrieval!

Afrikaans equivalent: *berggeheue.*

CADASTRAL MAP — **see under:** *MAP, CADASTRAL.*

CADASTRAL SURVEY — **see under:** *SURVEY, CADASTRAL.*

CADASTRE A register of the real property of a political subdivision with details of area, ownership and value [ASP 1980]. The public register of the quantity, value and ownership of the land of a country [DOE 1987].

Afrikaans equivalent: *kadaster.*

CALIBRATION The act or process of determining certain specific measurements in a camera or other instrument or device by comparison with a standard, for use for in correcting or compensating for errors for purposes of record [ASP 1980]. For data quality, calibration records are a very important component of the record of the lineage of the data.

Afrikaans equivalent: *kalibrering.*

CAPTURE, DATA The process of recording data in a computer from any selected medium.

Afrikaans equivalent: *datavaslegging.*

CARTOGRAPHIC FEATURE — **see under:** *FEATURE, CARTOGRAPHIC.*

CARTOGRAPHIC GENERALIZATION — **see under:** *GENERALIZATION, CARTOGRAPHIC.*

CARTOGRAPHIC LICENCE The freedom to adjust, add or omit map features within allowable limits to attain the best cartographic expression. Licence must not be construed as permitting the cartographer to deviate from specifications [ASP 1980].

Afrikaans equivalent: *kartografiese vryheid.*

CARTOGRAPHY The art and science of expressing graphically, by maps and charts, the known physical features of the earth, or of another celestial body, often including the work of people and their varied activities [ASP 1980].

Afrikaans equivalent: *kartografie.*

CARTOGRAPHY, COMPUTER-ASSISTED Simply put, the use of computers to produce maps and charts. However, the distinction between computer-assisted cartography (CAC) and GIS is blurred as most GISs incorporate some computer-assisted cartographic functions, and most neophytes see only the maps and charts when first confronted with GIS. CAC systems provide more functions for preparing maps and charts for publishing, and less modelling functions, than GISs do.

Afrikaans equivalent: *rekenaargesteunde kartografie.*

CCNLIS — see under: *COORDINATING COMMITTE FOR THE NATIONAL LAND INFORMATION SYSTEM.*

CENSUS A census is an official numbering of a population, with various statistics [Oxford 1983]. Generally, in a census, every individual household completes a census return on which they answer various questions about themselves, such as the number of inhabitants and their ages. Many countries hold censuses on a regular basis to obtain the basic demographic statistics that are used for a wide range of applications, from urban planning to market research. In South Africa, censuses were held every 10 years up to 1980, and then in 1985 and 1991. In some highly-developed societies, censuses have been stopped as they are perceived as being an invasion of privacy — however, because these societies are highly developed, the required demographic information can be obtained from other sources.

Afrikaans equivalent: *sensus.*

CENSUS DISTRICT — see under: *DISTRICT, CENSUS.*

CENTRAL PROCESSING UNIT In a computer, the unit containing the circuits that control the computer and that perform or execute the instructions of programs. The central processing unit (CPU) generally consists of the control unit, the arithmetic and logical units, and registers, and sometimes high-speed memory (for a cache) and a memory management unit.

Afrikaans equivalent: *sentrale verwerkeendheid.*

CHAIN An ordered undirected sequence of two or more n-tuples of coordinates. The first tuple in the chain and the last tuple in the chain are nodes (they could be the same node, in the case of a chain that forms the boundary of a region, for example). The remaining tuples in the chain are the internal coordinates of the chain. The direction of the chain is defined when the chain is used in a specific feature.

Afrikaans equivalent: *ketting.*

CHART A special purpose map, generally designed for navigation or other particular purposes, in which essential information is combined with various other data critical to the intended use [ASP 1980].

Afrikaans equivalent: *kaart.*

CHOROPLETH MAP — see under: *MAP, CHOROPLETH.*

CLARKE 1880 (MODIFIED) The reference surface used in South Africa (excluding the Walvis Bay enclave) is the Clarke 1880 (modified) ellipsoid, with its origin at Buffelsfontein. The equatorial radius (a) of the ellipsoid is defined as being 6 378 249.1 metres and the polar radius (b) as 6 356 514.9 metres. The flattening (f) of the ellipsoid is 1/293.46, which is derived from a and b [Snyder 1984]. In common with Namibia, the *Bessel 1841* ellipsoid is used for the Walvis Bay enclave.

Afrikaans equivalent: *Clarke 1880 (gewysigde).*

CLASS, FEATURE A specified group of features [Moellering 1985].

Afrikaans equivalent: *verskynselklas.*

CLASSIFICATION The arrangement of features into classes or groups on the basis of the defined characteristics of the features. Classification should be done on the basis of the qualitative characteristics of the features, such as their function, and not on the basis of their quantitative characteristics. Classification is done to speed up the retrieval of data from a data base and to group the data for other purposes, such as symbology.

Afrikaans equivalent: *klassifikasie.*

CLONE A clone is a computer that is binary compatible with an original computer produced by another manufacturer, and indeed, is often a close copy of the original. The most well known examples of clones are those produced in the Far East (especially in Taiwan) of the Apple *//* and the IBM PC. Clones are generally cheaper, and often more powerful, than the original computer.

Afrikaans equivalent: *kloon.*

CLOSE-RANGE PHOTOGRAMMETRY A branch of photogrammetry wherein object-to-camera distances are not more than 300 metres. Close-range photogrammetry encompasses *architectural photogrammetry*, *biostereometrics* and *industrial photogrammetry* [ASP 1980]. Of these, only industrial photogrammetry is likely to be used as a source of digital geo-referenced information, such as when it is used for modelling mine dumps.

Afrikaans equivalent: *kort-afstand fotogrammetrie.*

CODES A set of items, such as abbreviations or numbers, representing the members of another set [Moellering 1985].

Afrikaans equivalent: *kodes.*

COINCIDENCE If more than one feature shares the same spatial attributes then they are coincident with each other. Intersection is a special form of coincidence.

Afrikaans equivalent: *samevalling.*

COMPILATION The production of a new or revised map or chart, or portion thereof, from existing maps, aerial photographs, geodetic control data, surveys, new data, and other sources.

Afrikaans equivalent: *kompilasie.*

COMPILER A program designed to translate a high-level language source program into a corresponding machine-code program. The compiler checks for, and reports, any syntax errors in the source program. If the source program is free of syntax errors then a compiled object-code program is produced [Longley & Shain 1982].

Afrikaans equivalent: *kompileerder.*

COMPLETENESS An aspect of data quality, indicating whether the set of georeferenced information has all its necessary parts.

Afrikaans equivalent: *volledigheid.*

COMPUTER A device capable of accepting information, applying prescribed processes to the information, and supplying the results of these processes. It usually consists of input and output devices, storage, arithmetic and logical units, and a control unit [Sippl & Sippl 1974]. Different terms are used to describe the different types and sizes of computers, though the distinctions between them are blurring:

1. **supercomputer:** a very fast computer. As the power of computers is continually improving rapidly, a supercomputer is generally considered to be one that is faster than almost all other computers commercially available at the same time, rather than there being an absolute measure of a supercomputer. Supercomputers are generally mainframes.
2. **mainframe:** a large computer, generally for running many simultaneous interactive sessions and for batch processing. Mainframes tend to have many peripherals and front-end processors for dealing with the interactive sessions.
3. **minicomputer:** a computer similar to a mainframe but for a smaller group of users. Generally, minicomputers do not have front-end processors.
4. **superminicomputer:** a very fast minicomputer.
5. **workstation:** a computer for a single user. Generally, a workstation has a high-quality graphics display and is connected to a network [**See also:** *GRAPHICS WORKSTATION.*] .
6. **microcomputer:** the smallest type of computer, generally for a single user. Some microcomputers are very small, and can be operated in the palm of a hand (they are known as *palmtops*), while others approach the power of minicomputers.
7. **personal computer (PC):** IBM called their first range of microcomputers *personal computers*, and the abbreviation, *PC*, is now generically applied to microcomputers, as well as specifically to the IBM PC range and their compatibles.
8. **PC-compatible:** the term generally used for clones of the IBM PC range of microcomputers.

Although there are analogue computers, the term computer is generally used to refer to digital computers.

Afrikaans equivalent: *rekenaar.*

COMPUTER LANGUAGE — **see under:** *LANGUAGE.*

COMPUTER-ASSISTED CARTOGRAPHY — **see under:** *CARTOGRAPHY, COMPUTER-ASSISTED.*

COMPOUND FEATURE — **see under:** *FEATURE, COMPOUND.*

CONFORMAL PROJECTION In a conformal projection, at each point on a map, the scale of distance is kept the same in all directions. A very small figure on the ellipsoid is transformed into a figure of the same shape on the map [ASP 1980].

Afrikaans equivalent: *konforme projeksie.*

CONSISTENCY, LOGICAL — **see under:** *LOGICAL CONSISTENCY.*

CONSTITUENT FEATURE — **see under:** *FEATURE, CONSTITUENT.*

CONTAINMENT Any spatial attribute that lies within another spatial attribute is contained by that spatial attribute. The two forms of containment are exclusion and inclusion.

Afrikaans equivalent: *bevatting.*

CONTEXT-FREE GRAMMAR [**See also:** *GRAMMAR.*] In a context-free grammar, the translation of symbols is not dependent on their context, that is, the translation is not dependent on the symbols in the string that preceed and follow the symbol(s) being translated. To state it formally, a context-free grammar is one where all productions have the form $A \rightarrow v$ where A is a non-terminal symbol and $v \in (N \cup T)^*$ [Backhouse 1979]. That is, the non-terminal sysmbol on the left hand side is translated, without any reference to the symbols that preceed or follow it. An example of a context-free grammar is the Backus- Naur Form.

Afrikaans equivalent: *konteksvrye grammatika.*

CONTEXT-SENSITIVE GRAMMAR [**See also:** *GRAMMAR.*] In a context-sensitive grammar, the translation of symbols is dependent on their context, that is, the translation is dependent on the symbols in the string that preceed and follow the symbol(s) being translated. To state it formally, a context-sensitive grammar is one where all productions have the form $u \rightarrow v$ where $length(u) \leq length(v)$ and $u, v \in (N \cup T)^+$ [Backhouse 1979]. That is, a string of terminal and non-terminal symbols on the left hand side is translated into a string of symbols that are at least as long. The presence of terminals on the left hand side means that the translation of a symbol is dependent on the symbols that preceed and follow that symbol.

Afrikaans equivalent: *kontekssensitiewe grammatika.*

CONTOUR A contour is an isometric line (that is, a line of equal measures) of elevations above, or depths below, some geoid, such as Mean Sea Level.

Afrikaans equivalent: *kontoer.*

CONTROL POINT — **see under:** *POINT, CONTROL.*

CONTROL SURVEY — **see under:** *SURVEY, CONTROL.*

COORDINATE A coordinate is a value measured along one axis of a coordinate system [ICA 1980]. A coordinate is a linear or angular quantity which designates the position that a point occupies in a given reference frame or system [ASP 1980]. Coordinates are often grouped into tuples. A coordinate tuple is an ordered set of n coordinates specifying a location in n space. Typically, a coordinate tuple has two or three dimensions.

Afrikaans equivalent: *koöordinaat.*

COORDINATE SYSTEM A coordinate system is a well-defined reference frame for coordinates. The coordinate system determines the nature and meaning of the coordinates. Examples of coordinate systems are Cartesian, polar and spherical. In the context of digital geo-referenced information, most map projections are rendered as Cartesian coordinate systems, while geographical coordinates (degrees of latitude and longitude) are rendered as spherical coordinate systems.

Afrikaans equivalent: *koöordinaatstelsel.*

COORDINATE TUPLE — **see under:** *COORDINATE* & *TUPLE.*

COORDINATES, GEO-REFERENCED The coordinates of a position given in degrees of latitude and longitude. There is a one-to-one relationship between the geo-referenced coordinates and the projection coordinates.

Afrikaans equivalent: *geoverwysde koördinate.*

COORDINATES, PROJECTION The coordinates of a position given in the projection system.

Afrikaans equivalent: *projeksiekoördinate.*

COORDINATING COMMITTEE FOR THE NATIONAL LAND INFORMATION SYSTEM The State Inter-departmental Coordinating Committee for the National Land Information System (CCNLIS) is responsible for the National Land Information System (NLIS), which effectively means that it is responsible for coordinating GIS and related activities in government departments. The CCNLIS is chaired by the Chief Surveyor General, whose Directorate provides the secretarial functions for the CCNLIS.

Afrikaans equivalent: *Koördinerende Komitee van die Nasionale Grondinligtingstelsel.*

CPU — **see under:** *CENTRAL PROCESSING UNIT.*

CULTURE Culture is the collective term for man-made features on, above or below the earth's surface, such as buildings, roads, power lines, bridges, canals and tunnels. [**See also:** *TOPOGRAPHY.*]

Afrikaans equivalent: *kultuur.*

CURRENCY Part of data quality, the currency information indicate the age of the data, so that the user may determine how reliable the data are.

Afrikaans equivalent: *huidigheid.*

DATA A representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means [ICA 1980].

Afrikaans equivalent: *data.*

DATA ACQUISITION — see under: *ACQUISITION, DATA.*

DATA ANALYSIS — see under: *ANALYSIS, DATA.*

DATA BASE A collection of interrelated data stored so that they may be accessed by authorized users with simple user friendly dialogues. The data base structure is independent of the programs using the data and a common controlled approach is employed in adding, deleting or modifying the data contained therein [Longley & Shain 1982]. Commercial data bases are designed to handle precise, non-spatial alphanumeric data. Data bases are based on the hierarchical, network, relational, or object oriented data models.

Afrikaans equivalent: *databasis.*

DATA, BASE — see under: *BASE DATA.*

DATA BASE MANAGEMENT SYSTEM (DBMS) A special data processing system, or part of a data processing system, which aids in the storage, manipulation, reporting, management and control of data [Moellering 1985].

Afrikaans equivalent: *databasisbestuurstelsel.*

DATA CAPTURE — see under: *CAPTURE, DATA.*

DATA DICTIONARY In data bases, a catalogue giving details of the names and structures of data types [Longley & Shain 1982]. In an exchange standard, a data dictionary could be used to define the structure of part or all of the data set being exchanged, or more commonly, a classification scheme, a non-spatial attribute scheme, or how information on the quality of the data is provided.

Afrikaans equivalent: *data woordeboek.*

DATA DISPLAY Visual representation of data on a screen as a report, graph or drawing.

Afrikaans equivalent: *datavertoon.*

DATA INPUT — see under: *INPUT, DATA.*

DATA, GEO-REFERENCED Data that refer to the human-environment system and that can be localized in space and time. Their three dimensions in space are the two planimetric dimensions (typically latitude and longitude) and the vertical distance from some reference surface.

Afrikaans equivalent: *geoverwysde data.*

DATA, INTERVAL The interval level of measurement assigns an exact numerical value so that the difference between any two items on the scale is known precisely. Interval scales lack true zero points and can therefore be used only to measure differences and not absolute magnitudes. Scaling methods for measuring attitudes and preferences are usually given measurements at this level.

Afrikaans equivalent: *intervaldata.*

DATA, NOMINAL The nominal measuring level is employed when distinguishing among a set of features only on the basis of their intrinsic character, that is, the distinctions are based only on qualitative considerations without any implication of a quantitative relationship.

Afrikaans equivalent: *nominale data.*

DATA, ORDINAL Ordinal scales involve nominal classification, and also differentiate within a class of data on the basis of rank according to some quantitative measure. Rank only is involved, that is, the order of the variables from lowest to highest is given, but no definition of the numerical values.

Afrikaans equivalent: *ordinale data.*

DATA QUALITY Indications of the degree of excellence of the data. This includes information about the lineage, completeness, currency, logical consistency and accuracy of the data.

Afrikaans equivalent: *datakwaliteit.*

DATA, RASTER Data stored as a three-dimensional rectangular tessellation, with a two-dimensional matrix of elements as a base and one or more values associated with each element (cell).

Afrikaans equivalent: *roosterdata.*

DATA, RATIO This scale provides the maximum amount of information. All ratio scales possess a true zero point, as well as permitting precise differences to be calculated, so that measurements retain the same ratio to one another, no matter what units are employed.

Afrikaans equivalent: *verhoudingdata.*

DATA SIMPLIFICATION — **see under:** *SIMPLIFICATION, DATA.*

DATA, SPATIAL Data that have a position in an n-dimensional space. The basic entities in two-dimensional spatial data are nodes, chains, arcs, regions and matrices. These entities are also known as the spatial attributes of features. Three-dimensional space is not yet widely used in geo-referenced information.

