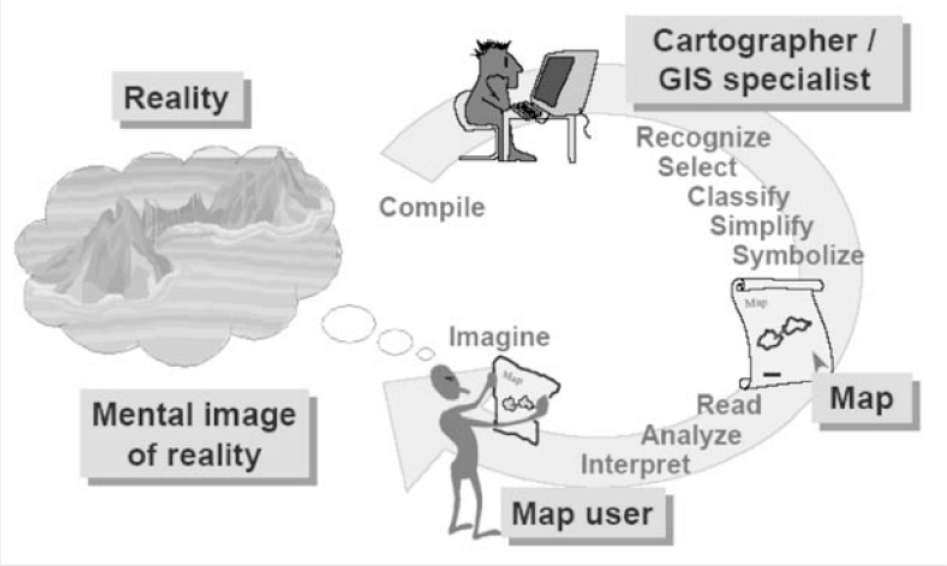
Chapter 1

Geographical Information Systems — Representing Geography



- Geographic importance
  - Almost everything that happens or exists occurs ‘somewhere’. Knowing ‘where’ it happened or existed is critically important.
  - All human activities require knowledge about the Earth, thus geographic location is very important.
- Spatial Information Technology is the outcome of developments in computer technology.
- Internet and computerization has opened a vast new potential in the way we perceive, communicate and analyze our surrounding spatial phenomena.
- Data representing the real world can be stored, processed and presented in relatively simplified forms to suit specific needs. This provides base for geographical information system.

- Geographical information allows us to apply general principles to the specific conditions of each location, allows us to track what is happening at any place, and helps us to understand how one place differs from another (Figure 1.1).
  - Geographical information, then, is essential for effective planning and decision making.

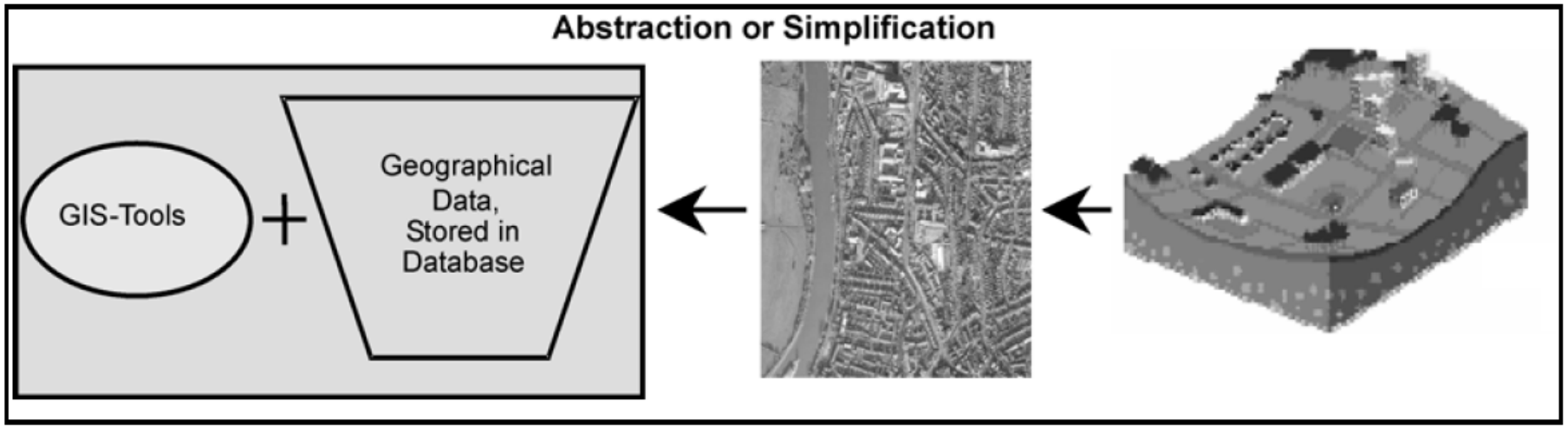


Figure 1.1: GIS builds database those results from data processing of real world informations.

