An Introduction to GEOGRAPHICAL INFORMATION SYSTEMS

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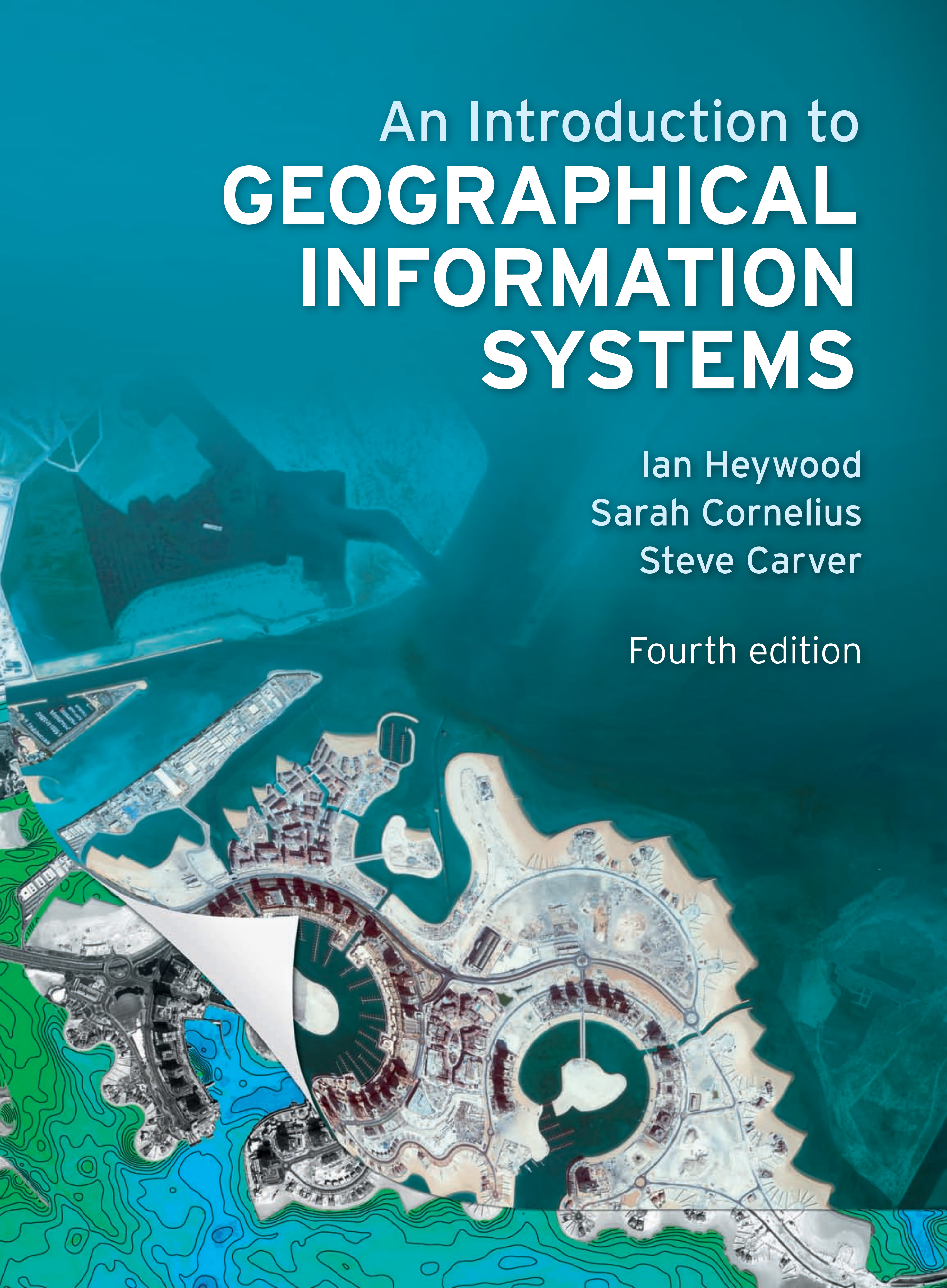
Fourth edition