Afrikaans equivalent: *ruimtelike data.*

DATA, TOPOLOGICAL — **see under:** *TOPOLOGICAL DATA.*

DATA, TOPOLOGICALLY STRUCTURED — **see under:** *TOPOLOGICALLY STRUCTURED DATA.*

DATA, VECTOR Data stored as a set of nodes, chains, arcs and regions having position. Additionally, the chains and arcs have magnitude and direction and the regions have magnitude.

Afrikaans equivalent: *vektordata.*

DATUM Any numerical or geometrical quantity or set of such quantities that may serve as a reference or base for other quantities [Moellering 1985]. The curved surface of an ellipsoid is often referred to as the *horizontal datum*, being the reference surface which is approximately perpendicular to the plumbline at all points. It is the surface to which measured angles and distances are referred or reduced. The *vertical* or *height datum* is the surface to which vertical distances are measured or reduced. This is normally either the geoid (or mean sea-level) surface of the ellipsoid surface [Methley 1986].

Afrikaans equivalent: *verwysingspunt/vlak.*

DBMS — **see under:** *DATA BASE MANAGEMENT SYSTEM.*

DECISION SUPPORT SYSTEM Decision support systems (DSS) have one primary purpose: to provide the manager with the necessary information for making intelligent decisions. A DSS is a specialized MIS designed to support a manager's skills at all stages of decision making [Ivancevich *et al* 1989].

Afrikaans equivalent: *beslissingsteunstelsel.*

DELAUNAY TRIANGLE Delaunay triangles are formed by the lines that are perpendicularly bisected by the sides of *Thiessen polygons* [Dale & McLaughlin 1988].

Afrikaans equivalent: *Delaunay driehoek.*

DELIMITER A specified character used to denote the end of a field [Longley & Shain 1982]. In the exchange standard, the delimiters used are the standard ASCII delimiters, namely (in ascending order):

- the Information Unit Separator (US), 31 (1F in hexadecimal);
- the Information Record Separator (RS), 30 (1E in hexadecimal);
- the Information Group Separator (GS), 29 (1D in hexadecimal);
- the Information File Separator (FS), 28 (1C in hexadecimal).

Afrikaans equivalent: *skeisimbool.*

DEM — **see under:** *DIGITAL ELEVATION MODEL.*

DEMOGRAPHIC ENUMERATOR AREA — **see under:** *ENUMERATOR AREA.*

DEMOGRAPHIC STATISTICS Statistics about people, such as the occurrences of births, deaths, diseases, marriages and divorces; and about incomes, occupations, dwellings, religious beliefs and political preferences. Demographic statistics are usually recorded through a census, by sampling, or by deduction from other evidence.

Afrikaans equivalent: *demografiese statistieke.*

DEMOGRAPHY The study of demographic statistics about people, as they illustrate the conditions of life in various communities.

Afrikaans equivalent: *demografie.*

DEPENDENCE, SCALE — **see under:** *SCALE INDEPENDENCE & DEPENDENCE.*

DESCRIPTIVE ATTRIBUTE — **see under:** *ATTRIBUTE.*

DEVELOPMENT REGION South Africa is divided into nine development regions with due regard to economic, political, social and security aspects in order to contribute to the utilization of the country's natural and human resources. These development regions in turn consist of smaller statistical and planning regions [CSS 1991].

Afrikaans equivalent: *ontwikkelingstreke.*

DIFFERENTIAL GPS — **see under:** *GLOBAL POSITIONING SYSTEM.*

DIGITAL ELEVATION MODEL A digital elevation model (DEM) is a tessellation of elevations of the earth's surface above a geoid. Each cell's value represents the elevation above or below the earth's surface at a single point, typically at the centre of the cell or at the bottom left-hand corner of the cell. The elevations recorded in each cell do not constitute a third dimension — they are attributes of the cells rather than part of the locational information of the cells. A DEM is a special form of a *digital terrain model* (DTM).

Afrikaans equivalent: *syferhoogte model.*

DIGITAL TERRAIN MODEL A digital terrain model (DTM) is a digital model of any single-valued surface covering a portion of the earth's surface. The most common DTM is the *digital elevation model (DEM)*, and the term DTM is often used in the place of DEM. DTMs can also model phenomena such as temperature, rainfall, population density and surface roughness.

Afrikaans equivalent: *syferterrein model.*

DIGITISE To convert an analogue measurement of a physical variable into a discrete numerical value, thereby expressing the quantity in digital form [Sippl & Sippl 1974].

Afrikaans equivalent: *versyfer.*

DIGITISING TABLE — **see under:** *TABLE, DIGITISING.*

DIMENSION, PLANIMETRIC — **see under:** *PLANIMETRIC DIMENSIONS.*

DIMENSION, VERTICAL — **see under:** *VERTICAL DIMENSIONS.*

DIMENSION, ZERO — **see under:** *ZERO DIMENSION.*

DIRICHLET CELL — **see under:** *THIESSEN POLYGON.*

DISC A flat disc with a magnetizable surface layer on which data can be stored by magnetic recording [Longley & Shain 1982]. Discs are the most common form of secondary storage in a computer. Also spelt *disk*.

Afrikaans equivalent: *skyf.*

DISPLACEMENT, CARTOGRAPHIC — **see under:** *CARTOGRAPHIC DISPLACEMENT.*

DISPLAY — **see under:** *DATA DISPLAY.*

DISTRICT, CENSUS The boundaries of a census district normally coincide with those of a magisterial district. Where differences between census districts and magisterial districts occur, it results from adjustments of magisterial district boundaries as determined by the former Department of Cooperation and Development [CSS 1991]. The census district is the basis for much reporting on national statistics by South Africa's Central Statistical Service. Each census district is subdivided into cities, towns, other areas with some form of local government, and the remaining non-urban area. These subdivisions in turn comprise of one or more enumerator areas.

Afrikaans equivalent: *sensusdistrik.*

DISTRICT, MAGISTERIAL Magisterial districts define the jurisdictions of magistrate courts in South Africa. Due to their size, they are convenient for other purposes as well, such as the reporting of agricultural and economic statistics.

Afrikaans equivalent: *landdrosdistrik.*

DOCUMENT — **see under:** *SOURCE DOCUMENT.*

DOMAIN, SPATIAL — **see under:** *SPATIAL DOMAIN.*

DOMESDAY PROJECT A project initiated by the BBC to mark the 900th anniversary of the Domesday Book (prepared in 1086), which aimed at presenting a contemporary snapshot of the United Kingdom in the 1980s. The project is significant for pioneering the inclusion of pictures in a GIS, and for being the first to promote GIS to school children and the man-in-the-street.

Afrikaans equivalent: *Domesday-projek.*

DOT-MATRIX PRINTER — **see under:** *PLOTTER.*

DSS — **see under:** *DECISION SUPPORT SYSTEM.*

DTM — **see under:** *DIGITAL TERRAIN MODEL.*

EBNF — **see under:** *BACKUS-NAUR FORM.*

EDGE DETECTION The process of enhancing the edges of area features in a raster image by passing digital filters over the image, and then using threshholds to select those pixels that constitute the edges. Because of noise in the data, it is often necessary to perform line following to cross gaps in the edges and thinning to make the edges narrower.

Afrikaans equivalent: *kant vasstelling.*

EDGE MATCHING Edge matching takes place in a GIS when two adjacent map sheets have been digitised and they are combined to form one, continuous map.

Typical edge matching problems are recreating a polygon that lies across the edge between the two maps, reconciling lines from the two maps that don't meet properly at the edge, and dealing with maps of different ages (for example, where the newer map shows features that do not continue onto the older map, or where different units were used for the contours, which then do not match up across the edge).

Afrikaans equivalent: *kantbypassend.* **[See also:** *INTEGRATION.*]

EDIS EDIS (an acronym for Earth Data Information Systems) is the title of a successful series of quadrennial conferences held in South Africa since 1983. The emphasis of the conferences has been remote sensing and GIS.

Afrikaans equivalent: *EDIS.*

EDITING The process of modifying data input to the system. This may involve verifying the validity of input and adding or deleting information in the data base. Editing can be fully automatic or it can be performed with varying degrees of operator intervention.

Afrikaans equivalent: *redigering.*

ELECTROMAGNETIC RADIATION (EMR) Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields [ASRS 1983].

Afrikaans equivalent: *elektromagnetiese uitstraling.*

ELECTROMAGNETIC SPECTRUM The ordered array of known electromagnetic radiations extending from the shortest cosmic rays, through gamma rays, X-rays, ultra-violet radiation, visible radiation, infrared radiation, and including microwave and all other wavelengths of radio energy [ASRS 1983].

Afrikaans equivalent: *elektromagnetiese spektrum.*

ELECTROSTATIC PLOTTER — see under: *PLOTTER.*

ELLIPSOID — see under: *SPHERE, SPHEROID & ELLIPSOID.*

EMR — see under: *ELECTROMAGNETIC RADIATION.*

ENTITY An object or event about which information is stored in a data base [Longley & Shain 1982].

Afrikaans equivalent: *entiteit.*

ENUMERATOR AREA The smallest area for which demographic statistics from a census are available. They generally contain around 200 households, and hence vary greatly in their physical size.

Afrikaans equivalent: *opnoemingsgebied.*

EQUAL AREA PROJECTION A type of map projection in which the area bounded by any two adjoining parallels and two adjoining meridians is equal to any other area similarly enclosed; in other words, the ratio between any area on the map and the corresponding area on the globe is constant [Moore 1968].

Afrikaans equivalent: *oppervlaktetroue projeksie.*

EQUI-DISTANT PROJECTION No map projection shows scale correctly throughout the map, but an equi-distant projection is in which the true scale is shown between one or two points and every other point on the map, or along every meridian [Snyder 1984].

Afrikaans equivalent: *afstandetroue projeksie.*

EXCHANGE FORMAT The procedures and/or rules used in the exchange of data between computer systems having different data bases and/or software and/or hardware.

Afrikaans equivalent: *uitruilformaat.* [**See also:** *TRANSFER FORMAT.*]

EXCLUSION Any spatial attribute that is contained by another spatial attribute but does not form a part of that spatial attribute is excluded by that spatial attribute.

Afrikaans equivalent: *uitsluiting.*

EXTENDED BACKUS-NAUR FORM — **see under:** *BACKUS-NAUR FORM.*

FEATURE A uniquely identifiable set of one or more objects in the real and/or potential world, where the defined characteristics of the objects are consistent throughout all the objects. These defined characteristics are the attributes of the feature, be they spatial or non-spatial. In a data base, a feature can be represented by one or more entities. At different degrees of generalization, a feature could be represented by different types of entity, be they point, line, area, grid or compound features. Features can be man-made or natural, real or abstract.

Afrikaans equivalent: *verskynsel.*

FEATURE, AREA The representation in a data base of a feature whose position is described by one or more regions that do not necessarily form a continuous object.

Afrikaans equivalent: *areaverskynsel.*

FEATURE, CARTOGRAPHIC A term applied to the natural or cultural items shown on a map or chart. The three main categories are: "point feature", "line feature" and "area feature" [ICA 1980].

Afrikaans equivalent: *kartografiese verskynsel.*

FEATURE CLASS — **see under:** *CLASS, FEATURE.*

FEATURE, COMPOUND The representation in a data base of a feature whose position is described by one or more other features that do not necessarily form a continuous object.

Afrikaans equivalent: *saamgestelde verskynsel.*

FEATURE, CONSTITUENT A constituent feature is one that forms a part of a compound feature.

Afrikaans equivalent: *samestellend verskynsel.*

FEATURE, GRID The representation in a data base of a feature whose position is described by one or more matrices that do not necessarily form a continuous object.

Afrikaans equivalent: *roosterverskynsel.*

FEATURE, LINE The representation in a data base of a feature whose position is described by one or more chains and/or arcs that do not necessarily form a continuous object.

Afrikaans equivalent: *lynverskynsel.*

FEATURE, POINT The representation in a data base of a feature whose position is described by a node.

Afrikaans equivalent: *puntverskynsel.*

FIDUCIAL MARKS Index marks, usually four, which are rigidly connected with the camera lens through the camera body and which form images on the negative and usually define the principle point (the centre) of the photograph [ASP 1980]. They are used in photogrammetry.

Afrikaans equivalent: *ykmerke.*

FIELD A specified area in a record in a data base reserved for a particular category of data.

Afrikaans equivalent: *veld.*

FLIGHT LINE A line drawn on a map or chart to represent the track of an aircraft [ASP 1980].

Afrikaans equivalent: *vluglyn.*

FLIGHT STRIP A succession of overlapping aerial photographs taken along a single course [ASP 1980]. The overlap in the photographs provides a stereo image of the earth.

Afrikaans equivalent: *vliegstrook.*

FOLLOWING, LINE — **see under:** *LINE FOLLOWING.*

FORMAT A pre-determined arrangement of data.

Afrikaans equivalent: *formaat.* [**See also:** *DATA EXCHANGE FORMAT.*]

FRONT-END PROCESSOR A small computer which interfaces a larger computer to a network. It handles the communications workload, thereby freeing the larger computer to handle other processing [Longley & Shain 1982].

Afrikaans equivalent: *voorverwerker.*

GAUSS CONFORMAL PROJECTION This is the map projection commonly used in South Africa for scales of 1:250 000 and larger. It is a cylindrical projection in which the central meridian, each meridian 90° from the central meridian and the Equator are straight lines and all other meridians and parallels are complex curves. It is effectively the same as the Transverse Mercator projection, though it is used in 2°-wide bands, as opposed to the more usual 4°-wide bands of the Transverse Mercator [Snyder 1984]. The narrower bands provide greater accuracy.

Afrikaans equivalent: *Gauss se konforme projeksie.*

GENERALIZATION, CARTOGRAPHIC Cartographic generalization is the process by which the amount of information shown on the map is reduced when the scale of the map is reduced. It is usually defined in terms of three interrelated sets of processes, namely simplification, classification and symbolisation.

Afrikaans equivalent: *kartografiese veralgemening.*

GEO-CODING
1. The use of geographical coordinates (longitude and latitude) as key information of data items [ICA 1980].
2. When applied to remotely sensed images, geo-coding means that ground control points have been established on the image and it has been transformed to a map projection.

Afrikaans equivalent: *geokodering.*

GEODETIC LEVELLING — see under: *LEVELLING.*

Afrikaans equivalent: *geodetiese nivellering.*

GEODETIC SURVEY — see under: *SURVEY, GEODETIC.*

GEOGRAPHICAL INFORMATION SYSTEM (GIS) A computer-based system that efficiently captures, stores, retrieves, maintains, validates, integrates, manages, manipulates, analyses and displays digital geographically referenced information.

Geographical information systems (GIS), *land information systems (LIS)* and *Automated Mapping/Facilities Management systems (AM/FM)* are different terms used to describe the same types of computer-based information systems, thought the terms are sometimes used to differentiate between various applications in which the systems are used. However, there are no differences between them, particularly as much information is now derived from non-map sources (and hence is scale independent) and some users perform analysis on physical and abstract phenomena together.

A GIS or an LIS or an AM/FM is a computer-based information system using digital geographically referenced information for a specific application, whether the application be broad or narrow, at a small or large scale (or both) or deals with physical or abstract phenomena, or both. These systems are applied to many different fields (or combinations thereof) and to varying degrees of sophistication (from using the system as a more cost-effective way to update maps, to using the system for complicated modelling). The author prefers the use of the term GIS, as it is more widely used and has a more generic ring.

Problems peculiar to GISs are:

- Enormous volumes of data.
- Availability of base data.

- Data captured at different scales.
- Varying quality of data captured, both in the source and the capture method.
- Generalization of the data.
- Different types of data (vector, raster and alphanumeric).
- Descriptive information attached to coordinates.
- The need to have the data accurately fixed to a well-defined model of the earth.
- Attributes varying from feature class to feature class with location being the only attribute common to all classes.
- Geometric and topological integration.

Because of their nature and the volumes involved, geographical data need the special handling that is not efficiently provided by conventional data base management systems. A true GIS is a system that is orientated to the analysis of geo-referenced data to produce useful information.

Afrikaans equivalent: *geografiese inligtingstelsel.*

GEOID The universally accepted best approximation of the shape of the earth is the equipotential surface at mean sea level, called the geoid. It is undulatory, smooth and continuous, fictitiously extending under the continents at the same level, and by definition, perpendicular at any point to the direction of gravity. The surface is not symmetrical about the axis of rotation, the distribution of the density within the earth's body being irregular [Richardus & Adler 1972]. The height, or vertical, datum is usually the "smooth mathematical surface that closely fits the mean sea-level surface throughout the area of interest" [Snyder 1987].

Afrikaans equivalent: *geoïed.*

GEOLOGY Geology is the science of the earth's crust, its strata, and their relations and changes [Oxford 1983].