Box 1: General questions with geographic importance

Every day people pose questions

- Where is GURGAON ?
- What are the soil characteristics there ?
- What is the land use pattern in Gurgaon District ?
- Which is the main economic activity in Gurgaon District ?
- What are the trends in rural and urban employment pattern in Gurgaon District ?
- Where would be a better location for opening a restaurant in Gurgaon District ?
- Which is the shortest route to reach Gurgaon from New Delhi railway station?

Almost everything that happens or exists occurs 'somewhere'. Knowing 'where' it happened or existed is critically important.

All human activities require knowledge about the Earth, thus geographic location is very important.

- If we can express the contents of a map or image in digital form, the power of the computer opens an enormous range of possibilities for communication, analysis, modelling, and accurate decision making (Figure 1.2).
- We must constantly be aware of the fact that the digital representation of geography is not equal to the geography itself- any digital representation involves some degree of approximation.

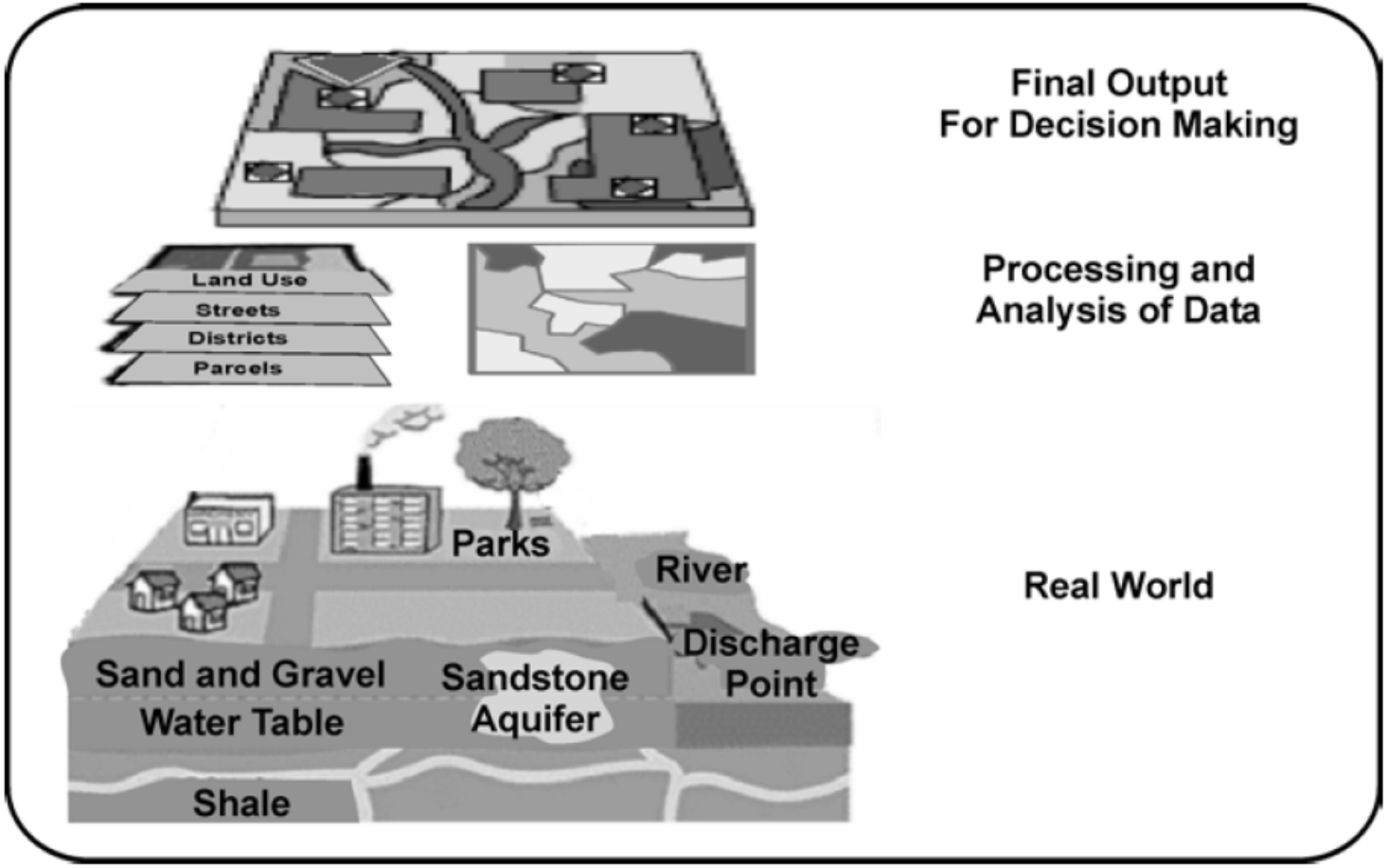


Figure 1.2: GIS simplifies the real world informations to bring it into computer. Different techniques are used to analyze data for decision making.

INFORMATION TECHNOLOGIES IN GEOGRAPHY

Discipline-Specific Tools

- 1. *Cartography and Computer:* Assisted Drafting:
  - Computers offer the same advantages to cartographers that word-processing software offers writers.
  - Automated techniques are now the rule rather than the exception in cartographic production.
- 2. *Photogrammetry and Remote Sensing:*
  - Aerial photogrammetry, a well – established technique for cartographic production and geographic analysis, is now complemented by the use of 'remotely sensed' information gathered by satellites in outer space.
  - Information technologies have made both sorts of information far more readily available and far easier to use.

- 3. *Spatial Statistics:*
  - Statistical analysis and modelling of spatial patterns and processes have long relied on computer technology.
  - Advances in information technology have made these techniques more widely accessible and have allowed models to expand in complexity and scale to provide more accurate depictions of real-world processes.
- 4. *Geographic Information Systems (GIS):*
  - These systems allow geographers to collate and analyze information far more readily than is possible with traditional research techniques.
  - GIS can be viewed as an integrating technology insofar as it draws upon and extends techniques that geographers have long used to analyze natural and social systems.