An Introduction to

GEOGRAPHICAL INFORMATION SYSTEMS

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INTRODUCTION

Data about our world are produced continuously. They are being collected by remote sensing satellites; from automatic environmental monitoring equipment; during automated business transactions; and by individuals engaged in research and survey work. A large proportion of these data are managed in databases. In your own discipline there are undoubtedly databases under construction and in current use, holding data in text, numeric and multimedia formats. For example:

- An archaeologist might use the British and Irish Archaeological Bibliography to obtain information about research into Neolithic sites in Scotland.
- An architecture student might refer to an American database containing images of buildings and cities to help with a design project on the American Mid-West.
- A business manager might source information on economic outlook from a statistical database such as OECD.
- A soil scientist might consult the Soil Geographical Database of Europe to assist research into soil properties.
- A population research group may maintain a database of research projects on the Web, which users update themselves with details of new projects.

Many of our everyday activities also produce data that automatically find their way into databases. Imagine, for example, purchasing some new ski equipment from a major sports retailer. If you paid by credit card, debit card or cheque, the data in your bank's database would be updated. If the bar code on the item you purchased was scanned, information in the store's database would be updated and might trigger reordering from a supplier's database. Information from the guarantee card you complete and send back by post may trigger a marketing database to start sending targeted mail to you. If you used a store card to make your purchase, extra data about your buying habits are now available, and the store can also target mail to you. Four, or even more, databases may be updated as a result of one purchase. Since each database holds your address, your postal code may be used as a spatial reference to link these new data to other data in a GIS.

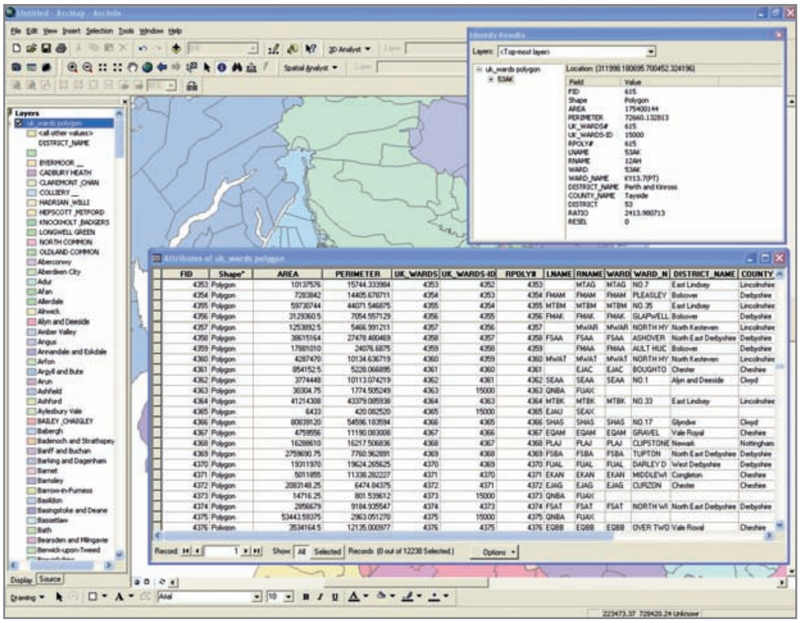
The ski-buying example illustrates the amount of data which may be generated by one sales transaction. Scaling this up to consider the data generated by all the sales transactions in a day begins to give an idea of the amount of data that our society is generating. These data, if transformed into information, are a valuable resource, which can be traded in the same way that commodities were traded in the past. Market research companies now sell information about the characteristics of the population; environmental agencies sell information relating to nature conservation; and mapping agencies sell topographic information. We are in an age where the information resource will not run out; rather the problem is that we have too much of it. We need to be able to manage and share data and information efficiently to realize their value. One method of management is to use a database. Once the data are in a database you can list them in an order most appropriate for you, and undertake searches for specific information. For example, a bibliographic database can be searched using key words. The results can be sorted by date or author's surname. In many cases you can perform additional operations on the database. For example, using an online library database, it may be possible to reserve or renew books. Linking databases to GIS to provide additional spatial capabilities can further enhance the value of data and provide useful information.