Afrikaans equivalent: *geologie.*

GEOMETRIC INTEGRATION — **see under:** *INTEGRATION, GEOMETRIC.*

GEO-REFERENCED COORDINATES — **see under:** *COORDINATES, GEO-REFERENCED.*

GEO-REFERENCED DATA — **see under:** *DATA, GEO-REFERENCED.*

GIS — **see under:** *GEOGRAPHICAL INFORMATION SYSTEM.*

GLOBAL POSITIONING SYSTEM (GPS) The Global Positioning System (GPS) is a satellite-based radio location system. A constellation of GPS satellites has been placed in orbit around the world (the intention is that there will ultimately be 24 satellites, including three spares). Each satellite contains an atomic clock, and each satellite broadcasts highly accurate time information. On the ground, GPS receivers are used to detect these broadcast signals, either for the timing information itself, or to use that information for a locational fix, that is, to determine the position of the GPS receiver in three-dimensional space on or above the ground. The GPS receiver needs to have line-of-sight contact with at least three satellites simultaneously to be able to make a locational fix. The more satellites that are available, the better and quicker the fix. GPS receivers can also be used to determine one's bearing and speed. For accurately determining a locational fix, *differential GPS* would be used, where one uses two GPS receivers, one at a point of known position and the other at the point whose position needs to be determined, and one works out the position of the unknown point relative to the known point. However, for differential GPS to work, both GPS receivers must have line-of-sight contact with exactly the same set of satellites. Under ideal conditions, using differential GPS, one can determine a locational fix with an accuracy of 1cm with less than 10 minutes of observation time (the time that the two GPS receivers are simultaneously receiving information from the GPS satellites). Because of the need for line-of-sight contact with several satellites, GPS does not work well in highly urbanized areas, in valleys, or in forests.

Afrikaans equivalent: *Globale Plasing Stelsel.*

GPS — **see under:** *GLOBAL POSITIONING SYSTEM.*

GRAMMAR A grammar defines how symbols may be combined to form strings, and how the strings may be combined to form valid sentences in a language. Formally, a grammar consists of four items:

1. A finite set N of *non-terminal symbols*.
2. A finite set T of *terminal symbols*, where $N \cap T = \emptyset$.
3. A distinguished symbol $S \in N$ called the *start* or *sentence* symbol.
4. A set P of *productions* each of which has the form $u \rightarrow v$ where $u \in (N \cup T)^+$ and $v \in (N \cup T)^*$. We call u the *left-hand side* (LHS) and v the *right-hand side* (RHS) of the production.

[Backhouse 1979]. Types of grammars are, in order going from the fewest to the most restrictions placed on the grammars, *context-sensitive grammars*, *context-free grammars* and *regular grammars*.

Afrikaans equivalent: *grammatika.*

GRANULARITY The granularity of information on data quality is an indication of the level of the information in the structure of a GIS. Thus, information with a fine granularity would be attached to individual coordinates, while information with a coarse granularity would be attached to the data base as a whole.

Afrikaans equivalent: *korrelrigheid.*

GRAPHICS WORKSTATION A stand-alone collection of peripherals including one or more of the following: display screens, keyboards, digitizing tables or tablets, local memory, local discs and local processors, which usually have special graphics handling capabilities. A graphics workstation may be connected by means of data communications to a host computer or to a network.

Afrikaans equivalent: *grafiese werkstasie.* [**See also:** *COMPUTER.*]

GREAT CIRCLE A circle on the surface of a sphere (or the earth) whose plane passes through the centre of the sphere (or the earth) [Oxford 1983]. A great circle path is the shortest route between two points on the surface of a sphere. The great circle path is usually shorter than the *rhumb line* path between two points. It is the same length as a rhumb line only if the two points are both on the Equator or on the same meridian.

Afrikaans equivalent: *grootsirkel.*

GRID FEATURE — **see under:** *FEATURE, GRID.*

HARD COPY Output in a permanent form, usually by printing on paper, but can include computer output microfilm (COM) [Longley & Shain 1982]. [**See also:** *PLOTTER.*]

Afrikaans equivalent: *sigkopie.*

HARDWARE In computing, a term used to describe physical equipment such as computers, disc drives and printers, as opposed to programs, procedures, rules and associated documentation [Longley & Shain 1982].

Afrikaans equivalent: *apparatuur.*

HEXADECIMAL A numbering system in which the digits can have one of sixteen values (or states or conditions). These are typically written as: $0, 1, 2, 3,\ 4, 5, 6, 7,\ 8, 9, A, B,\ C, D, E, F$.

Afrikaans equivalent: *heksadesimaal.*

HIERACHICAL DATA BASE — **see under:** *DATA BASE.*

HIERARCHY An organization with grades or classes ranked one above another [Oxford 1983]. A hierarchy is one of the three standard data base models. In the exchange standard, the classification is implemented as a variable-level hierarchy.

Afrikaans equivalent: *hiërargie.*

HORIZONTAL Parallel to the plane of the horizon, at right angles to the vertical [Oxford 1983]. The term *horizontal coordinates* is sometimes used instead of *planimetric coordinates*.

Afrikaans equivalent: *horisontaal.*

HORIZONTAL INTEGRATION — **see under:** *INTEGRATION, HORIZONTAL.*

HORIZONTAL PHOTOGRAPH A photograph taken with the axis of the camera horizontal [ASP 1980].

Afrikaans equivalent: *horisontale foto.*

HUMAN-ENVIRONMENT SYSTEM People, the environment around them, and the interaction between people and their environment.

Afrikaans equivalent: *mens-omgewingstelsel.*

HYDROGRAPHIC SURVEY — **see under:** *SURVEY, HYDROGRAPHIC.*

HYDROGRAPHY Hydrography is the collective term for water and drainage features, such as rivers, lakes and seas. [**See also:** *TOPOGRAPHY.*]

Afrikaans equivalent: *hidrografie.*

HYPSOGRAPHY Hypsography is the collective term for relief features, such as elevation and bathymetric contours, mountains, valleys and plains. [**See also:** *TOPOGRAPHY.*]

Afrikaans equivalent: *hoogtebeskrywing.*

IDENTIFICATION TAG A string of characters that uniquely identifies a group of data. In the National Exchange Standard (NES), identification tags are used to identify relations and entries.

Afrikaans equivalent: *identifikasie-etiket.*

IMAGE A spatial representation of an object or scene. Mathematically, an image may be thought of as a continuous function of two variables defined on some bounded region of a plane [ICA 1980].

Afrikaans equivalent: *beeld.*

IMAGE PROCESSING Image processing encompasses all the various operations that can be applied to photographic or image data. These include, but are not limited to, image compression, image restoration, image enhancement, pre-processing, quantization, spatial filtering and other image pattern recognition techniques [ASRS 1983].

Afrikaans equivalent: *beeldverwerking.*

IMPACT PRINTER — **see under:** *PLOTTER.*

INCLUSION Any spatial attribute that is contained by another spatial attribute and that forms a part of that larger spatial attribute is included by that larger spatial attribute.

Afrikaans equivalent: *insluiting.*

INDEPENDENCE, SCALE — **see under:** *SCALE INDEPENDENCE & DEPENDENCE.*

INFORMATION Knowledge that was not previously known to its receiver. Information can be derived from data only to the extent that the data are accurate, timely, unexpected and relevant to the subject under consideration [Sippl & Sippl 1974]. The information $I(x)$ for event x of probability $p(x)$ is given by $I(x) = -\log p(x)$, that is, the information is highest for the least probable event [Longley & Shain 1982].

Afrikaans equivalent: *inligting.*

INFORMATION SYSTEM, GEOGRAPHICAL — see under: *GEOGRAPHICAL INFORMATION SYSTEM.*

INFORMATION TECHNOLOGY The acquisition, processing, storage and dissemination of vocal, pictorial, textual and numerical information by a microelectronics-based combination of computing and telecommunications [Longley & Shain 1982]. The abbreviation *IT* is often used.

Afrikaans equivalent: *inligtings tegnologie.*

INPUT, DATA The process of entering data into a computer system by means of peripheral devices. Spatial data are most often captured by digitizing source documents.

Afrikaans equivalent: *data-invoer.*

INTEGRATION Integration is the process of combining several data sets together, be they coincident (describing the same area on the earth's surface), or adjacent (describing adjacent areas on the earth's surface). Typical integration problems are those of edge matching (*horizontal integration*), and those of reconciling the different digital versions from each data set for the same feature (*vertical integration*). Integration problems are a symptom of the varying quality of the data sets being combined and a lack of awareness about quality issues. When integrating, one has to match up both the *topology* and the *spatial* data.

Afrikaans equivalent: *integrasie.* [**See also:** *INTEGRATION, HORIZONTAL; INTEGRATION, SPATIAL; INTEGRATION, TOPOLOGICAL; INTEGRATION, VERTICAL; EDGE MATCHING.*]

INTEGRATION, HORIZONTAL Horizontal integration is the process whereby data sets representing adjacent areas on the earth's surface are combined together to form a new, continuous data set.

Afrikaans equivalent: *horisontale integrasie.* [**See also:** *EDGE MATCHING.*]

INTEGRATION, SPATIAL Spatial integration is the process of combining data from adjacent or coincident source documents, and rectifying the coordinates in the data sets so that the resulting image looks correct. That is, so that each point, line or area has only one representation, straight lines run straight across the boundaries of the data sets, lines don't just end at the boundaries of data sets, and the boundary lines of the data sets are removed. Spatial integration has to be combined with *topological integration*, because while the corrected data set might look correct, it might not be logically correct.

Afrikaans equivalent: *ruimte integrasie.*

INTEGRATION, TOPOLOGICAL Topological integration is the process of combining features from adjacent or coincident source documents so that the topology of the data is maintained. Typical topological integration problems are that features might not be consistent across data set boundaries (eg: a tar road becomes a dirt track when it crosses a boundary), and that features might not be consistent with their surrounding features (eg: a river crossing the same contour line several times). Topological integration has to be combined with *spatial integration*, because while the corrected data set might be topologically correct, it might not look correct.

Afrikaans equivalent: *topologiese integrasie.*

INTEGRATION, VERTICAL Vertical integration is the process whereby different coincident data sets (representing the same area on the earth's surface) are combined together to form a new, integrated data set. The most common vertical integration problem is when the same feature has different representations in each of the data sets being combined — the best version has to be selected, or a new, better version determined, which might necessitate the adjustment of other features. Another problem concerns logical consistency — the position of a feature from one data set (eg: a bridge) might be inconsistent with the positions of features from the other data set (eg: a river the bridge purports to cross).

Afrikaans equivalent: *vertikale integrasie.*

INTERACTIVE PROCESSING The processing of data in a conversational system where a dialogue takes place between one or more users and the computer. Typical response times are between one-tenth of a second and 15 seconds and are very dependent on the load on the computer and the complexity of the individual transactions.

Afrikaans equivalent: *interaktiewe verwerking.*

INTERPRETATION, PHOTO — **see under:** *PHOTO INTERPRETATION.*

INTERSECTION Intersection is that form of coincidence where one or more spatial attributes have one coordinate tuple in common.

Afrikaans equivalent: *snyding.*

INTERVAL DATA — **see under:** *DATA, INTERVAL.*

ISARITHMIC MAP — **see under:** *MAP, ISARITHMIC.*

ISOMETRIC LINE MAP — **see under:** *MAP, ISOMETRIC LINE.*

ISOPLETH MAP — **see under:** *MAP, ISOPLETH.*

IT — **see under:** *INFORMATION TECHNOLOGY.*

KEY A set of one or more characters (making up a field) that identifies a record in a data base. A primary key is a key that uniquely identifies the record, while all other keys are secondary keys as they do not identify the record uniquely.

Afrikaans equivalent: *sleutel.*

LAMBERT CONFORMAL CONIC PROJECTION This is the map projection commonly used in South Africa for scales between 1:500 000 and 1:2 000 000 inclusive. It is a conic projection in which the parallels are unequally spaced arcs of concentric circles, more closely spaced near the centre of the map, and in which the meridians are equally spaced radii of the same circles, cutting the parallels at right angles [Snyder 1984].

Afrikaans equivalent: *Lambert se konforme koniese projeksie.*

LAND INFORMATION SYSTEM A land information system (LIS) is generally regarded as being synonymous with a geographical information system (GIS). Historically, an LIS was for land record management and was based on land parcels, or a cadastre. The debate about these terms is discussed in Section 1.2.2. [**See also:** *GEOGRAPHICAL INFORMATION SYSTEM.*]

Afrikaans equivalent: *grond inligtingstelsel.*

LANGUAGE A set of characters, conventions and rules used to convey information. A language may formally be considered to consist of pragmatics, semantics and syntax [Longley & Shain 1982]. A language is defined by a *grammar*. Languages used to control computers are known as programming languages.

Afrikaans equivalent: *taal.*

LARGE-SCALE MAP Generally, a map at a scale larger than 1:25 000. However, in South Africa the 1:50 000 series is the largest scale providing coverage of the whole of the country, and the 1:50 000 sheets are often considered to be large-scale maps.

Afrikaans equivalent: *grootskaalkaart.*

LASER PRINTER — **see under:** *PLOTTER.*

LATITUDE & LONGITUDE The latitude of a point on the ellipsoid is defined as the angular distance between the normal at the point and the plane of the equator of the ellipsoid. The longitude of a point on the ellipsoid is the angular distance between a meridian plane through the point and an arbitrarily defined meridian (usually the Greenwich Meridian).

Afrikaans equivalent: *breedtegraad & lengtegraad.*

LEVELLING Levelling is the determination of elevations with a surveying instrument [McCormac 1985]. The elevations are computed relative to a known datum.

Afrikaans equivalent: *gelykmaking, hoogtemeeting, nivellering.*

LEXICAL ANALYSER A lexical analyser reads in a stream of characters and groups them into *tokens* that are sequences of characters having a collective meaning [Aho *et al* 1986]. A lexical analyser is part of a compiler and the first component to be invoked.

Afrikaans equivalent: *leksikale analiseerder.*

LICENCE, CARTOGRAPHIC — **see under:** *CARTOGRAPHIC LICENCE.*

LINEAGE Lineage is a component of data quality — the record of the origin of the geo-referenced information and the processes and transformations through which it has gone to reach its current state. "The basis of any quality report is a narrative of the lineage of the data" [Moellering 1985]. A lineage report is like an audit trail. Examples of documents which would make up a lineage report include the calibration records of equipment such as aerial cameras and digitising tables, details of how the data were derived, and details of projection transformations performed on the data.

Afrikaans equivalent: *herkoms.*

LINE FEATURE — **see under:** *FEATURE, LINE.*

LINE FOLLOWING Line following is the tracing of "lines" (really, strips of pixels of the same or similar values) in a raster image to produce vector data. Generally, the strips of pixels are first thinned until they are only one pixel wide, to facilitate the line following. Line following can be performed semi-automatically (with operator intervention), or sometimes even fully automatically (depending on thew quality of the source data).

Afrikaans equivalent: *lyn volging.* [**See also:** *VECTORISE.*]

LIS — **see under:** *LAND INFORMATION SYSTEM.*

LO An abbreviation for "longitude origin". It is used to designate the standard (or central) meridian for a zone in the South African Survey Coordinate System (Y and X coordinates on the Gauss Conformal projection). Such zones are two-degree wide strips running from the equator to the South Pole. The standard meridians are the odd-numbered meridians.

Afrikaans equivalent: *Lo.*

LOGICAL CONSISTENCY Logical consistency is a component of data quality — the degree to which geo-referenced information is represented accurately in the data structure and fulfills all the internal requirements of the data structure [Moellering 1985, modified from]. This reflects the fidelity of the information, that is, does the information make sense?

Afrikaans equivalent: *logiese nie-strydigheid/konsekwentheid.*

LONGITUDE — **see under:** *LATITUDE & LONGITUDE.*

LONGITUDE ORIGIN — **see under:** *LO.*

LOXODROME — **see under:** *RHUMB LINE.*

MACHINE CODE A language providing programs that can be expressed directly in a binary format acceptable to the central processing unit [Longley & Shain 1982].

Afrikaans equivalent: *masjienkode.*

MAGISTERIAL DISTRICT — **see under:** *DISTRICT, MAGISTERIAL.*

MAINFRAME COMPUTER — **see under:** *COMPUTER.*

MANAGEMENT INFORMATION SYSTEM A management information system (MIS) is:

1. a system designed to provide management and supervisory staff with required data that are accurate, relevant and timely, possibly on a realtime basis.

2. a system in which data are recorded and processed for operational purposes. The problems are detected for higher management decision making and information is fed back to higher levels on the progress, or lack of it, in achieving management objectives.

[Longley & Shain 1982].

Afrikaans equivalent: *bestuursinligtingstelsel.*

MAP A map is a representation (usually on a flat medium) of all or a portion of the earth or other celestial body, showing the relative size and position of features to some given scale or projection. A map may emphasise, generalize or omit the representation of certain features to satisfy specific requirements [ASP 1980].