General Communication, Research, and Publication Technologies

- 1. *Communication and Collaboration:*
  - Electronic mail, discussion lists, and computer bulletin boards make it far easier for colleagues to communicate ideas and share ideas, locally, nationally, and internationally.
  - Distance – learning techniques make it possible to hold interactive classes and workshops simultaneously at distant locations.
- 2. *Access to Library and Research Materials and Sources:*
  - Network access to both primary and secondary research resources is expanding rapidly.
  - From their offices, scholars can now get information held by libraries, government agencies, and research institutions all over the world.

- 3. *Publication and Dissemination:*
  - Information technologies are reducing substantially the cost of publishing and distributing information as well as reducing the time required to circulate the latest news and research results.

THE COURSE OF TECHNOLOGICAL INNOVATION

Four phases of the technological innovation

- 1. *Initiation:* An innovation first becomes available.
- 2. *Contagion:*
  - Far-ranging experimentation follows to see how the innovation can be adapted to meet a wide variety of research and commercial needs.
  - Some, but not necessarily all of these experiments will work.
- 3. *Coordination:*
  - The most promising applications of the innovation gradually gain acceptance and are developed collaboratively.
  - The coordination of experimentation helps to distribute the potentially high costs of further development and implementation.
- 4. *Integration:* An innovation is accepted and integrated into routine research tasks.

Four phases of Innovations in geography

- 1. *Initiation:*
  - Late 1950s, 1960s and early 1970s.
  - Methods of sophisticated mathematical and statistical modelling were developed and the first remote sensing data became available.
- 2. *Contagion:*
  - The mid-1970s to early 1990s.
  - The first commercially available software for GIS became available in the late 1970s and spurred many experiments.
- 3. *Coordination:*
  - Early 1990s, or perhaps just a bit earlier.
  - The strengths and weaknesses of many information technologies were by then apparent, and researchers began to work together to cultivate the most promising applications on a large scale.

- 4. *Integration:*
  - Arguably, the complete integration of information technologies in geography has yet to be achieved except perhaps in a few relatively specialized research areas.
  - Complete integration across the discipline may, in fact, be many years away.