Large organizations such as utilities, multinational companies, retailers and government agencies have adopted GIS for a whole range of applications, from automated mapping and facilities management (AM/FM) to decision support applications. An important issue for successful implementation of many of these new systems is their ability to integrate GIS with existing internal databases. Many of these existing databases (managing customer databases, inventories of parts or financial information) are relational, as the relational database approach to data management has permeated all sectors of the business world. These business databases may be data sources for GIS, or be required to integrate with GIS for decision support within the framework of a larger organizational 'information management strategy'. Issues of database management for large-scale, corporate applications of GIS are addressed in this chapter. The demands of large-scale applications are examined, along with the strengths and weaknesses of the current database approaches.

First, this chapter considers the conceptual and theoretical ideas behind databases in order to explain why they are used and how they work. Whichever type of GIS is being used, an understanding of databases is important. This chapter will introduce the main types of database in current use and explain their characteristics, advantages and disadvantages. As the relational database is the most commonly used at present, the steps involved in establishing a relational database will be discussed in some detail.

Terminology recap

In GIS, there are two types of data to be managed: spatial data and attribute data. An entity (point,



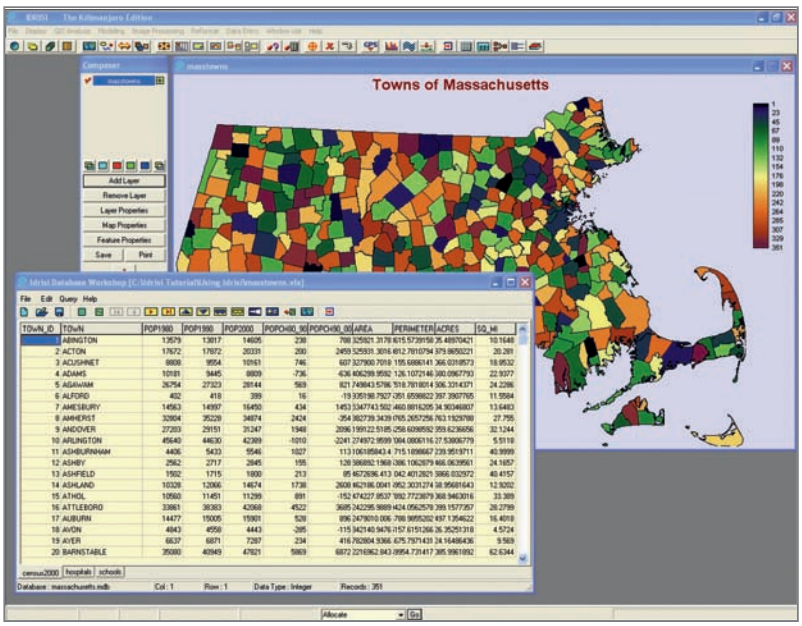


Figure 4.1 Database facilities in GIS
Sources: (a) Screenshot shows the Esri Graphical User Interface (GUI). ArcMap/ArcView/ArcInfo Graphical User Interface is the intellectual property of Esri and is used herein with permission.Copyright © 2011 Esri all rights reserved; (b) IDRISI interface used by permission of Clark Labs, Clark University

line or area) has both spatial and attribute data to describe it (**Chapter 2**). Put simply, spatial data are the 'where things are' data and attribute data the 'what things are'. For example, a latitude and longitude reference gives the location of a point entity and to accompany this there would be attribute data about the nature of the real-world feature the point represents. If the point were a city in a global cities database, then the attribute information stored might include the city name, the country in which the city is situated and up-to-date population figures.

Conventionally, databases have stored only non-spatial entities; however, all entities in GIS are spatial. As a result the conventional database has been adapted to GIS in various ways. Some GIS are good at handling attribute data; some rely on links with conventional databases; and others have very limited database capabilities but good analysis facilities. Figure 4.1 shows some of the database facilities in some common GIS.

Databases offer more than just a method of handling the attributes of spatial entities; they can help to convert data into information with value. **Chapter 2** introduced the concept that data are raw facts that have little value without structure and context. A single number, for example '10', is data. With some explanation, this number becomes information. 'Ten degrees Celsius' is information, since now there is some meaning that can be interpreted by a user. Information results from the analysis or organization of data, and, in a database, data can be ordered, re-ordered, summarized and combined to provide information. A database could be used to sort a range of temperature values into order; to calculate maximum and minimum values or average temperature; show the temperature for a particular date; or to convert degrees Celsius to degrees Fahrenheit. With the additional mapping capabilities of a GIS, the locations of the points at which the temperatures have been monitored could be mapped, thus adding further value to the original data. Decision makers using GIS need information, not data, so a database offers one method of providing that information by organizing data into a more meaningful and usable form.