Afrikaans equivalent: *kaart.*

MAP, BASE — see under: *BASE MAP.*

MAP, CADASTRAL Cadastral maps are large-scale maps based on accurate land survey and show administrative and property boundaries and the outlines of individual buildings. These maps are used for administrative purposes, for the identification of properties described in legal documents, and for various detailed proceedings regarding land tenure.

Afrikaans equivalent: *kadastrale kaart.*

MAP, CHOROPLETH A choropleth map is a map on which the data appear as representative of certain units of surface area, so that each data zone on the map is demarcated by a boundary that is related to an actual unit area. The name is derived from the Greek choros = place and plethos = magnitude. The statistical surface represented is discontinuous or stepped. The unit areas employed are usually administrative or enumeration areas, and the value of a single point is assigned to the whole data zone.

Afrikaans equivalent: *choropleetkaart.*

MAP COMPILATION — see under: *COMPILATION.*

MAP, ISARITHMIC An isarithmic map is the orthogonal projection of the traces of the intersections of a number of z-level planes, parallel to the horizontal datum, with a continuous statistical surface. The word isarithm is derived from the Greek isos = equal and rithmos = number, and is a general term referring to any line on a map that joins points having the same z-value. Synonyms for isarithm are isoline and isogram.

Afrikaans equivalent: *isaritmiese kaart,* isoline map: *isolynkaart.*

MAP, ISOMETRIC LINE An isometric line map is an isarithmic or isoline map on which the z-values represent actual or derived values that can occur at points on the earth's surface. Actual values that can occur at points are exemplified by data such as elevation above sea-level, while derived values that can occur at points are either measures of dispersion such as means, medians or standard deviations, or ratios and percentages of point values.

Afrikaans equivalent: *isometriese lynkaart.*

MAP, ISOPLETH An isopleth map is an isarithmic or isoline map on which the z-values represent derived values that cannot occur at points on the earth's surface. Representative of this class are percentages and other kinds of ratios that include area in their definition directly or by implication, such as persons per square kilometre.

Afrikaans equivalent: *isopleetkaart.*

MAP, LARGE-SCALE MAP — see under: *LARGE-SCALE MAP.*

MAP, MEDIUM-SCALE — see under: *MEDIUM-SCALE MAP.*

MAP, ORTHOPHOTO A map produced by assembling orthophotographs at a specified uniform scale in a map format [ASP 1980].

Afrikaans equivalent: *ortofoto-kaart.*

MAP PROJECTION — see under: *PROJECTION.*

MAP, SMALL-SCALE — see under: *SMALL-SCALE MAP.*

MAP, THEMATIC A thematic map is an illustration of a special theme, usually compiled by individual researchers or research organizations, rather than by large mapping organizations. The objective is to portray the form or structure of a spatial distribution, and the mapped information is usually collected by means of physical, socio-economic and geographical surveys, which differ from land surveys in purpose and technique. Thematic maps are usually compiled at medium, small and very small scales.

Afrikaans equivalent: *tematiese kaart.*

MAP, TOPO-CADASTRAL A topo-cadastral map is a map showing both topographical and cadastral data. Generally, the base mapping of a country (often the country's national mapping series) consists of topo-cadastral maps, such as South Africa's 1:50 000 series.

Afrikaans equivalent: *topokadastrale kaart.*

MAP, TOPOGRAPHICAL MAP Topographical maps (Greek: topos = place, graphos = describe or write) are maps at large and medium scales showing the exact position of the main physical and cultural features within a certain area according to given specifications. The basic topographic coverage (a country's largest scale map series) is based on field survey and/or photogrammetrical results. Derived topographical maps (of medium and small scales) are prepared by reduction and generalization from the original base maps.

Afrikaans equivalent: *topografiese kaart.*

MAP, VERY SMALL-SCALE — see under: *VERY SMALL-SCALE MAP.*

MATCHING, EDGE — see under: *EDGE MATCHING.*

MATRIX A matrix consists of an n-tuple of coordinates, that define its origin and an m-dimensional rectangular tessellation of data values encoded in a pre-defined format.

Afrikaans equivalent: *matriks.*

MEAN SEA LEVEL The average elevation of the sea, as recorded over a number of years at a number of stations. Mean sea level is the most commonly used datum for vertical coordinates. In South Africa, mean sea level is based on the sea level at Cape Town, Port Elizabeth, East London and Durban.

Afrikaans equivalent: *gemiddelde seevlak.*

MEDIUM-SCALE MAP Typically, a map at a scale between 1:25 000 and 1:250 000, though in a large country, scales larger than 1:100 000 might still be considered large-scale maps.

Afrikaans equivalent: *mediumskaalkaart.*

MENSURATION Mensuration is measuring, and rules for finding lengths, areas and volumes [Oxford 1983].

Afrikaans equivalent: *meetkuns.*

ALBERS' EQUAL AREA PROJECTION This is the map projection commonly used in South Africa for scales of 1:2 500 000 and smaller. It is a conic projection in which the parallels are unequally spaced arcs of concentric circles, more closely spaced at the North and South edges of the map, and in which the meridians are equally spaced radii of the same circles, cutting the parallels at right angles [Snyder 1984].

Afrikaans equivalent: *Albers se vlaktroue projeksie.*

MERCATOR PROJECTION On a Mercator projection, rhumb lines are represented by straight lines, which is why it is the basis for virtually all nautical charts. Unfortunately, it has often been used as the basis for general world maps, where it provides a distorted view of the relative sizes of land maps. It is a cylindrical projection in which the meridians are equally spaced straight lines, and in which the parallels are unequally spaced straight lines, more closely spaced near the Equator, cutting the meridians at right angles [Snyder 1984].

Afrikaans equivalent: *Mercator-projeksie.*

MERIDIAN A circle passing through the celestial poles and zenith of any place on the earth's surface. A prime meridian is one from which longitude is reckoned [Oxford 1983], for example, Greenwich Meridian.

Afrikaans equivalent: *meridiaan.*

MERIDIAN, STANDARD — **see under:** *STANDARD MERIDIANS, PARALLELS & SCALE FACTORS.*

MICROCOMPUTER — **see under:** *COMPUTER.*

MINICOMPUTER — **see under:** *COMPUTER.*

MINE SURVEY — **see under:** *SURVEY, MINE.*

MIS — **see under:** *MANAGEMENT INFORMATION SYSTEM.*

MODEL A description or representation of objects or processes of the real world which reduces the real variety of aspects of these objects or processes to the essential ones from a particular point of view and/or for a particular purpose [ICA 1980].
Afrikaans equivalent: *model.*

MULTIPURPOSE CADASTRE A multipurpose cadastre is a system, generally computer based, which relates specifically to records based on the proprietary land parcel. It is a subset of a land information system (LIS).
Afrikaans equivalent: *veeldoelig kadaster.* [**See also:** *LAND INFORMATION SYSTEM.*]

MULTISPECTRAL The use of two or more spectral bands.
Afrikaans equivalent: *multispektraal.*

NAGIS NAGIS is the acronym for the Natal/KwaZulu Association for Geographic Information Systems, which was the first group formed in South Africa that dealt specifically with GIS.
Afrikaans equivalent: *NAGIS.*

NATIONAL LAND INFORMATION SYSTEM The National Land Information System (NLIS) is intended to be a mechanism for pooling all digital geo-referenced information available from government departments, and indeed, data available from other sources. Initially, NLIS will be merely an inventory of available information and how to get it, but ultimately, NLIS will be a mechanism for ordering and obtaining information in real time over computer networks). There are two standards associated with NLIS, namely NES [Standards Committe 1990] and the Data Standard [Standards Committee 1991]. NLIS is the responsibility of the State Inter-departmental Coordinating Committee for the National Land Information System (CCNLIS).
Afrikaans equivalent: *Nasionale Grondinligtingstelsel (NGIS).*

NATIONAL PROGRAMME FOR REMOTE SENSING The National Programme for Remote Sensing (NPRS) was founded in 1975, and was one of several National Programmes of the Foundation for Research Development (FRD) that funded and promoted scientific and engineering research in South Africa during the 1970s and 1980s. For example, the NPRS was closely involved with the EDIS conferences. The NPRS was also the main sponsor of the project that developed the original version of NES, as they realised that there was a need for such standards to stimulate the use of digital geo-referenced information, especially products derived from remote sensing.
Afrikaans equivalent: *Nasionale Program vir Afstandswaarneming.*

NCGIA NCGIA is an acronym for the National Center for Geographic Information and Analysis, which was established by the National Science Foundation in the

Unuted States of America to promote research and education based on GIS. The NCGIA is sited at the University of California at Santa Barbara (UCSB), the State University of New York (SUNY) at Buffalo, and the University of Maine at Orono.

NETWORK A system of interconnected communications facilities, especially for allowing computers to communicate with each other.

Afrikaans equivalent: *netwerk.*

NETWORK DATA BASE — **see under:** *DATA BASE.*

NIBBLE — **see under:** *NYBBLE.*

NLIS — **see under:** *NATIONAL LAND INFORMATION SYSTEM.*

NODE A point indicating a topological junction, the end of a chain or arc, or the spatial attribute of a point feature.

Afrikaans equivalent: *nodus.*

NOMINAL DATA — **see under:** *DATA, NOMINAL.*

NON-SPATIAL ATTRIBUTE Non-spatial attributes are those attributes of a feature that are independent of the position of the feature. They describe the nature and the appearance of the feature.

Afrikaans equivalent: *nie-ruimtelike attribuut.*

NON-TERMINAL SYMBOL A non-terminal symbol is one that is used in the definition of a grammar, but that does not constitute a part of the alphabet of the language being defined by the grammar.

Afrikaans equivalent: *nie-eindsimbool.*

NORMAL FORM In relational data bases, a class of relations with defined properties of interrelationship between the attributes. The use of normal forms in a data base reduces problems in the manipulation and storage of data which arise from inherent relationships between attributes [Longley & Shain 1982]. Currently, there are the first, second, third, Boyce-Codd and fifth normal forms (See Section 6.2).

Afrikaans equivalent: *normaalvorm.*

NPRS — **see under:** *NATIONAL PROGRAMME FOR REMOTE SENSING.*

NYBBLE Four consecutive bits forming half an 8-bit byte. A nybble can hold a single hexadecimal digit. It can also be spelt *nibble*.

Afrikaans equivalent: *halfgreep.*

OBJECT CODE The code of a program after it has been translated to run on a specific type of computer.

Afrikaans equivalent: *objekkode.*

OBJECT ORIENTED Object oriented programming and other techniques are based on raising the level of abstraction (removing the user as far as possible from the bits and bytes) through the use of *encapsulation* and *class inheritance*, as follows:

- **Encapsulation** is the ability to store all the attributes of an object (known as its state) and all the operations that it is capable of performing, together with the object.
- **Class inheritance:** objects are arranged in a hierarchy of super-classes and sub-classes, and the attributes and operations of a super-class can be passed on to the objects in a sub-class.

Afrikaans equivalent: *objekgeoriënteerde.*

OBJECT ORIENTED DATA BASE — **see under:** *DATA BASE.*

OBLIQUE PHOTOGRAPH A photograph taken with the camera axis intentionally directed between the horizontal and the vertical [ASP 1980].

Afrikaans equivalent: *skuins foto.*

OCTREE An octree is the three-dimensional equivalent of a quadtree. In an octree, space is divided recursively into eight parts (each part is known as a *voxel*) until any part of the subdivision is empty (wholly without any object) or full (wholly within any object), though the process normally continues to a pre-determined level of resolution. The advantages of this form of indexing are the very efficient conduct of Boolean operations on objects, and the reduction in disc space needed to store data.

Afrikaans equivalent: *oktboom.*

OPERATING SYSTEM Software that controls the generic operations of a computer, such as input and output, storage allocation, and the scheduling and control of the programs of users.

Afrikaans equivalent: *bedryfstelsel.*

ORDINAL DATA — **see under:** *DATA, ORDINAL.*

ORTHOGRAPHIC PROJECTION An orthographic projection is a perspective projection in which the observer is supposedly infinitely distant, so that the projection lines are parallel [Oxford 1983].

Afrikaans equivalent: *ortografiese projeksie.*

ORTHOPHOTOGRAPH A photograph having the properties of an orthographic projection. It is derived from a conventional perspective photograph by simple or differential rectification so that the image displacements caused by camera tilt and relief of terrain are removed [ASP 1980].

Afrikaans equivalent: *ortofoto.*

ORTHOPHOTO MAP — **see under:** *MAP, ORTHOPHOTO.*

OVERLAP, AREA OF The intersection of two areas in the data base that do not intersect in the real world. An area of overlap usually occurs when two or more data sets are combined and the boundaries from the data sets do not match properly.

Afrikaans equivalent: *area van oorvleueling.*

OVERLAY The technique of superimposing a number of data sets on top of each other to form a new data set which records the intersections and correlations from all the data sets superimposed.

Afrikaans equivalent: *oorlê.* [**See also:** *POLYGON OVERLAY.*]

OVERLAY, POLYGON — **see under:** *POLYGON OVERLAY.*

PARALLEL One of the parallel circles of constant latitude on the earth's surface [Oxford 1983]. The equator and the Tropics of Capricorn and Cancer are examples of parallels.

Afrikaans equivalent: *parallel.*

PARALLEL, STANDARD — **see under:** *STANDARD MERIDIANS, PARALLELS & SCALE FACTORS.*

PARAMETERS, PROJECTION — **see under:** *PROJECTION PARAMETERS.*

PC — **see under:** *COMPUTER.*

PC-COMPATIBLE — **see under:** *COMPUTER.*

PEDOLOGY Pedology is the science of natural soils [Oxford 1983].

Afrikaans equivalent: *bodemkunde.*

PEN PLOTTER — **see under:** *PLOTTER.*

PERIPHERAL In computing, a device to perform an auxilliary action in the system, such as input, output and archiving [Longley & Shain 1982].

Afrikaans equivalent: *randtoerusting.*

PERSONAL COMPUTER — **see under:** *COMPUTER.*

PHOTOGRAMMETRY The art, science and technology of obtaining reliable measurements of physical objects and the environment through processes of recording, measuring and interpreting photographic images.

Afrikaans equivalent: *fotogrammetrie.*

PHOTO INTERPRETATION (PI) The detection, identification, description and assessment of the significance of objects and patterns imaged on a photograph [ASP 1980]. Unlike the case with photogrammetry, to perform reliable PI, it is not necessary to correct the photograph for distortions caused by the camera optics, camera tilt, atmosphere, terrain roughness and the like.

Afrikaans equivalent: *fotovertolking.*

PI — **see under:** *PHOTO INTERPRETATION.*

PIXEL A single picture element. The smallest displayable area on the display surface whose characteristics can differ from those of its nearest neighbours. It generally applies to raster displays [Yen & Kelly 1980], and it is a data element having both spatial and spectral aspects [ASRS 1983].

Afrikaans equivalent: *beeldelement.*

PLANE SURVEY — **see under:** *SURVEY, PLANE.*

PLANIMETRIC Taken in the plane of the earth's surface. Also known as horizontal.

Afrikaans equivalent: *planimetries.*

PLANIMETRIC DIMENSIONS The planimetric dimensions are the two dimensions in which coordinates are measured along the reference surface. As the reference surface is curved, the coordinates are not Cartesian coordinates but they are spherical. However, on large-scale maps, users often perceive the coordinates to be Cartesian as the curvature is slight. But, a close examination of maps in the South African 1:50 000 national mapping services will reveal that the left and right margins of the map are not parallel and that they converge far to the South of the map. In addition, both the top and bottom margins are curved.

Afrikaans equivalent: *planimetriese koördinate.*

PLANNING REGIONS By dividing development regions into smaller more manageable units, planning regions have been created to serve as an aid for the identification of the needs of individual regions on a meaningful physical, economical and social basis [CSS 1991].

Afrikaans equivalent: *beplanningstreke.*

PLOTTER Strictly, a computer peripheral for producing graphs, diagrams and/or images on hard copy (on paper or film). A printer is strictly a computer peripheral for producing text on hard copy. However, the distinction between plotters and printers has become blurred as many such devices are capable of producing both graphics and text simultaneously, and the terms are often used interchangeably for devices producing graphics output. Many different types are available using different technologies, including electrostatic plotters, pen plotters, laser printers, impact printers, dot-matrix printers, and thermal wax transfer printers.

Afrikaans equivalent: *stipper.*

POINT A 0-dimensional object with a geometric location specified by a set of coordinates.

Afrikaans equivalent: *punt.*

POINT, CONTROL Any station in a horizontal and vertical control system that is identified in the cartographic data and used for correlating the cartographic data with the horizontal and vertical control systems [Moellering 1985].

Afrikaans equivalent: *beheerpunt.*

POINT FEATURE — **see under:** *FEATURE, POINT.*

POINT, TRIG — **see under:** *TRIANGULATION STATION.*

POLYGON A plane figure consisting of three or more vertices connected by lines or sides. The plane region bounded by the sides of the polygon is the interior of the polygon [ICA 1980]. In practice, in a GIS a polygon is often **not** a plane figure as it is draped over an undulating surface, though it is generally processed as a plane figure. A polygon is generally synonymous with a *region*.