GIS as an Integrating Technology

- In the context of the innovations, geographic information systems have served an important role as an integrating technology.
  - Rather than being completely new, GIS have evolved by linking a number of discrete technologies into a whole that is greater than the sum of its parts.
  - With GIS it is possible to map, model, query, and analyze large quantities of data all held together within a single database.
- The development of GIS has relied on innovations made in many different disciplines:
  - Geography, Cartography, Photogrammetry, Remote Sensing, Surveying, Geodesy, Civil Engineering, Statistics, Computer Science, Operations Research, Artificial Intelligence, Demography, and many other branches of the social sciences, natural sciences, and engineering have all contributed.

GEOGRAPHIC INFORMATION SYSTEMS: A GENERIC DEFINITION

- GIS is a special-purpose digital database in which a common spatial coordinate system is the primary means of reference.
- Comprehensive GIS require a means of:
  - 1. Data input, from maps, aerial photos, satellites, surveys, and other sources.
  - 2. Data storage, retrieval, and query.
  - 3. Data transformation, analysis, and modelling, including spatial statistics.
  - 4. Data reporting, such as maps, reports, and plans.
- THREE OBSERVATIONS SHOULD BE MADE ABOUT THIS DEFINITION
  - First, GIS are related to other database applications, but with an important difference.
    - GIS database uses geo-references as the primary means of storing and accessing information.

- Second, GIS integrates technology.
- Third, GIS, with its array of functions, should be viewed as a process rather than as merely software or hardware.
  - GIS are for making decisions.

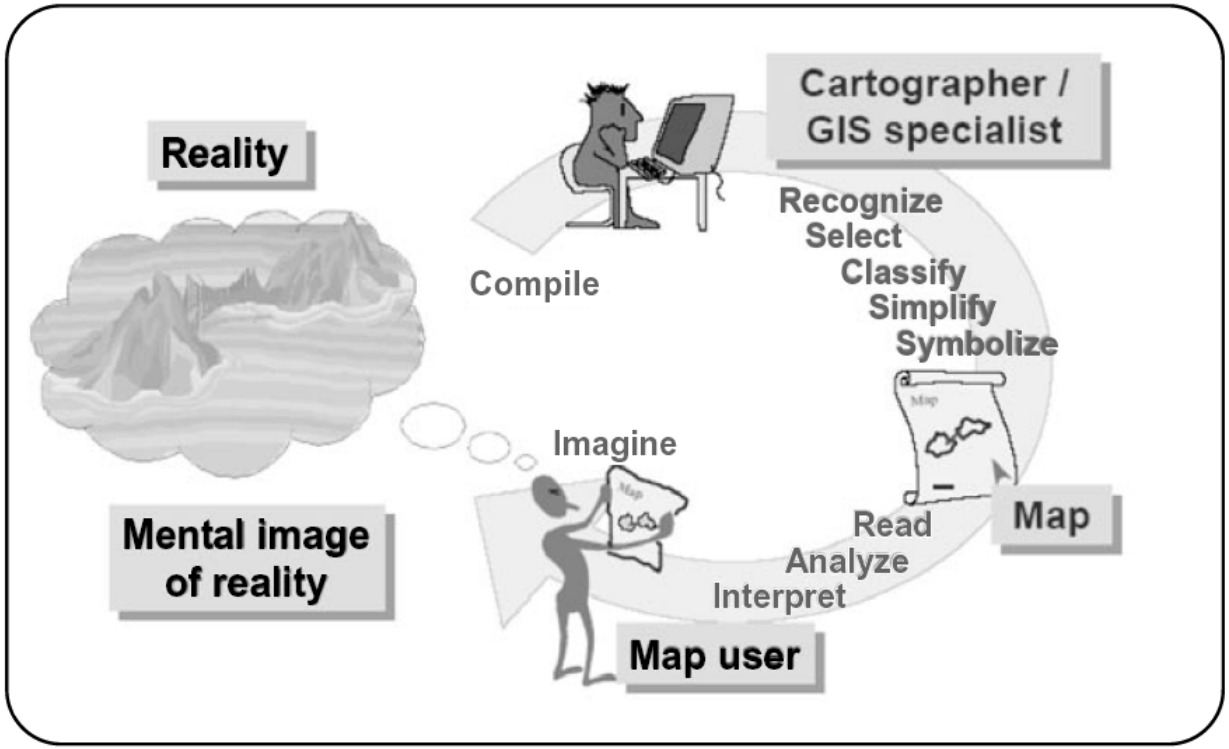


Figure 1.3: Different stages of information transfer in GIS.