There are nearly as many definitions of a database as there are of GIS. Perhaps the simplest definition is that a database is a set of structured data. An organized filing cabinet is a database, as is a dictionary, telephone directory or address book. Thus, databases can be computer-based or manual.

WHY CHOOSE A DATABASE APPROACH?

Elsewhere in this book are examples of the difficulties faced when handling spatial data manually (see especially **Chapter 9**). Problems can also be encountered when processing attribute data manually. Imagine Happy Valley, the ski resort, as it might have been in the days before computerized databases. Different organizations and companies within the resort could be producing and using similar data for different purposes. There are ski schools, hotels and travel companies, all handling data such as clients' names and addresses and details of where they are staying. All these data are stored in different formats and separately by each organization. A box file may be used by one organization, a set of index cards by another and a third may have the data stored in the head of one of the employees! Each organization uses the data for different purposes: the ski school for booking lessons; the hotels for booking rooms; and the travel companies for arranging flight details and allocating hotels. The situation is illustrated schematically in Figure 4.2.

There is considerable duplication of data using traditional data management approaches. For example, a single visitor's address may be held three times, once by the travel company, then again by the hotel and ski school. It is likely that there will be errors made during the transcription and copying of an address, or even that different parts of the address will be held or omitted in each case. If a visitor changes their home address, they may remember to tell the travel company, but forget to tell the hotel or the ski school. Thus, different versions of the data could exist in the three companies. Errors are inevitable, and there is considerable effort involved in handling the data. Difficulties would be encountered if the organizations attempted to share their data. Even if the data were in computer files of one sort or another, there might be incompatibilities in data

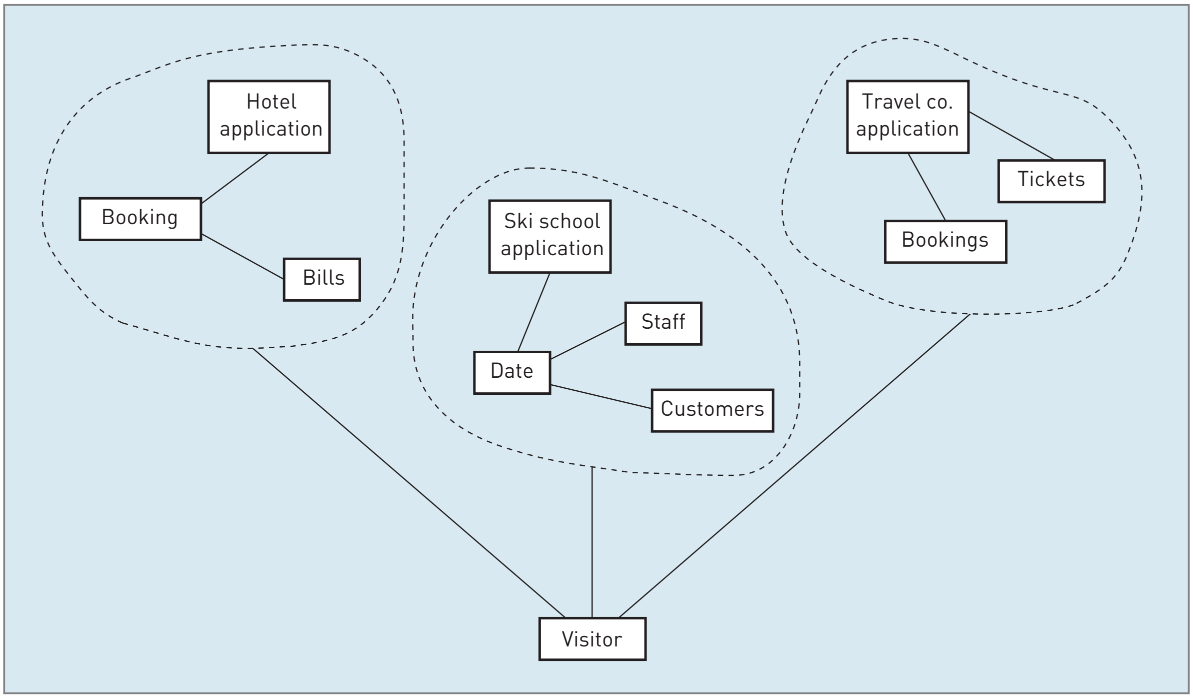


Figure 4.2 The traditional approach to data handling. A different version of the visitor's details may be stored in each of the separate databases

formats which would prevent efficient data exchange.