Afrikaans equivalent: *veelhoek.*

POLYGON OVERLAY A polygon overlay is the result of the vertical integration of various thematic maps consisting of area data. That is, one data set consisting of areas or polygons displaying one theme, or a set of themes, is combined with another data set of the same form, to produce a new data set. Invariably, the new data set will consist of many more polygons than the original data sets did.

Afrikaans equivalent: *veelhoek oorlegsel.*

PRAGMATICS In languages, the relationship between signs and those who use them [Longley & Shain 1982].

Afrikaans equivalent: *pragmatiek.*

PRECISION Statistical measure of repeatability. It is usually expressed as variance or standard deviation of repeated measurements [ICA 1980]. If one repeatedly digitizes the same point, precision is the measure of how close the digitized values are to each other — ideally, they will all be equal. In computing, the precision of a number is determined by the number of bits allocated to the number.

Afrikaans equivalent: *noukeurigheid, presisie.*

PRECISION, ULTIMATE — **see under:** *ULTIMATE PRECISION.*

PRINTER Strictly, a printer is a computer peripheral for producing text on hard copy (paper or film). However, the distinction between plotters and printers has become blurred as many such devices are capable of producing both graphics and text simultaneously.

Afrikaans equivalent: *drukker.* [**See also:** *PLOTTER.*]

PROCESS A systematic sequence of operations to produce a specific result [ICA 1980].

Afrikaans equivalent: *proses.*

PROCESSING, BATCH — **see under:** *BATCH PROCESSING.*

PROCESSING, INTERACTIVE — **see under:** *INTERACTIVE PROCESSING.*

PROCESSING, REAL-TIME — **see under:** *REAL-TIME PROCESSING.*

PRODUCTION In a grammar, a production is a rule specifying how a particular set of symbols may be translated into another set of symbols. Formally, a production is of the form $u \rightarrow v$ where $u \in N \cup (N \cup T)^*$ and $v \in (N \cup T)^+$.

Afrikaans equivalent: *produksie.*

PROGRAM A complete series of definitions and instructions, conforming to the syntax of a given programming language, that when executed on a computer will perform a required task [Longley & Shain 1982].

Afrikaans equivalent: *program.*

PROGRAMMING LANGUAGE — **see under:** *language.*

PROJECTION A map projection is a transformation for representing "all or part of a round body on a flat sheet. Since this cannot be done without distortion, the cartographer must choose the characteristic which is to be shown accurately at the expense of others, or a compromise of several characteristics" [Snyder 1987].

Afrikaans equivalent: *projeksie.*

PROJECTION COORDINATES — **see under:** *COORDINATES, PROJECTION.*

PROJECTION PARAMETERS The function defining the one-to-one mapping of the lines and/or points of latitude and longitude between the reference surface and the projection surface.

Afrikaans equivalent: *projeksieparameters.*

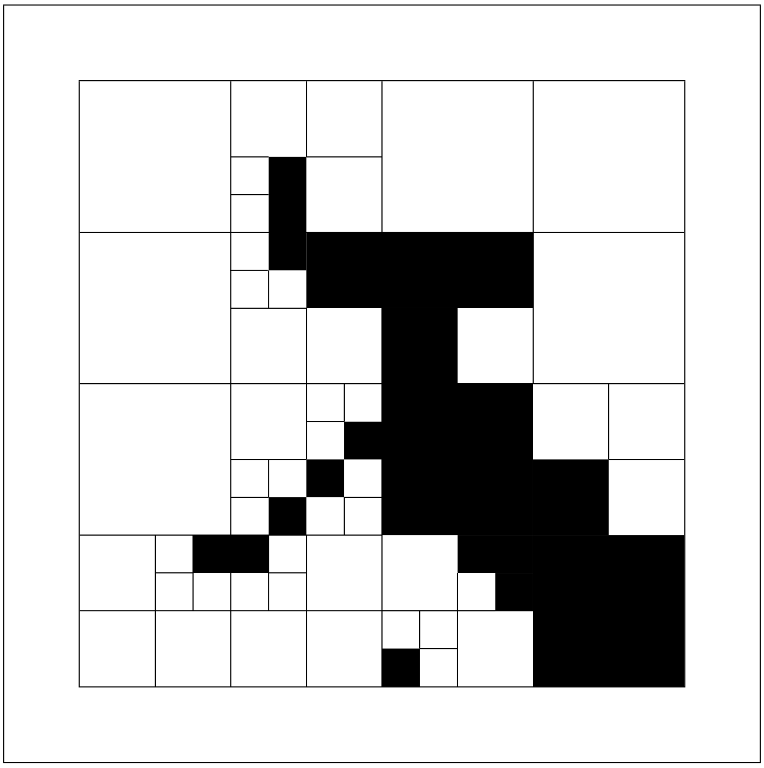

Figure C.1: The quadtree data structure

QUADTREE A quadtree is a structure for for storing raster data. The data set is divided into four quadrants. Each is then further subdivided until either the minimum pixel size is reached or the quadrant is homogeneous, that is, all the pixels in the quadrant have the same value. Hence, large areas of contiguous and identical pixels are stored at higher levels in the hierarchical tree than areas with great variety. The quadtree structure is illustrated in Figure C.1. Quadtrees can be very efficient for storing raster data and for some forms of raster data processing, and there are several commercial GISs based on quadtrees. The equivalent of a quadtree in three dimensions is the *octree*.

Afrikaans equivalent: *kwadboom.*

QUALITY, DATA — **see under:** *DATA QUALITY.*

RADIATION, ELECTROMAGNETIC RADIATION — **see under:** *ELECTROMAGNETIC RADIATION.*

RADIOMETRIC RESOLUTION — **see under:** *RESOLUTION, RADIOMETRIC.*

RASTER DATA — **see under:** *DATA, RASTER.*

RASTERISE To convert vector data into a raster form.

Afrikaans equivalent: *verrooster.*

RATIO DATA — **see under:** *DATA, RATIO.*

REAL-TIME PROCESSING The processing of data in a sufficiently rapid manner so that the results of the processing are available in time to influence the process being monitored or controlled [Sippl & Sippl 1974]. Real-time processing is generally used in those applications that are too fast for human intervention — typical response times ranging from milliseconds down to the absolute limits of processing speed, currently picoseconds.

Afrikaans equivalent: *intydse verwerking.*

REFERENCE SURFACE A standard sphere, spheroid or ellipsoid that is used as the planimetric datum. In South Africa, the standard reference surface is the Clarke 1880 ellipsoid (modified).

Afrikaans equivalent: *verwysingsvlak.*

REGION The interior of a continuous and closed sequence of one or more chains and/or arcs, known as the region's outer boundary.

Afrikaans equivalent: *streek.* [**See also:** *polygon.*]

REGION, STATISTICAL A statistical region generally consists of one or a number of related adjoining magisterial or census districts. Homogeneity in respect of physical characteristics and economic activities has been explored as far as possible [CSS 1991].

Afrikaans equivalent: *statistiese streek.*

REGULAR EXPRESSION A string including wildcard patterns that get expanded to form a full string or set of strings. Regular expressions are widely used in grammars.

Afrikaans equivalent: *reguliere uitdrukking.*

REGULAR GRAMMAR A regular grammar is one where all productions have the form $A \rightarrow tB$ or $A \rightarrow t$ (also known as a right-linear grammar), or the form $A \rightarrow Bt$ or $A \rightarrow t$ (also known as a left-linear grammar), where t is a terminal string and A and B are non-terminal strings.

Afrikaans equivalent: *reguliere grammatika.*

RELATION A two-dimensional flat file. The rows in the relation are called tuples, and the columns are called attributes.

Afrikaans equivalent: *relasie.*

RELATIONAL DATA BASE — **see under:** *DATA BASE.*

REMOTE SENSING Remote sensing is the acquisition of data and derivative information about objects or materials (targets) located on the earth's surface or in its atmosphere by using sensors mounted on platforms located at a distance from the targets to take measurements (usually multispectral) of interactions between the targets and electromagnetic radiation [Short 1982].

Afrikaans equivalent: *afstandswaarneming.*

RESOLUTION The smallest unit that can be detected. Resolution provides a limit to precision and accuracy [Moellering 1985].

Afrikaans equivalent: *resolusie.*

RESOLUTION, RADIOMETRIC Radiometric resolution is the range of wavelengths of electromagnetic radiation that a remote sensing device can detect.

Afrikaans equivalent: *radiometriese resolusie.*

RESOLUTION, SPATIAL The spatial resolution of digitizing equipment is the minimum distance that the equipment can detect between any two points, while the spatial resolution of a plotter is the minimum increment with which the pen can be moved in the X or Y directions. The spatial resolution of remote sensing devices is the distance between the centres of two orthogonally adjacent pixels.

Afrikaans equivalent: *ruimtelike resolusie.*

RESOLUTION, SPECTRAL Spectral resolution is the number of different bands of the electromagnetic spectrum (from within the radiometric resolution of the device) in which a multi-scanner operates.

Afrikaans equivalent: *spektrale resolusie.*

RESOLVING POWER A measure of the ability of an imaging system to image closely spaced objects. Synonymous with "resolution" [ICA 1980].

Afrikaans equivalent: *skeidings vermoë.*

RESPONSE TIME The time taken by a system to attain a specified state, or produce a specified output, after receiving input [Longley & Shain 1982].

Afrikaans equivalent: *reaksietyd.*

RESTITUTION The determination of the true (map) position of objects or points; the image of which appears distorted or displaced on aerial photographs. Restitution corrects for distortion resulting from both tilt and relief displacement [ASP 1980].

Afrikaans equivalent: *restitusie.*

RHUMB LINE A line (curved) on the surface of the earth, crossing all meridians at a constant angle [ASP 1980]. That is, it is a line of constant direction. In the Mercator projection, developed for navigation, a sailing route between two points is shown as a straight line, if the direction or azimuth of the ship remains constant with respect to North. The rhumb line is usually longer than the *great circle* path. It is the same length as a great circle only if it follows the Equator or a meridian [Snyder 1984]. A rhumb line is also known as a *loxodrome.*

Afrikaans equivalent: *loksodroom.*

SAGIS SAGIS is a term used in the title of two very successful conferences on GIS in Southern Africa, namely SAGIS'89 and EDIS/SAGIS'91. It is also the acronym of the favoured name for the umbrella body for GIS in South(ern) Africa that is in the process of being formed, namely the South(ern) African Geographical Information Society.

Afrikaans equivalent: *SAGIS.*

SAPGIS The South African Photogrammetry and Geo Information Society (usually known by its acronym SAPGIS) is a philosophical society for GIS and the related disciplines of photogrammetry, cartography and remote sensing. Its title in Afrikaans is *Die Suid-Afrikaanse Fotogrammetrie en Geo-inligting Vereniging.* Formerly the South African Society for Photogrammetry, Remote Sensing and Cartography (SASPRSC), it is known colloquially as the *Photogram Society.*

Afrikaans equivalent: *SAFGIV.*

SATELLITE IMAGERY Remotely sensed images taken from a space-based platform, such as LANDSAT, SPOT, METEOSAT and AVHRR.

Afrikaans equivalent: *satellietbeelde.*

SCALE The ratio between a distance on a map, graphics screen or any other display device or medium and the corresponding distance in the real world. A scale of 1:10 000 is a larger scale than one of 1:250 000.

Afrikaans equivalent: *skaal.*

SCALE DEPENDENCE — **see under:** *SCALE INDEPENDENCE & DEPENDENCE.*

SCALE FACTOR The quantity used in scaling by which the quantities being altered are multiplied or divided in order to bring them within the desired limits. The scale factor is the denominator of the representative fraction [ICA 1980].

Afrikaans equivalent: *skaalfaktor.* [**See also:** *STANDARD MERIDIANS, PARALLELS & SCALE FACTORS.*]

SCALE INDEPENDENCE & DEPENDENCE Data can be independent of scale (such as non-spatial attributes) or dependent of scale (such as entities that are not displayed at small scales).

Afrikaans equivalent: *skaalonafhanklikheid & -afhanklikheid.*

SCALING Transformation of the size of a graphic or part thereof according to a given factor and relative to a given scaling origin, the point which is kept at its place during the transformation. This is achieved by multiplication of coordinates relative to this origin by the scaling factor [ICA 1980].

Afrikaans equivalent: *skalering.*

SCANNER A device that scans a source document, recording at regular intervals the intensity of the light that is reflected off the document, to produce a raster image of the document. Each pixel in the resultant image represents a discrete measurement of the light reflection. Hence, the resolution of the resultant raster image is determined by the spacing of the recordings.

Afrikaans equivalent: *taster.*

SEMANTICS The relationships between symbols and their meaning.

Afrikaans equivalent: *semantiek.*

SEPARATOR — **see under:** *DELIMITER.*

SIMPLIFICATION, DATA Data simplification is the determination of the important characteristics of data, the elimination of unwanted detail, and the retention and possible exaggeration of the important characteristics. Simplification algorithms fall into two classes, namely elimination routines and modification routines. Elimination routines include point elimination and feature elimination, whereby points and features are eliminated to reduce clutter on a map or display. Simplification by modification refers to smoothing operators such as surface-fitting techniques and enhancement routines applied to raster data.

Afrikaans equivalent: *datavereenvoudiging.*

SLIVERS The narrow areas of overlap and underlap created by the misalignment of boundaries in the data base.

Afrikaans equivalent: *splinters.*

SMALL-SCALE MAP Map at a scale varying from 1:250 000 to 1:2 500 000.

Afrikaans equivalent: *kleinskaalkaart.*

SOCIAL STATISTICS — **see under:** *DEMOGRAPHIC STATISTICS.*

SOFTWARE The programs, procedures, routines and possibly documents associated with the operation of a data processing system [Longley & Shain 1982].

Afrikaans equivalent: *programmatuur.*

SOURCE DOCUMENT A document that supplies the basic data to be input into the data processing system. The data could consist of text or could be in a graphical format (for capture by digitizing).

Afrikaans equivalent: *brondokument.*

SOUTH AFRICAN SURVEY COORDINATE SYSTEM The projection and coordinate system used in South Africa for most large and medium scale data. The planimetric datum is the Clarke 1880 (modified) ellipsoid, with its origin at Buffelsfontein. The vertical datum is Mean Sea Level. The projection used is the Gauss Conformal projection, which is used in two-degree wide zones centered on odd-numbered meridians.

Afrikaans equivalent: *Suid-Afrikaanse Opmeting Koördinaat Stelsel.*

SPAGHETTI DATA Vector data without any topology.

Afrikaans equivalent: *spaghetti-data.*

SPATIAL ATTRIBUTE The spatial attributes of a feature determine its position, and if the feature is large enough, the size and shape of the feature as well. Spatial attributes include nodes, chains, arcs, regions and matrices.

Afrikaans equivalent: *ruimtelike attribuut.*

SPATIAL ATTRIBUTE, ALTERNATE — **see under:** *ALTERNATE SPATIAL ATTRIBUTE.*

SPATIAL DATA — **see under:** *DATA, SPATIAL.*

SPATIAL DOMAIN The scope of the spatial attributes of a feature.

Afrikaans equivalent: *ruimtelike gebied.*

SPATIAL INTEGRATION — **see under:** *INTEGRATION, SPATIAL.*

SPATIAL RESOLUTION — **see under:** *RESOLUTION, SPATIAL.*

SPECTRAL BAND An interval in the electromagnetic spectrum defined by two wave-lengths, frequencies or wave-numbers [ASRS 1983].

Afrikaans equivalent: *spektrale band.*

SPECTRAL RESOLUTION — **see under:** *RESOLUTION, SPECTRAL.*

SPECTRUM, ELECTROMAGNETIC — **see under:** *ELECTROMAGNETIC SPECTRUM.*

SPHERE, SPHEROID & ELLIPSOID Because of the difficulty in using a geoid for calculating planimetric coordinates, distances and angles, and because the geoid is not completely known for the whole earth, a symmetrical surface of revolution is used as a best fit of the total geoid. However, the relative positions of the continents on the earth are not known to a necessary degree of precision to make it possible to map the whole world on one ellipsoid. Thus one uses an ellipsoid whose surface constitutes the best fit for one's region of interest. A spheroid is an ellipsoid with less flattening. A sphere can be used when the zero dimension of the map is greater than the loss of accuracy that would be incurred by the use of the less accurate spherical surface. Spheres, spheroids and ellipsoids provide the reference surface for planimetric coordinates. In South Africa, the Clarke 1880 (modified) Ellipsoid is used.