What Actually GIS is?

- GIS can be defined as *'A system for Capturing, storing, checking, integrating, manipulating, analysing and displaying data which are spatially referenced to the Earth. This is normally considered to involve a spatially referenced computer database and appropriate applications software'.*
- Geographic Information System (GIS) can also be defined as: The organized activity by which people
  - Measure aspects of geographic phenomena and processes;
  - Represent these measurements, usually in the form of a computer database, to emphasize spatial themes, entities, and relationships;
  - Operate upon these representations to produce more measurements and to discover new relationships by integrating disparate sources; and

- Transform these representations to conform to other frameworks of entities and relationships.

- These activities reflect the larger context (institutions and cultures) in which these people carry out their work.

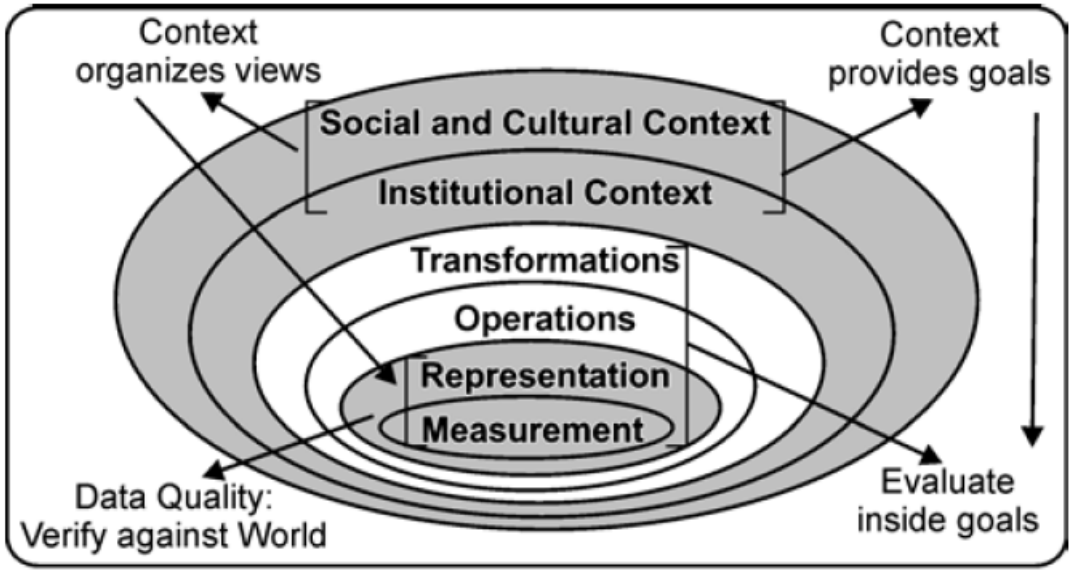


Figure 1.4: GIS framework.

Other definitions

- A definition quoted in William Huxhold's Introduction to Urban Geographic Information Systems:
  - *'. . . The purpose of a traditional GIS is first and foremost spatial analysis. Therefore, capabilities may have limited data capture and cartographic output. Capabilities of analyses typically support decision making for specific projects and / or limited geographic areas. The map data-base characteristics (accuracy, continuity, completeness, etc.) are typically appropriate for small-scale map output. Vector and raster data interfaces may be available. However, topology is usually the sole underlying data structure for spatial analyses.'*

- C. Dana Tomlin’s definition, from Geographic Information Systems and Cartographic Modelling:
  - *‘A geographic information system is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. This is a broad definition . . . a considerably narrower definition, however, is more often employed. In common parlance, a geographic information system or GIS is a configuration of computer hardware and software specifically designed for the acquisition, maintenance, and use of cartographic data.’*

- From Jeffrey Star and John Estes, in Geographic Information Systems: An Introduction:
  - *'A geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-reference data, as well [as] a set of operations for working with data . . . In a sense, a GIS may be thought of as a higher-order map.'*
- In the range of definitions presented, different emphases are placed on various aspects of GIS.
  - Some miss the true power of GIS, its ability to integrate information and to help in making decisions.
  - But all include the essential features of spatial references and data analysis.