Date (1986) summarizes the problems with the traditional approach to data management as:

- redundancy (the unnecessary repetition or duplication of data);
- high maintenance costs;
- long learning times and difficulties in moving from one system to another;
- the possibility that enhancements and improvements to individual files of data will be made in an *ad hoc* manner;
- data-sharing difficulties;
- a lack of security and standards; and
- the lack of coherent corporate views of data management.

In addition, the data storage mechanisms may be inflexible, creating difficulties in dealing with *ad hoc* 'one-off' queries. Oxborrow (1989) also identifies the problem of modelling the real world with traditional data management methods – many are simply not suitable. Data should be structured in such a way that they represent features from the real world and the relationships between them. Traditional methods of storing data cannot represent these relationships, so a database approach is necessary.

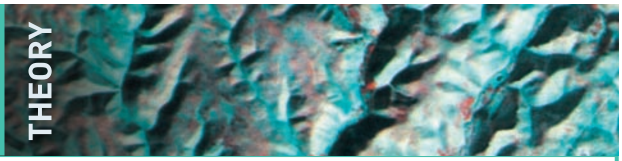
The database approach

A database is a simply a collection of related data. This can include non-computerized data such as those found in a telephone directory or address book. A generally accepted feature of data in a database is that they can be shared by different users (Stern and Stern, 1993). Data within a database are also organized to promote ease of access and prevent unnecessary duplication. In a paper-based telephone directory the entries are organized, usually alphabetically by surname, to allow ease of access to different users. However, there are problems with this paper-based database. It is not possible to search by first name, or using only part of an address. It is not possible to extract a list of all those people who live in a particular district. There is no security, as anyone who can read can access the information (the only security mechanism is to be ex-directory, then the data set is incomplete). It is not possible to adapt the telephone book for other uses, such as direct mailing. Updating requires expensive and time-consuming reprinting. A computer approach can overcome these problems. Some of the most often cited advantages of computer-based databases are summarized in Box 4.1. The electronic telephone directory enquiry service available in most countries provides an example of a computerized database.

Database management systems

The data in a computer database are managed and accessed through a database management system (DBMS). Individual application programs will access the data in the database through the DBMS. For example, to book a new client's ski lessons, the

BOX 4.1 Advantages of computer-based databases



Imagine that there is a box containing index cards with the names, addresses and telephone numbers of all the ski school clients in Happy Valley, together with details of the ski lessons they have undertaken. A single index card is held for each individual, and cards are stored alphabetically by surname in the box. A typical card is shown in Figure 4.3.

If the data from the cards are transferred to a computer database, the following benefits could be achieved:

1 *Different data access methods will be possible*. Data can be accessed by country of residence or lessons undertaken, not just surname of client as in the index box.

2 *Data are stored independently of the application for which they will be used*. The database may have been established to assist the sending of bills to clients. However, the database could also be used to produce mailing lists for the promotion of special events, or for summarizing client data (where clients came from, number of beginners courses undertaken, number of one-off lessons) for annual reports.

Surname	Smith
First name	Jane
Home Address	12 High Street, Northton, Northtonshire, NN1 1NN
Telephone No.	~~0181 234 443~~ 020 8222 442
Lessons taken	Beginners 1 week course (Jan 2001) Private lesson × 2 (March 2002)

Figure 4.3 Card index record from ski school manual database

3 *Redundancy (the unnecessary duplication of data) will be minimized*. In a paper-based records system it may have been necessary to keep two sets of records for one client. For example, when one index card is full, another one may be started and the old one left behind. Alternatively, should a client change address, a new card may be added, and the old one not removed.

4 *Access to data will be controlled and centralized*. A card index box kept on a desk is not very secure, and, unless it can be locked, can be viewed by anyone in the office. A computer database can have security built in – passwords can prevent access to all or part of the information, or to functions that will allow the updating or deletion of data. Allowing only one individual to access the raw data for updates and changes will also improve the reliability of the data.