Afrikaans equivalent: *sfeer, sferoïed & ellipsoïed.*

SPHEROID — **see under:** *SPHERE, SPHEROID & ELLIPSOID.*

STANDARD MERIDIANS, PARALLELS & SCALE FACTORS Used with map projections, the standard meridians and parallels determine where that map projection most closely fits the earth, that is, the origin of the projection. The scale factor determines by how much the scale at the origin has been adjusted, which increases the area of the map for which that projection and its standard meridian and parallels may be used effectively.

Afrikaans equivalent: *standard meridiane, parallele & skaalfaktor.*

STATION, TRIANGULATION — **see under:** *TRIANGULATION STATION.*

STATISTICAL REGION — **see under:** *REGION, STATISTICAL.*

STATISTICAL SURFACE — **see under:** *SURFACE, STATISTICAL.*

STATISTICS, DEMOGRAPHIC — **see under:** *DEMOGRAPHIC STATISTICS.*

STEREO Perceiving depth and three dimensions from a pair of images.

Afrikaans equivalent: *stereo.*

STEREO PAIR A pair of photographs or other images of the same scene, but taken from slightly different angles, so that when one image is viewed with the left eye and the other is viewed with the right eye, a three-dimensional stereo view of the scene is perceived. The greater the angle between the two views, the greater the exaggeration of the three-dimensional effect, but also the greater the difficulty in seeing the scene in three dimensions.

Afrikaans equivalent: *stereopaar.*

STEREOPLOTTER An instrument for plotting a map or obtaining spatial solutions by observation of stereoscopic models formed by stereo pairs of photographs [ASP 1980].

Afrikaans equivalent: *stereostipmasjien.*

STEREOSCOPE A binocular optical instrument for assisting the observer view two properly oriented photographs or diagrams to obtain the mental impression of a three-dimensional model [ASP 1980].

Afrikaans equivalent: *stereoskoop.*

STEREOSCOPY The science and art that deals with the use of binocular vision for observation of a pair of overlapping photographs or other perspective views, and with the methods by which such viewing is produced [ASP 1980].

Afrikaans equivalent: *stereoskopie.*

STEREO VISION The ability to look at a pair of stereo pictures and see the image in three dimensions. Some people can see the three-dimensional image without any aids, while some others struggle to see the three-dimensional image, even with the aid of stereo instruments.

Afrikaans equivalent: *stereo sig.*

SUPERCOMPUTER — see under: *COMPUTER.*

SURFACE, REFERENCE — see under: *REFERENCE SURFACE.*

SURFACE, STATISTICAL A statistical surface implies a base datum and a distribution of z-values on an ordinal, interval or ratio scale measured at right angles to that datum. By connecting the z-values, a smooth undulating statistical surface is formed, and the character of this surface is displayed on the map.

Afrikaans equivalent: *statistiese oppervlak.*

SURVEY, CADASTRAL A survey relating to land boundaries and subdivisions, made to create units suitable for transfer or to define the limitations of title [ASP 1980].

Afrikaans equivalent: *kadasteropmeting.*

SURVEY, CONTROL A survey made to establish the horizontal and vertical position of various points. The points are selected so that they form a net over the area under consideration and they are placed where other work can be conveniently tied into them [McCormac 1985]. In South Africa, the most visible evidence of control surveys are the trigonometric beacons placed at the tops of many hills.

Afrikaans equivalent: *beheeropmeting.*

SURVEY, GEODETIC A survey adjusted for the curved shape of the earth's surface [McCormac 1985].

Afrikaans equivalent: *geodetiese opmeting.*

SURVEY, HYDROGRAPHIC A survey pertaining to seas, lakes, streams and other bodies of water. Shorelines are charted, shapes of areas beneath water surfaces are determined, water flow of streams is estimated, and other information needed relative to navigation, flood control, development of water resources, and so on, is obtained [McCormac 1985].

Afrikaans equivalent: *hidrografiese opmeting.*

SURVEY, MINE A survey made to obtain the relative positions and elevations of underground shafts, geological formations, and so on, and to determine quantities and establish lines and grades for work to be done [McCormac 1985].

Afrikaans equivalent: *mynopmeting.*

SURVEY, PLANE A survey conduced on such a small area that the effect of the earth's curvature may be neglected. In a plane survey the earth is considered to be a flat surface and north-south lines are assumed to be parallel [McCormac 1985]. A plane survey is easier to conduct than a geodetic survey.

Afrikaans equivalent: *vlakopmeting.*

SURVEY, TOPOGRAPHICAL A survey made for locating objects and measuring the relief, roughness or three-dimensional variations of the earth's surface. Detailed information is obtained pertaining to elevations as well as to the locations of man-made and natural features and the entire information is plotted on maps (called topographical maps) [McCormac 1985].

Afrikaans equivalent: *topografiese opmeting.*

SURVEYING The science of determining the dimensions and shape (or three-dimensional characteristics) of the earth's surface by the measurements of distances, directions and elevations. It also involves the staking out of lines and grades. In addition to these field measurements, surveying includes the computation of areas, volumes and other quantities, as well as preparing the necessary maps and diagrams [McCormac 1985].

Afrikaans equivalent: *opmeetkunde.*

SYMBOL A mark or character taken as the conventional sign of some object or idea or process [Oxford 1983].

Afrikaans equivalent: *simbool.*

SYMBOLOGY The assignment of icons, for cartographic or other output, to groups of features based on the classification of the features or some attribute(s) of the features.

Afrikaans equivalent: *simbologie.*

SYNTAX The set of rules governing the grammatical arrangement of symbols to show their connection and relation [Oxford 1983].

Afrikaans equivalent: *sintaksis.*

SYNTAX ANALYSER A syntax analyser scans an input stream to determine whether or not the syntax of the input stream matches that of some grammar being used.

Afrikaans equivalent: *sintaksisontleder.*

SYSTEM, COORDINATE — **see under:** *COORDINATE SYSTEM.*

TABLE, DIGITISING A digitising table is an input device with a flat, rectangular surface that provides positional input to a computer system by continually digitising the position of a stylus moved on the table surface. The complete digitising table consists of the table surface, the stylus, and electronics to sense the location of the stylus [ICA 1980]. The resolution of the digitising table is the finest difference between two positions of the stylus that the table can detect. Positioning is normally determined by the strengths of the electronic signals received by a grid of wires under the table's surface, from the stylus.

Afrikaans equivalent: *versyfertafel.*

TAG A tag is a unique string of symbols that identifies a field or record.

Afrikaans equivalent: *etiket.*

TAGIS TAGIS is the Transvaal Association for Geographical Information Systems. Its founding, late in 1986, was prompted by the work of the project team developing the National Exchange Standard (NES).

Afrikaans equivalent: *TAGIS.*

TEMPLATE A pattern governing the assembly of some data. In the exchange standard, templates are used to fix the lengths of the fields in the relations when delimiters are not being used.

Afrikaans equivalent: *sjabloon.*

TEMPORAL DATA Data with a time component.

Afrikaans equivalent: *tyddata.*

TERMINAL SYMBOL A terminal symbol is one that is used in the definition of a grammar, and that constitutes a part of the alphabet of the language being defined by the grammar.

Afrikaans equivalent: *eindsimbool.*

TERRESTRIAL PHOTOGRAPH A photograph taken by a camera located on the ground, as opposed to an aerial photograph. Terrestrial photographs are often used in close-range photogrammetry.

Afrikaans equivalent: *landfoto.*

TESSELLATION A repeating pattern of either regular or irregular shapes [Moellering 1985].

Afrikaans equivalent: *mosaïekwerk.*

THIESSEN POLYGON Given a set of points distributed irregularly across a plane, a Thiessen polygon surrounds each point such that all places within that polygon are nearer the controlling point than any other [Dale & McLaughlin 1988]. A Thiessen polygon is also known as a *Voronoi polygon* or a *Dirichlet cell* [Burrough 1986].

Afrikaans equivalent: *Thiessen veelhoek.*

THEMATIC MAP — see under: *MAP, THEMATIC.*

THERMAL WAX TRANSFER PRINTER — see under: *PLOTTER.*

TIME, RESPONSE — see under: *RESPONSE TIME.*

TIN — see under: *TRIANGULATED IRREGULAR NETWORK.*

TOPO-CADASTRAL MAP — see under: *MAP, TOPO-CADASTRAL.*

TOPOGRAPHICAL MAP — see under: *MAP, TOPOGRAPHICAL.*

TOPOGRAPHICAL SURVEY — see under: *SURVEY, TOPOGRAPHICAL.*

TOPOGRAPHY Those features of the surface of the earth that are considered collectively to form the earth's surface. Topography is subdivided into *hypsography* (relief features), *hydrography* (water and drainage features) and *culture* (manmade features) [ASP 1980].

Afrikaans equivalent: *topografie.*

TOPOLOGICAL DATA Data that are invariant under geometrical deformations and stretchings [Moellering 1985].

Afrikaans equivalent: *topologiese data.*

TOPOLOGICAL INTEGRATION — see under: *INTEGRATION, TOPOLOGICAL.*

TOPOLOGICALLY STRUCTURED DATA Data that have the spatial relationships inherent in the data explicitly coded [USGS 1984].

Afrikaans equivalent: *topologies-gestruktureerde data.*

TOPOLOGY The branch of mathematics that "treats ideas like dimension and continuous deformation. These ideas are especially important in the construction of automated systems because, in a machine, human intuition is absent" [White 1984]. Topology is the relationship between the spatial attributes of the same or different features.

Afrikaans equivalent: *topologie.*

TRANSFER FORMAT A transfer format is exactly the same as an *exchange format*, though some prefer the term "transfer format", as the term "exchange format" implies a two-way flow of data, while the term "transfer format" implies only a one-way transfer of data. With digital geo-referenced information, most data flows will be one-way.

Afrikaans equivalent: *oordragformaat.* [**See also:** *EXCHANGE FORMAT.*]

TRIANGULATED IRREGULAR NETWORK A triangulated irregular network (TIN) consists of a set of continuous, connected triangles based on a *Delaunay triangulation* of irregularly spaced nodes or observation points. The specific attribute being modelled is then recorded at each of the nodes. TINs are often used to model elevations, as an alternative to *digital elevation models*.

Afrikaans equivalent: *trianguleerde onreëlmatige netwerk.*

TRIANGULATION A method of surveying in which the stations are points on the ground at the vertices of a chain or network of triangles whose angles are observed instrumentally and whose sides are derived by computation from selected triangle sides called base lines, whose lengths are obtained from direct measurement on the ground [ASP 1980].

Afrikaans equivalent: *triangulasie.*

TRIANGULATION STATION A point on the earth whose position is determined by triangulation. Also known as a *trig point* [ASP 1980].
Afrikaans equivalent: *triangulasiestasie.*

TRIG POINT — **see under:** *TRIANGULATION STATION.*

TUPLE A related set of values [Longley & Shain 1982]. A coordinate tuple is an ordered set of n coordinates specifying a location in an n-space.
Afrikaans equivalent: *tal.*

ULTIMATE PRECISION The ultimate precision of a map is the degree of discrimination with which the map has been plotted and may be read. It is generally 0.15 mm, independent of the scale of the map.
Afrikaans equivalent: *eindnoukeurigheid.*

UNDERLAP, AREA OF The area between two areas in the data base that are adjacent in the real world. An area of underlap usually occurs when two or more data sets are combined and the boundaries from the data sets do not match properly.
Afrikaans equivalent: *gaping.*

UNIVERSAL TRANSVERSE MERCATOR PROJECTION (UTM) A map projection based on a conformal projection of geodetic coordinates to a cylinder whose axis is perpendicular to the earth's axis of rotation. The world is divided into 60 zones of 6-degree increments from the Greenwich meridian. All zones are limited in latitude by 80 degrees north and south [ASP 1980]. UTM is commonly used by the military in many countries.
Afrikaans equivalent: *universele transversale Mercator projeksie.*

UNIX A widely used operating system, on which most significant commercial GISs run. The name UNIX is a weak pun on the name of the operating system from which it was derived, namely Multics.
Afrikaans equivalent: *UNIX.*

UTM — **see under:** *UNIVERSAL TRANSVERSE MERCATOR PROJECTION.*

VAPOURWARE Products announced far in advance of any release (which may or may not take place) [Raymond 1991]. Unfortunately, at present, much digital georeferenced data sets are vapourware.
Afrikaans equivalent: *dampware.*

VECTOR A variable that has magnitude and direction [Longley & Shain 1982]. Effectively, a vector is a line with direction.
Afrikaans equivalent: *VEKTOR.*

VECTOR DATA — **see under:** *DATA, VECTOR.*

VECTORISE To convert raster data into vector data. This is a non-trivial process, as noise in the raster data makes it difficult to identify features within the raster data. The two components of vectorising are detecting line features by performing *line following* through the raster data, and detecting area features by performing *classification*, *edge detection* and/or *contouring*.

Afrikaans equivalent: *vektoriseer.*

VERTEX Meeting-point of lines that form an angle [Oxford 1983]. In vector data, nodes are at vertices.

Afrikaans equivalent: *HOEKPUNT.*

VERTICAL Taken perpendicular to the plane of the earth's surface. Vertical measurements reflect elevation and height.

Afrikaans equivalent: *vertikaal.*

VERTICAL DIMENSION The vertical dimension is the dimension in which coordinates are measured at right-angles to the geoid. The coordinates are either elevations or depths.

Afrikaans equivalent: *vertikale dimensie.*

VERTICAL INTEGRATION — see under: *INTEGRATION, VERTICAL.*

VERTICAL PHOTOGRAPH An aerial photograph made with the camera axis vertical (or as near as practicable) in an aircraft [ASP 1980]. Vertical photographs are the most commonly taken of aerial photographs as they are the easiest from which to take measurements.

Afrikaans equivalent: *vertikale foto.*

VERY SMALL-SCALE MAP Map at a scale smaller than 1:2 500 000.

Afrikaans equivalent: *baie kleinskaalkaart.*

VORONOI POLYGON — see under: *THIESSEN POLYGON.*

VOXEL A rectangular parallelepiped of space, the three-dimensional equivalent of a *pixel*. A voxel is the primitive element in an *octree*.

Afrikaans equivalent: *oktboom element.*

WAX TRANSFER PRINTER — see under: *PLOTTER.*

WORD A collection of bytes. A word is generally considered to consist of four bytes. In some computers and for some instructions data items have to begin at full-word (at the beginning of a word) or half-word (at the beginning of the second half of a word) boundaries.

Afrikaans equivalent: *woord.*

WORKSTATION, GRAPHICS — see under: *GRAPHICS WORKSTATION.*

X X-values are normally the first coordinates in a coordinate tuple, though in the Gauss Conformal projection, they are the second coordinates. They normally specify one of the planimetric dimensions.

Afrikaans equivalent: *X.*

Y Y-values are normally the second coordinates in a coordinate tuple, though in the Gauss Conformal projection, they are the first coordinates. They normally specify one of the planimetric dimensions.

Afrikaans equivalent: *Y.*

Z Z-values are normally the third coordinates in a coordinate tuple, and they normally specify the elevation or depth.

Afrikaans equivalent: *Z.*

ZERO DIMENSION Measurements taken from a map and scaled to real-world measurements cannot be more precise than the zero dimension of the map, which is the ultimate precision of the plotting of the map scaled to the real world. Zero dimension is a measure of the resolution of a map.

Afrikaans equivalent: *nul-afmeting.*

Bibliography

[Abler 1987] Abler RF, 1987, *The National Science Foundation National Center for Geographic Information and Analysis*, International Journal of Geographical Information Systems, Vol 1, No 4, pp 303–326.

[AGI 1989] AGI Standards Committee, 1989, *Standards*, *in* Shand PJ & Moore RV, eds, *The Association for Geographic Information Yearbook 1989*, Taylor & Francis *and* Miles Arnold, pp161–164.

[Aho *et al* 1986] Aho AV, Sethi R & Ullman JD, 1986, *Compilers: principles, techniques, and tools*, Addison-Wesley, 796 pp.

[Akuyama & Yauchi 1991] Akuyama M & Yauchi A, 1991, *The standardized efforts for digital cartographic data in Japan*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 123–134.

[Albertz & Kreiling 1972] Albertz J & Kreiling W, 1972, *Photogrammetrisches Taschenbuch / Photogrammetric Guide / Guide Photogrammétrique / Manual Fotogramétrico de Bolsillo*, Herbert Wichmann Verlag, Karlsruhe, 214 pp.

[Anon 1991] Anon, 1991, *AGI — a review of 1990*, *in* Cadoux-Hudson J & Heywood DI, eds, *Geographic information 1991: The yearbook of the Association for Geographic Information*, Taylor & Francis *and* Miles Arnold, pp 3–6.

[ANSI 1986] American National Standards Institute, 1986, *ANSI X3.4-1986, coded character sets — 7-bit american national standard code for information interchange (7-bit ASCII)*, American National Standards Institute, New York, 27 pp.

[Arndt 1988] Arndt RR, August 1988, *The new Foundation for Research Development: the new strategy and its implementation*, Remote Sensing for Southern Africa Newsletter, Foundation for Research Development, Pretoria, pp 1–3.