THE GIS VIEW OF THE WORLD

- GIS provide powerful tools for addressing geographical and environmental issues.
- In the case below, a set of maps that will be helpful for urban transportation planning have been gathered.

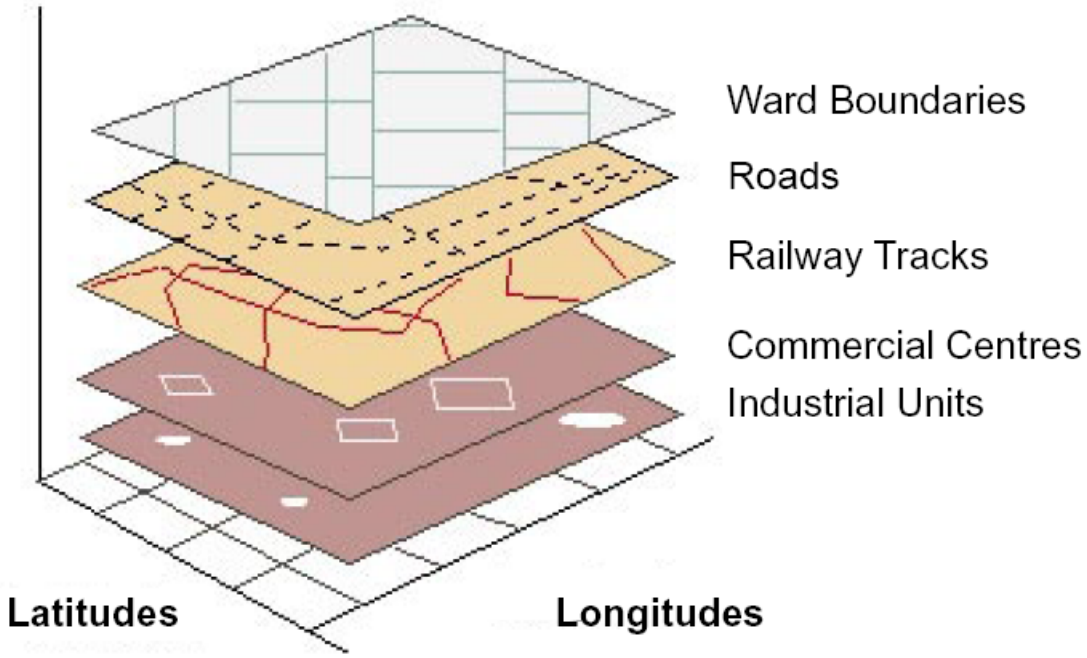


Figure 1.5: GIS: an integrating technology.

- Each of these separate thematic maps is referred to as a **layer, coverage, or level.**
- Each layer has been carefully overlaid on the others so that every location is precisely matched to its corresponding locations on all the other maps.
- The bottom layer of this diagram is the most important, for it represents the grid of a locational reference system (such as latitude and longitude) to which all the maps have been precisely registered.

WHY IS GIS IMPORTANT?

- 'GIS technology is to geographical analysis what the microscope, the telescope, and computers have been to other sciences.... (It) could therefore be the catalyst needed to dissolve the regional-systematic and human-physical dichotomies that have long plagued geography' and other disciplines which use spatial information.
- GIS integrates spatial and other kinds of information within a single system – it offers a consistent framework for analyzing geographical data.
- By putting maps and other kinds of spatial information into digital form, GIS allows us to manipulate and display geographical knowledge in new and exciting ways.

- GIS makes connections between activities based on geographic proximity
  - looking at data geographically can often suggest new insights, explanations.
  - these connections are often unrecognized without GIS, but can be vital to understanding and managing activities and resources.
  - *e.g.* we can link toxic waste records with school locations through geographic proximity.
- GIS allows access to administrative records – property ownership, tax files, utility cables and pipes – via their geographical positions.
- Maps are fascinating and so are maps in computers and there is increasing interest in geography and geographic education in recent times. GIS gives a ‘high tech’ feel to geographic information.

Box 2: Definitions of GIS and the groups who find them useful.