5 *A computer database is relatively easy to maintain and updating is possible*. The cards in the index box will soon become unreadable if clients' details change repeatedly. The computer version will prevent problems caused by unreadable text, and allow efficient updating.

6 *Simple query systems and standardized query languages are available*. Queries, such as 'which clients have completed advanced training courses?', or 'how many Americans have taken training courses?' would be time-consuming with the card index box. A computerized system will offer simple query methods, or a standardized query language.

Datasets and activities relating to the Happy Valley Case Study can be found online at **www.pearsoned.co.uk/ heywood**.

Sources: Oxborrow (1989); Healey (1991) booking clerk will use an application produced using capabilities offered by the DBMS. This will instruct them to fill in a data entry form, which will then automatically update data in the database. The clerk will not need to interact with the database directly or understand how data are structured within the database. A conceptual view of the Happy Valley data as they might be organized for such a computer database, and the role of the DBMS, is shown in Figure 4.4 (adapted from Reeve, 1996).

There are many definitions of a DBMS. Dale and McLaughlin (1988) define a DBMS as a computer program to control the storage, retrieval and modification of data (in a database). Stern and Stern (1993) consider that a DBMS will allow users to join, manipulate or otherwise access the data in any number of database files. A DBMS must allow the definition of data and their attributes and relationships, as well as providing security and an interface between the end users and their applications and the data itself. From such definitions the functions of a DBMS can be summarized as:

- file handling and file management (for creating, modifying or deleting the database structure);
- adding, updating and deleting records;
- the extraction of information from data (sorting, summarizing and querying data);
- maintenance of data security and integrity (housekeeping, logs, backup); and
- application building.

The overall objective of a DBMS is to allow users to deal with data without needing to know how the data are physically stored and structured in the computer. To achieve this, DBMS usually comprise

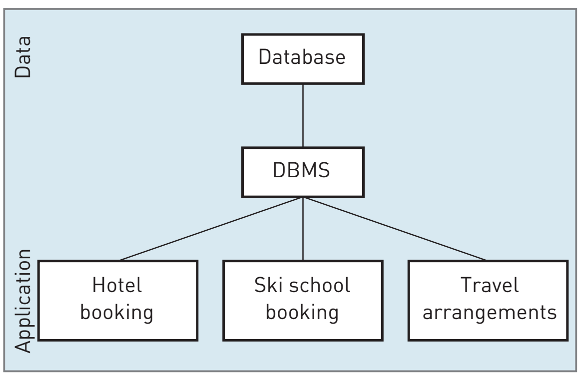


Figure 4.4 The database approach to data handling

software tools for structuring, relating and querying data; tools for the design of data entry and report forms; and application generators for the creation of customized applications.

A DBMS manages data that are organized using a database data model. This is analogous to the way in which spatial data are organized in a GIS according to a spatial data model (for example, raster or vector). Database data models for GIS are similar to those used for databases elsewhere.

DATABASE DATA MODELS

There are a number of different database data models. Amongst those that have been used for attribute data in GIS are the hierarchical, network, relational, object-relational and object-oriented data models. Of these the relational data model has become the most widely used and will be considered in detail here, whilst the models based on objects are growing in popularity. Further details of the hierarchical and network models can be found in older GIS texts (Aronoff, 1991; Bernhardsen, 1999; DeMers, 2005).

The Relational Database Model

At present the relational database model dominates GIS. Many GIS software packages link directly to commercial relational database packages, and others include their own custom-designed relational database software. Some GIS use a relational database to handle spatial as well as attribute data.

The relational data model is based on concepts proposed by Codd (1970). Data are organized in a series of two-dimensional tables, each of which contains records for one entity. These tables are linked by common data known as *keys*. Queries are possible on individual tables or on groups of tables. For the Happy Valley data, Figure 4.5 illustrates an example of one such table.

Each table in a relational database contains data for one entity. In the example in Figure 4.5 this entity is ‘hotel’. The data are organized into rows and columns, with the columns containing the attributes of the entity. Each of the columns has a distinctive name, and each of the entries in a single column must be drawn from the same domain (where a domain may be all integer values, or dates