[ASP 1980] American Society of Photogrammetry, 1980, *Manual of Photogrammetry, 4th ed*, American Society of Photogrammetry, Falls Church, VA, USA, 1056 pp.

[ASRS 1983] American Society of Remote Sensing, 1983, *Manual of Remote Sensing, 2nd ed*, American Society of Remote Sensing.

[Baltsavias *et al* 1991] Baltsavias EP, Gruen A & Meister M, 1991, *DOW — a system for generation of digital orthophotos from aerial and SPOT images*, Proceedings EDIS/SAGIS '91 Conference, Pretoria RSA, 10 pp.

[Backhouse 1979] Backhouse RC, 1979, *Syntax of programming languages: theory and practice*, Prentice-Hall International Series in Computer Science, 301 pp.

[Barr 1993] Barr C, June 1993, *The evolution of the Pentium*, PC Magazine Southern Africa, Vol 1, No 1, pp 40–41.

[Bierman 1992] Bierman K, October 1992, *Personal electronic mail to AK Cooper*, 1 pp.

[Bosman *et al* 1984] Bosman DB, Van der Merwe IW & Hiemstra LW, 1984, *Tweetalige woordeboek / Bilingual dictionary, 8th Ed*, Tafelberg, Cape Town, 1351 pp.

[Brady 1977] Brady JM, 1977, *The theory of computer science: a programming approach*, Chapman and Hall, 287 pp.

[Burrough 1986] Burrough PA, 1986, *Principles of geographical information systems for land resources assessment*, Monographs on soil and resources survey No 12, Oxford Science Publications, Oxford, 194 pp.

[Buttenfield & Mackaness 1991] Buttenfield BP & Mackaness WA, 1991, *Visualization*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 427–443.

[Cadoux-Hudson & Heywood 1991] Cadoux-Hudson J & Heywood DI, eds, 1991, *Geographic information 1991: The yearbook of the Association for Geographic Information*, Taylor & Francis *and* Miles Arnold, 422 pp.

[Carter 1989] Carter JR, 1989, *On defining the geographic information system*, *in* Ripple WJ (ed), *Fundamentals of geographic information systems: a compendium*, ASPRS/ACSM, Falls Church VA, USA, pp 3–7.

[CEDD 1986a] Committee on the Exchange of Digital Data, November 1986, *Final report of the IHO Committee on the Exchange of Digital Data*, International Hydrographic Organization, 76 pp.

[CEDD 1986b] Committee on the Exchange of Digital Data, November 1986, *Format for the exchange of digital hydrographic data*, International Hydrographic Organization, 350 pp.

[Chrisman 1986] Chrisman NR, September 1986, *Obtaining information on quality of digital data*, Proceedings Auto Carto London, Vol 1, pp 350–358.

[Chrisman 1987] Chrisman NR, April 1987, *Fundamental principles of geographic information systems*, Proceedings Auto Carto 8, Baltimore USA, pp 32–41.

[Chrisman 1990] Chrisman NR, 1990, *Deficiencies of sheets and tiles: building sheetless databases*, International Journal of Geographical Information Systems, Vol 4, No 2, pp 157–167.

[CHS 1985] Canadian Hydrographic Service, October 1985, *Evolving communications standards in the mapping and charting world: a report and a proposal*, submitted to the International Hydrographic Organization's Committee on the Exchange of Digital Data, 42 pp.

[Clarke 1991] Clarke AL, 1991, *Australian standards for spatial data transfer*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 28–36.

[Clarke *et al* 1986a] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, May 1986, *Questionnaire on GIS exchange format proposals*, National standards for GIS exchange, 24 pp.

[Clarke *et al* 1986b] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, May 1986, *Glossary of GIS terms and English/Afrikaans translations*, National standards for GIS exchange, 28 pp.

[Clarke *et al* 1987a] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, March 1987, *A proposed national standard for the exchange of digital geo-referenced information: Draft*, NRIMS CSIR Technical Report TWISK 517, 151 pp.

[Clarke *et al* 1987b] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, September 1987, *A national standard for the exchange of digital geo-referenced information*, CSIR Special Report SWISK 45, 201 pp, ISBN 0 7988 3073 5.

[Clarke *et al* 1987c] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, September 1987, *In proposing a national standard for the exchange of digital geo-referenced information*, Proceedings EDIS '87 Conference, Pretoria RSA, 13 pp.

[Clarke *et al* 1987d] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, September 1987, *A Proposed national standard for the exchange of digital geo-referenced information*, Final report of the project team to the National Committee for Remote Sensing, CSIR, 7 pp.

[Clarke *et al* 1988] Clarke DG, Cooper AK, Liebenberg EC & Van Rooyen MH, March 1988, *On proposing a national standard for the exchange of digital geo-referenced information*, South African Journal of Photogrammetry, Remote Sensing and Cartography, Vol 15, Part 1, pp 35–41.

[Clarke & Cooper 1991] Clarke DG & Cooper AK, September 1991, *Issues encountered in developing and establishing national standards for digital geo-referenced information*, 15th International Cartographic Conference, Bournemouth UK, Vol 2, pp 735–739.

[Cline 1992] Cline D, October 1992, *Personal electronic mail to AK Cooper*, 1 pp.

[Coetzee *et al* 1985] Coetzee N, Du Plooy NF & Cluver ADdeV, 1985, *Tweetalige rekenaarwoordeboek / Bilingual computer dictionary*, McGraw-Hill Boekmaatskappy, Johannesburg, 292 pp.

[Cooper 1986a] Cooper AK, January 1986, *Report on the GIS project planning discussions*, NRIMS CSIR Internal Report I668, 13 pp.

[Cooper 1986b] Cooper AK, July 1986, *National standards for geographical information systems (GIS) data exchange*, Proceedings 1st Computer Science Research Students Conference, Stutterheim RSA, *also* NRIMS CSIR Technical Report TWISK 478, 15 pp.

[Cooper 1986c] Cooper AK, September 1986, *An introduction to geographical information systems*, NRIMS CSIR Internal Report I718, 7 pp.

[Cooper 1986d] Cooper AK, December 1986, *personal communication to P Haywood*, 4pp.

[Cooper 1987a] Cooper AK, March 1987, *Thoughts on exchanging geographical information*, Proceedings 1987 ASPRS-ACSM Annual Convention, Baltimore USA, Vol 5, pp 1–9, *also* NRIMS CSIR Technical Report TWISK 500, 13 pp.

[Cooper 1987b] Cooper AK, June 1987, *Comments on "Design of a spatial data structure using relational normal forms"*, NRIMS CSIR Internal Report I766, 4 pp.

[Cooper 1987c] Cooper AK, September 1987, *Geographical information systems*, Proceedings Computer Graphics '87, Johannesburg RSA, *also* NRIMS CSIR Technical Report TWISK 542, 10 pp.

[Cooper 1987d] Cooper AK, December 1987, *Experiences in drafting an exchange standard*, Proceedings 2nd Computer Science Research Students Conference, Stellenbosch RSA, *also* CACDS CSIR Internal Report I800, 12 pp.

[Cooper 1988a] Cooper AK, March 1988, *Temporal terrain shading*, Proceedings 1988 ACSM-ASPRS Annual Convention, St Louis USA, Vol 2, pp 282–290.

[Cooper 1988b] Cooper AK, September 1988, *A data structure for exchanging geographical information*, Quæstiones Informaticæ, Vol 6, No 2, pp 77–82, *also* NRIMS CSIR Technical Report TWISK 535, 14 pp.

[Cooper 1988c] Cooper AK, September 1988, *Exchanging geographically referenced information — a status report*, Proceedings Computer Graphics '88, Johannesburg RSA, pp B1-6 – B1-20, *also* CACDS CSIR Technical Report PKOMP 88/17, 12 pp.

[Cooper 1988d] Cooper AK, September 1988, *News from South Africa: The South African standard for the exchange of digital geo-referenced information*, SORSA News, Vol 6, No 4, pp 17–19.

[Cooper 1989a] Cooper AK, April 1989, *The South African standard for the exchange of digital geo-referenced information*, Proceedings Auto Carto 9, Baltimore RSA, pp 745–753, *also* CACDS CSIR Technical Report PKOMP 89/10, 11 pp.

[Cooper 1989b] Cooper AK, 1989, *A survey of standards for the exchange of digital geo-referenced information*, South African Journal of Photogrammetry, Remote Sensing and Cartography, Vol 15, Part 3, pp 136–140, *also* CACDS CSIR Technical Report PKOMP 89/7, 8 pp.

[Cooper 1989c] Cooper AK, July 1989, *Research into the nature of digital geographical information*, Proceedings SAGIS'89, Pietermaritzburg, *also* CACDS CSIR Technical Report PKOMP 89/8, 6 pp.

[Cooper 1989d] Cooper AK, September 1989, *Report on SAGIS'89*, CACDS Internal Report IKOMP 89/15, 4 pp.

[Cooper 1993] Cooper AK, April 1993, *A formal specification of the National Exchange Standard (NES), Version 2.0*, *submitted to* South African Journal of Photogrammetry and Geo-information.

[Cooper & Clarke 1991] Cooper AK & Clarke DG, 1991, *The South African standard for the exchange of digital geo-referenced information*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 154–168.

[Cooper & Greenwood 1993] Cooper AK & Greenwood PH, 1992, *A mechanism for sharing non-spatial attributes between features*, *in preparation.*

[Cooper & Hobson 1991] Cooper AK & Hobson CD, September 1991, *GIS education — maximising the effectiveness of available skilled personnel in developing countries*, 15th International Cartographic Conference, Bournemouth UK.

[Cooper & Scheepers 1989] Cooper AK & Scheepers CF, April 1989, *Classification of digital geographical information*, Poster paper at Survey and Mapping 89, Coventry UK, *also* CACDS CSIR Technical Report PKOMP 89/9, 13 pp.

[Coppock 1988] Coppock JT, July 1988, *The analogue to digital revolution: a view from an unreconstructed geographer*, The American Cartographer, Vol 15, No 3, pp 263–275.

[Coppock & Rhind 1991] Coppock JT & Rhind DW, 1991, *The history of GIS*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 21–43.

[Cowen 1988] Cowen DJ, 1988, *GIS vs CAD vs DBMS: what are the differences?*, Photogrammetric Engineering and Remote Sensing, Vol 54, pp 1551–1554.

[Cracknell & Hayes 1991] Cracknell AP & Hayes LWB, 1991, *Introduction to remote sensing*, Taylor & Francis, 293 pp.

[CSS 1991] Central Statistical Services, January 1991, *Standaardgebiedskodelys / Standard code list of areas*, Central Statistical Services, Pretoria.

[Dale 1989] Dale PF, 1989, *Land information systems and the land parcel*, *in* Shand PJ & Moore RV, eds, *The Association for Geographic Information Yearbook 1989*, Taylor & Francis *and* Miles Arnold, pp 59–63.

[Dale 1991] Dale PF, 1991, *Land information systems*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 2: Applications*, Longman Scientific & Technical, London, pp 85–99.

[Dale & McLaughlin 1988] Dale PF & McLaughlin JD, 1988, *Land information management*, Clarendon Press, Oxford, 266 pp.

[Department of Water Affairs 1986] Department of Water Affairs, 1986, *Management of the water resources of the Republic of South Africa*, Department of Water Affairs, Pretoria.

[DCDSTF 1988] Digital Cartographic Data Standards Task Force, January 1988, *The proposed standard for digital cartographic data*, American Cartographer, Vol 16, No 1.

[DCDSTF 1991] Digital Cartographic Data Standards Task Force, April 1991, *Spatial data transfer standard: Version 12/90*, US Geological Survey, Reston, 320 pp.

[DOE 1987] Department of the Environment, May 1987, *Handling geographic information*, Report to the Secretary of State for the Environment of the Committee of Enquiry chaired by Lord Chroley, Her Majesty's Stationery Office, 208 pp.

[FICCDC 1986a] Federal Interagency Coordinating Committee on Digital Cartography, August 1986, *Federal geographic exchange format, a uniform format for the exchange of spatial data among federal agencies*, FICCDC, 67 pp.

[FICCDC 1986b] Federal Interagency Coordinating Committee on Digital Cartography, December 1986, *Federal geographic exchange format, a standard format for the exchange of spatial data among federal agencies*, Version 01.08, FICCDC, 52 pp.

[FICCDC 1988] Federal Interagency Coordinating Committee on Digital Cartography, 1988, *A process for evaluating geographic information systems*, Technical Report 1 of the Technology Exchange Working Group, US Geological Survey Open-File Report 88-105, 134 pp.

[Fisher 1991] Fisher PF, 1991, *Spatial data sources and data problems*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, 1991, *Geographical information systems, Vol 1: Principles*, Vol 1, Longman Scientific & Technical, London, pp 175–189.

[Flowerdew 1991] Flowerdew R, 1991, *Spatial data integration*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, 1991, *Geographical information systems, Vol 1: Principles*, Vol 1, Longman Scientific & Technical, London, pp 375–387.

[Gatrell 1991] Gatrell AC, 1991, *Concepts of space and geographical data*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, 1991, *Geographical information systems, Vol 1: Principles*, Vol 1, Longman Scientific & Technical, London, pp 119–134.

[Gazdar *et al* 1985] Gazdar G, Klein E, Pullum G & Sag I, 1985, *Generalized Phrase Structure Grammar*, Basil Blackwell, 276 pp.

[Gereformeerde Blues Band 1989] Gereformeerde Blues Band, 1989, *Hillbrow*, off the album *Eet Kreef*, Shifty Music.

[Goodchild 1992] Goodchild MF, 1992, *Geographical information science*, International Journal of Geographical Information Systems, Vol 6, No 1, pp 31–45.

[Goodchild *et al* 1992] Goodchild MF, Haining R, Wise S and twelve others, 1992, *Integrating GIS and spatial data analysis: problems and possibilities*, International Journal of Geographical Information Systems, Vol 6, No 5, pp 407–423.

[Greenwood 1988] Greenwood PH, September 1988, *Using the proposed national exchange standard for GIS data*, Proceedings Computer Graphics '88, Johannesburg RSA, pp B1-21 – B1-29, *also* CACDS CSIR Technical Report PKOMP 89/13, 9pp.

[Greenwood 1989] Greenwood PH, September 1989, *Thoughts on choosing GIS software*, Proceedings Computer Graphics '89, Johannesburg RSA, *also* CACDS CSIR Technical Report PKOMP 89/14, 8pp.

[Gries 1981] Gries D, 1981, *The science of programming*, Springer-Verlag, 366 pp.

[Guptill 1991] Guptill SC, 1991, *Spatial data exchange and standardization*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 515–530.

[Haywood 1986] Haywood P, chair, September 1986, *The national transfer format: final draft (Issue 1.3)*, Ordnance Survey, 158 pp.

[Hemenway 1985] Hemenway D, October 1985, *Interview: David Rhind*, Photogrammetric Engineering & Remote Sensing, Vol LI, No 10, pp 1651–1658.

[Herbert 1988] Herbert N, November 1988, *Personal communication to AK Cooper*, SABS, 1 pp.

[House of Lords 1983] House of Lords Select Committee on Science and Technology, 1983, *Remote sensing and digital mapping*, Vol 1, Her Majesty's Stationery Office.

[ICA 1980] International Cartographic Association, 1980, *Glossary of terms in Computer Assisted Cartography*, International Cartographic Association, Commission III: Computer-assisted Cartography, 157 pp.

[ICA 1992] International Cartographic Association, September 1992, *Technical characteristics for assessing standards for the transfer of spatial data: Discussion draft # 3*, International Cartographic Association, Commission on Standards for the Transfer of Spatial Data, 23 pp.

[ISO 1983] International Organization for Standardization, 1983, *ISO 646, Information processing — ISO 7-bit coded character set for information interchange*, International Organization for Standardization, Genève, 15 pp.

[ISO 1985] International Organization for Standardization, 1985, *ISO 8211, Information processing — specification for a data descriptive file for information interchange*, International Organization for Standardization, Genève, 27 pp.

[ISO 1990] International Organization for Standardization, 1990, *ISO catalogue 1990*, International Organization for Standardization, Genève, 926 pp.

[Ivancevich *et al* 1989] Ivanevich JM, Donnelly JH jr & Gibson JL, 1989, *Management: principles and functions, 4th ed*, BPI Irwin, Homewood IL, 765 pp.

[Jackson & Woodsford 1991] Jackson MJ & Woodsford PA, 1991, *GIS data capture hardware and software*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 239–249.

[Jaret 1991] Jaret P, January 1991, *Stalking the world's epidemics: The disease detectives*, National Geographic, pp 114–140.

[Jobson 1986] Jobson TA, November 1986, *Integration of geographic feature data*, NRIMS CSIR Internal Report I731, 16 pp.