A container of maps in digital form	the general public
A computerized tool for solving geographic problems	decision makers, planners
A spatial decision support system	managers, operations researchers
A mechanized inventory of geographically distributed features	utility managers, resource managers
A tool for revealing what is otherwise invisible in geographic information	scientists, investigators
A tool for performing operations on geographic data that are too tedious if performed by manual methods	resource managers, planners, GIS experts

CONTRIBUTING DISCIPLINES

- Geography:
  - Geography is broadly concerned with understanding the world and man's place in it.
  - The discipline of geography provides techniques for conducting spatial analysis and a spatial perspective on research.
- Cartography:
  - Cartography is concerned with the display of spatial information.
  - Cartography provides long tradition in the design of maps which is an important form of output from GIS.
    - Computer cartography (also called 'digital cartography', 'automated cartography') provides methods for digital representation and manipulation of cartographic features and methods of visualization.
- Remote Sensing:
  - This emerging technique which records images from space and the air are major source of geographical data.
  - The main advantage of it is that interpreted data from a remote sensing system can be merged with other data layers in a GIS.

- Photogrammetry:
  - Using aerial photographs and techniques for making accurate measurements from them, photogrammetry is the source of most data on topography (ground surface elevations) used for input to GIS.
- Surveying:
  - Surveying is concerned with the measurement of locations of objects on the Earth's surface, particularly property boundaries.
  - Surveying provides high quality data on positions of land boundaries, buildings, etc.
- Statistics:
  - Many models built using GIS are statistical in nature, many statistical techniques used for analysis in GIS.
  - Statistics is important in understanding issues of error and uncertainty in GIS data.

- Computer Science:
  - Computer science is one of the main engines for GIS development.
    - Artificial intelligence (AI) uses the computer to make choices based on available data in a way that is seen to emulate human intelligence and decision-making.
    - Computer aided design (CAD) provides software, techniques for data input, display and visualization, representation, particularly in 3 dimensions.
    - Advances in computer graphics provide hardware, software for handling and displaying graphic objects, techniques of visualization.
    - Database management systems (DBMS) contribute methods for representing data in digital form, procedures for system design and handling large volumes of data, particularly access and update.
- Mathematics:
  - Several branches of mathematics, especially geometry and graph theory, are used in GIS system design and analysis of spatial data.

MAJOR AREAS OF APPLICATION

Classification of GIS applications

- Functional classification:
  - One way to classify GIS applications is by functional characteristics of the systems; this includes a consideration of characteristics of data themes, functionality and product.
  - A classification based on these characteristics quickly becomes fuzzy since GIS is a flexible tool whose great strength is the ability to integrate data themes, functionality and output.
- GIS as a decision support tool:
  - Another way to classify GIS is by the kinds of decisions that are supported by the GIS. Decisions range from major to minor.
  - Decision support is a good basis for definition of GIS, but not for differentiating between applications since individual GIS systems are generally used to make several different kinds of decisions.

- GIS users:
  - a. mature technologies which interact with GIS, sharing its technology and creating data for it such as surveyors and engineers, cartographers, scientists using remote sensing techniques.
  - b. management and decision-making groups such as resource inventors, and resource managers, urban planners, municipal officials managing land records for taxation and ownership control, facilities managers, managers involved in marketing and retail planning or vehicle routing and scheduling.
  - c. science and research activities at universities and government labs – these groups of GIS activity seeking to find distinctions and similarities between them.

Some important areas where GIS is being used are:

- *Different Streams of Planning:* Urban planning, housing, transportation planning architectural conservation, urban design, landscape planning etc.
- *Street Network Based Application*: It is an addressed matched application, vehicle routing and scheduling: location, development and site selection and disaster planning.
- *Natural Resource Based Application:* Management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, acquifers, forests, and wildlife.
- *View Shed Analysis:* Hazardous or toxic factories siting and ground water modelling. Wildlife habitat study and migrational route planning.

- *Land Parcel Based:* Zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance etc.
- *Facilities Management:* Can locate underground pipes and cables for maintenance, planning, tracking energy use.

THE APPEAL AND POTENTIAL OF GIS

- The great appeal of GIS stems from their ability to integrate great quantities of information about the environment and to provide a powerful repertoire of analytical tools to explore this data.
- The ability to separate information in layers, and then combine it with other layers of information is the reason why GIS hold such great potential as research and decision-making tools.