[Jordan 1987] Jordan ES, September 1987, *The application of DTMs to electromagnetic propagation modelling at VHF and UHF*, Proceedings EDIS '87 Conference, Pretoria SA, 9 pp.

[Kubo 1986] Kubo S, 1986, *TRINITY: a GIS with intelligence*, Proceedings 4th International Conference on Spatial Data Handling.

[Kubo 1991] Kubo S, 1991, *The development of GIS in Japan*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, 1991, *Geographical information systems, Vol 2: Applications*, Vol 2, Longman Scientific & Technical, London, pp 47–56.

[Lane 1988] Lane A, 1988, *Book review: A national standard for the exchange of digital referenced information*, International Journal of Geographical Information Systems, Vol 2, No 1, pp 81–82.

[Langen 1990] Langen G, March 1990, *A translator program converting a digitized map into the format of the American proposed standard for digital cartographic data*, MS thesis (unpublished), Oregon State University, 207 pp.

[Langran 1989] Langran G, 1989, *A review of temporal data base research and its use in GIS applications*, International Journal of Geographical Information Systems, Vol 3, No 3, pp 215–232.

[Langran & Chrisman 1988] Langran G & Chrisman NR, 1988, *A framework for temporal geographic information*, Cartographica, Vol 25, No 3, pp 1–14.

[Lee & Coleman 1990] Lee YC & Coleman DJ, 1990, *A framework for evaluating interchange standards*, Canadian Institute of Surveying and Mapping Journal, Vol 44, No 4, pp 391–402.

[Levine *et al* 1992] Levine JR, Mason T & Brown D, 1992, *lex & yacc, 2nd ed*, O'Reilly & Associates, Inc, Sebastopol, CA, 366 pp.

[Light 1986a] Light DL, March 1986, *Mass storage estimates for the digital mapping era*, Photogrammetric Engineering and Remote Sensing, Vol 52, No 3, pp 419–425.

[Light 1986b] Light DL, April 1986, *Planning for optical disk technology with digital cartography* Photogrammetric Engineering and Remote Sensing, Vol 52, No 4, pp 551–557.

[Longley & Shain 1982] Longley D & Shain M, 1982, *Dictionary of Information Technology*, Macmillan Reference Books, 381 pp.

[Maguire 1991] Maguire DJ, 1991, *An overview and definition of GIS*, in Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 9–20.

[Maguire & Dangermond 1991] Maguire DJ & Dangermond J, 1991, *The functionality of GIS*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 319–335.

[Maguire *et al* 1991] Maguire DJ, Goodchild MF & Rhind DW, eds, 1991, *Geographical information systems: Principles and applications*, Longman Scientific & Technical, London, 1096 pp.

[Maling 1991] Maling DH, 1991, *Coordinate systems and map projections for GIS*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 135–146.

[Mandelbrot 1967] Mandelbrot BB, 1967, *How long is the coast of Britain? statistical self-similarity and fractional dimension*, Science, Vol 156, pp 636-638.

[Mather 1976] Mather PM, 1976, *Computational methods of multivariate analysis in physical geography*, Wiley, London.

[McCormac 1985] McCormac JC, 1985, *Surveying*, 2nd Ed, Prentice-Hall Inc, 381 pp.

[Medyckyi-Scott & Board 1991] Medyckyi-Scott D & Board C, 1991, *Cognitive cartography: a new heart for a lost soul*, *in* Müller JC, ed, *Advances in cartography*, International Cartographic Association *and* Elsevier Applied Science, pp 201–230.

[Methley 1986] Methley BDF, 1986, *Computational models in surveying and photogrammetry*, Blackie & Son Ltd, 346 pp.

[Meyer 1990] Meyer B, 1990, *Introduction to the theory of programming languages*, Prentice Hall International Series in Computer Science, 448 pp.

[Miller 1991] Miller HJ, 1991, *Modelling accessibility using space-time prism concepts within geographical information systems*, International Journal of Geographical Information Systems, Vol 5, No 3, pp 287–301.

[Moellering 1985] Moellering H, ed, January 1985, *Digital cartographic data standards: an interim proposed standard*, Report no 6, National Committee for Digital Cartographic Data Standards, 164 pp.

[Moellering 1986] Moellering H, ed, April 1986, *Digital cartographic data standards: a report on evaluation and empirical testing*, Report no 7, National Committee for Digital Cartographic Data Standards, 219 pp.

[Moellering 1987a] Moellering H, ed, January 1987, *A draft proposed standard for digital cartographic data*, Report no 8, National Committee for Digital Cartographic Data Standards, 286 pp.

[Moellering 1987b] Moellering H, May 1987, *A final bibliography for digital cartographic data standards*, Report no 9, National Committee for Digital Cartographic Data Standards, 71 pp.

[Moellering 1991a] Moellering H, ed, 1991, *Spatial database transfer standards: current international status*, International Cartographic Association *and* Elsevier Applied Science, 247 pp.

[Moellering 1991b] Moellering H, 1991, *Cartographic database exchange standards*, *in* Müller JC, ed, *Advances in cartography*, International Cartographic Association *and* Elsevier Applied Science, pp 141–159.

[Moore 1968] Moore WG, 1968, *A dictionary of geography*, 4th Ed, Penguin Reference Books, Harmondsworth, 234 pp.

[Morrison 1991] Morrison JL, 1991, *The organizational home for GIS in the scientific and professional community*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 1: Principles*, Longman Scientific & Technical, London, pp 91–100.

[Mounsey 1991] Mounsey HM, 1991, *Multisource, multinational environmental GIS: lessons learned from CORINE*, *in* Maguire DJ, Goodchild MF & Rhind DW, eds, *Geographical information systems, Volume 2: Applications*, Longman Scientific & Technical, London, pp 185–200.

[Müller 1991] Müller JC, ed, 1991, *Advances in cartography*, International Cartographic Association *and* Elsevier Applied Science, 251 pp.

[NAWG 1985] North American Work Group Committee on the Exchange of Digital Data, 1985, *Proposed format for the exchange of digital hydrographic data*, submitted to the International Hydrographic Organization's Committee on the Exchange of Digital Data.

[NESC 1988] National Exchange Standard Committee, July 1988, *Questionnaire: National Exchange Standard*, Chief Directorate: Surveys and Mapping, 11 pp.

[Newell *el al* 1992] Newell RG, Theriault D & Easterfield M, May 1992, *Temporal GIS — modelling the evolution of spatial data in time*, Computers & Geosciences, Vol 18, No 4, pp 427–433.

[Olivier *et al* 1989] Olivier JJ, Greenwood PH, Cooper AK, McPherson DR & Engelbrecht R, April 1989, *Selecting a GIS*, Proceedings 1989 ASPRS-ACSM Annual Convention, Baltimore USA, Vol 4, pp 102–111.

[Olivier *et al* 1990] Olivier JJ, Greenwood PH, Cooper AK, McPherson DR & Engelbrecht R, November 1990, *Selecting a GIS for a national water management authority*, Photogrammetric Engineering & Remote Sensing, Vol 56, No 11, pp 1471–1475.

[Openshaw *et al* 1990] Openshaw S, Cross A & Charlton M, 1990, *Building a prototype Geographical Correlates Exploration Machine*, International Journal of Geographical Information Systems, Vol 4, No 3, pp 297–311.

[Openshaw & Mounsey 1987] Openshaw S & Mounsey H, 1987, *Geographic information systems and the BBC's Domesday interactive videodisk*, International Journal of Geographical Information Systems, Vol 1, No 2, pp 173–179.

[Oxford 1983] Oxford University, 1983, *The Consise Oxford Dictionary of Current English*, 7th Ed, Oxford University Press, Oxford, 1260 pp.

[Oxford 1989] Oxford University, 1989, *The Oxford English Dictionary*, 2nd Ed, Clarendon Press, Oxford, 20 vols.

[Pascoe & Penny 1990] Pascoe RT & Penny JP, 1990, *Construction of interfaces for the exchange of geographic data*, International Journal of Geographical Information Systems, Vol 4, No 2, pp 147–156.

[Peuquet 1981] Peuquet DJ, 1981, *An examination of techniques for reformatting digital cartographic data, Part 1: the raster-to-vector process*, Cartographica, Vol 18, No 1, pp 34–48.

[Peuquet 1983] Peuquet DJ, 1983, *A hybrid structure for the storage and manipulation of very large spatial data sets*, Computer Vision, Graphics, and Image Processing, Vol 24, pp 14–27.

[Peuquet 1984] Peuquet DJ, 1984, *A conceptual framework and comparison of spatial data models*, Cartographica, Vol 21, No 4, pp 66-113.

[Radack 1992] Radack S, October 1992, *Personal electronic mail to AK Cooper*, 1 pp.

[Raymond 1991] Raymond ES, ed, 1991, *The new hacker's dictionary*, The MIT Press, Cambridge, Mass, 433 pp.

[Rhind 1988] Rhind DW, July 1988, *Personality as a factor in the development of a discipline: the example of computer-assisted cartography*, The American Cartographer, Vol 15, No 3, pp 277–289.

[Rhind 1989] Rhind DW, March 1989, *Geographical and land information systems: their relationship, shortcomings and future prospects*, Proceedings Ninth Conference of Southern African Surveyors, Cape Town RSA, Vol 1, pp 6.1.1–6.1.12.

[Richardus & Adler 1972] Richardus P & Adler RK, 1972, *Map projections for geodesists, cartographers and geographers*, North-Holland, Amsterdam.

[Ritchie 1992] Ritchie DM, April 1992, *Discussions held with the Division of Information Services, CSIR*, at CSIR, Pretoria.

[Rossmeissl & Rugg 1991] Rossmeissl HJ & Rugg RD, 1991, *The United States spatial data transfer standard*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 204–216.

[Rugg & Schmidt 1986] Rugg RD & Schmidt WE, September 1986, *Digital cartographic data feature standards in the United States*, Proceedings Auto Carto London, Vol 1, pp 340–349.

[Salgé 1991] Salgé F, 1991, *La normalisation des échanges d'informations géographiques en France*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 85–98.

[Scheepers 1987a] Scheepers CF, October 1987, *Polygon shading on vector type devices* Quæstiones Informaticæ, Vol 5, No 2, pp 46–55.

[Scheepers 1987b] Scheepers CF, November 1987, *'n Vektorbenadering tot grafiese voorstelling in rekenaar-ondersteunde kartografie*, MSc thesis (unpublished), Randse Afrikaanse Universiteit, *also* CACDS CSIR Technical Report TWISK 571, 168 pp.

[Scheepers 1988] Scheepers CF, March 1988, *Computer-assisted map symbolism*, Proceedings 1988 ASPRS-ACSM Annual Convention, St Louis USA, Vol 2, pp 47–56.

[Scheepers 1989] Scheepers CF, April 1989, *Vector-based computer graphics in automated map compilation*, Proceedings Auto Carto 9, Baltimore USA, pp 724–734, *also* CACDS CSIR Technical Report PKOMP 88/20, 16 pp.

[Scheepers & Van Biljon 1985] Scheepers CF & Van Biljon WR, August 1985, *Symbology: formal specifications and implementation strategy*, NRIMS CSIR Internal Report I643, 30 pp.

[Scheepers *et al* 1986] Scheepers CF, Van Biljon WR & Cooper AK, September 1986, *Guidelines to set up a classification for geographical information*, NRIMS CSIR Internal Report I723, 12 pp.

[Shand & Moore 1989] Shand PJ & Moore RV, eds, 1989, *The Association for Geographic Information Yearbook 1989*, Taylor & Francis *and* Miles Arnold, 423 pp.

[Shetler 1990] Shetler T, February 1990, *Birth of the BLOB*, BYTE, Vol 15, No 2, pp 221–226.

[Sippl & Sippl 1974] Sippl CJ & Sippl CP, 1974, *Computer dictionary*, 2nd Ed, Howard W Sams, 488 pp.

[Short 1982] Short NM, 1982, *The LANDSAT tutorial workbook: basics of satellite remote sensing*, NASA Reference Publication 1078, NASA Scientific and Technical Information Branch, Washington DC, 553 pp.

[Smith 1992] Smith B (smithb@durer.cme.nist.gov), June 1992, *ISO standards process, posted to the Usenet newsgroup* `comp.std.internat`, 193 lines.

[Snyder 1984] Snyder JP, 1984, *Map projections used by the US Geological Survey*, 2nd Ed, US Geological Survey Bulletin 1532, United States Government Printing Office, Washington, DC, 313 pp.

[Snyder 1987] Snyder JP, 1987, *Map projections — a working manual*, U S Geological Survey professional paper 1395, United States Government Printing Office, Washington, DC, 383 pp.

[Sowton & Haywood 1987] Sowton M & Haywood P, chair, January 1987, *The national transfer format release 1.0*, Ordnance Survey, Southampton.

[Sowton 1991a] Sowton M, 1991, *The National Transfer Format*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 191–203.

[Sowton 1991b] Sowton M, 1991, *CERCO considerations concerning an European Transfer Format*, *in* Moellering H, ed, *Spatial database transfer standards: current international status*, International Cartographic Association & Elsevier Applied Science, pp 217–222.

[SAA 1981] Standards Association of Australia, August 1981, *Interchange of feature coded digital mapping data*, Australian Standard 2482-1981, 24 pp.

[Standards Committe 1990] Standards Committee, April 1990, *The standard for data for the National Land Information System, Version 1.0*, Standards Committee of the Co-ordinating Committee of the National Land Information System, CCNLIS Publication No 2, 19 pp.

[Standards Committee 1991] Standards Committee, November 1991, *National standard for the exchange of digital geo-referenced information, Version 2.0*, Standards Committee of the Co-ordinating Committee of the National Land Information System, CCNLIS Publication No 1.

[Stevens 1946] Stevens SS, 1946, *On the theory of scales of measurement*, Science, Vol 103, pp 677–680.

[Stuart 1992] Stuart N, 1992, *Book review: Time in geographic information systems, by Langran G*, International Journal of Geographical Information Systems, Vol 6, No 6, pp547.

[Tomlinson 1972] Tomlinson RF, ed, 1972, *Geographic data handling*, Commission on Geographical Data Sensing and Processing, International Geographical Union, Ottawa, Canada.

[Tomlinson 1988] Tomplinson RF, 1988, *The impact of the transition from analogue to digital cartographic representation*, The American Cartographer, Vol 15, No 3, pp 249–261.

[Tomlinson *et al* 1976] Tomlinson RF, Calkins HW & Marble DF, 1976, *Computer handling of geographical data*, Natural Resources Research Series XIII, UNESCO Press, Paris.

[Ullman 1980] Ullman JD, 1980, *Principles of database systems*, Pitman, London, 379 pp.

[USGS 1984] U S Geological Survey, 1984, *USGS Digital Cartographic Data Standards*, Geological Survey Circulars 895-A to 895-G.

[Vaktaalkommissie 1965] Vaktaalkommissie, 1965, *Opmeetwoordeboek / Survey dictionary*, Suid-Afrikaanse Akademie vir Wetenskap en Kuns, Pretoria, 91 pp.

[Van Biljon 1987a] Van Biljon WR, March 1987, *A geographic database system*, Proceedings Auto Carto 8, Baltimore USA, pp 689–700.

[Van Biljon 1987b] Van Biljon WR, September 1987, *Towards a fuzzy mathematical model of data quality in a GIS*, Proceedings EDIS '87 Conference, Pretoria SA, 11 pp.

[Van Roessel 1987] Van Roessel JW, 1987, *Design of a spatial data structure using the relational normal forms*, International Journal of Geographical Information Systems, Vol 1, No 1, pp 33–50.

[Van Rooyen & Boerstra 1987] Van Rooyen MH & Boerstra J, September 1987, *Topology in geographical information systems*, Proceedings EDIS '87 Conference, Pretoria SA, 14 pp.

[Wang *et al* 1990] Wang F, Hall GB & Subaryono, 1990, *Fuzzy information representation and processing in conventional GIS software: database design and application*, International Journal of Geographical Information Systems, Vol 3, No 3, pp 261–283.

[White 1984] White MS, 1984, *Technical requirements and standards for a multipurpose geographic data system*, The American Cartographer, Vol 11, No 1, pp 15–26.

[Yen & Kelly 1980] Yen EH & Kelly RF, 1980, *A graphics glossary*, Grumman Data Systems Corporation.

Colophon

The text in this version of my MSc dissertation is the same as for the final version submitted in June 1993, though the formatting in this version differs in places from the printed version as submitted, because of the changes to LaTeX over the last 17 years. Three of the images had to be rescanned, so their quality is not ideal.

This version was produced using TeXnicCenter, version 1.0 Stable Release Candidate 1; MikTex, version 2.9; pdfTeX, version 3.1415926-1.40.11; dvips, version 5.99; Ghostscript, version 9.01; and related software. The document class is book with 11pt, a4paper and dvips. The packages used are graphicx, subfig and breaksit.

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