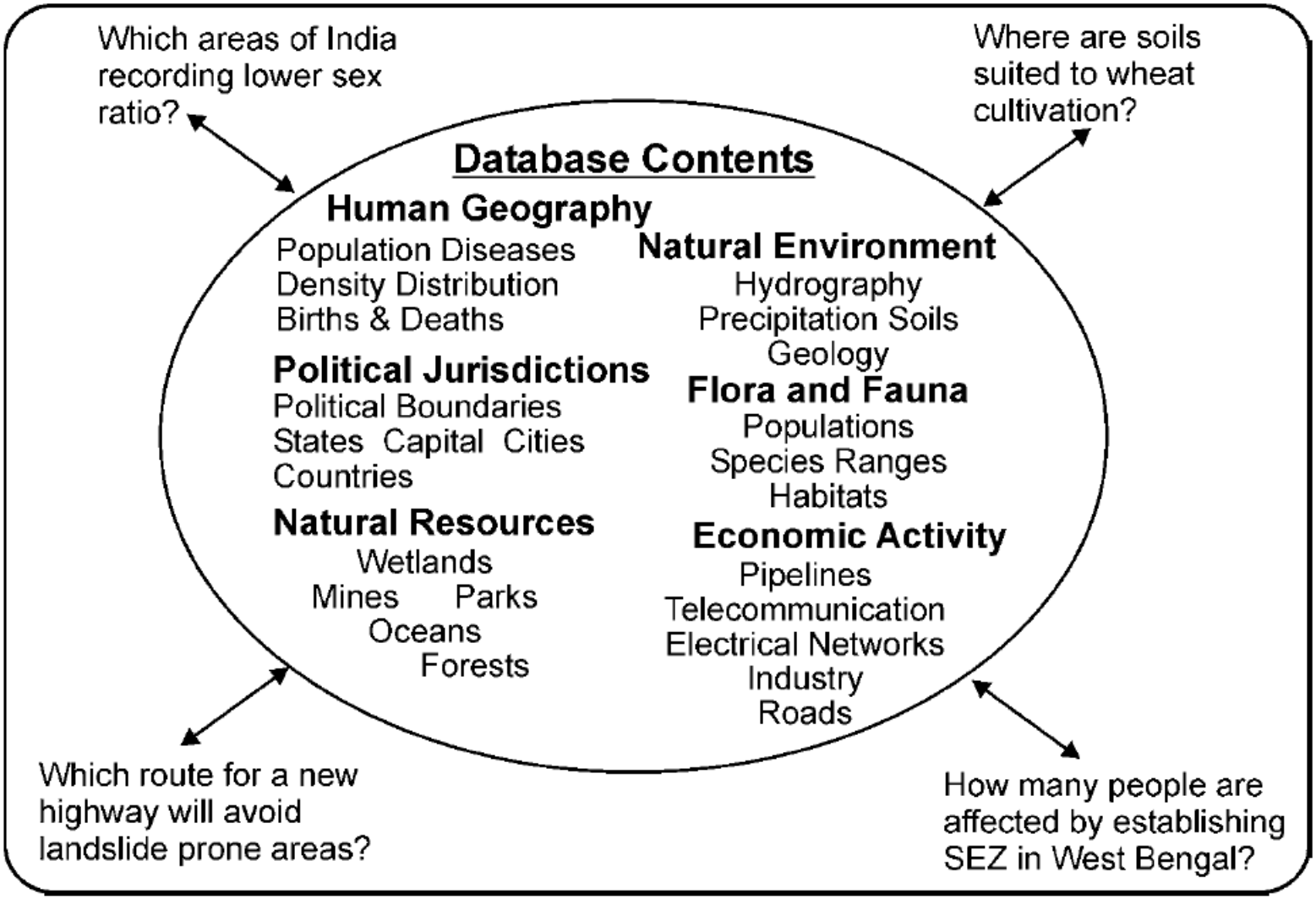


Figure 1.6: Application potential of GIS for geographical studies.

Development of GIS

- Since the mid - 1970s, specialized computer systems have been developed to process geographical information in various ways.
- Techniques to input geographical information, converting the information to digital form.
- Techniques for storing such information in compact format on computer disks, compact disks (CDs), and other digital storage media.
- Methods for automated analysis of geographical data, to search for patterns, combine different kinds of data, make measurements, find optimum sites or routes, and a host of other tasks.
- Methods to predict the outcome of various scenarios, such as the effects of climate change on vegetation.
- Techniques for display of data in the form of maps, images, and other kinds of displays.
- Capabilities for output of results in the form of numbers and tables.

COMPONENTS OF GIS

Hardware:

- It consists of the computer system on which the GIS software will run.
- These computer systems should have essentially an efficient processor to run the software and sufficient memory to store enough information (data).

Software:

- GIS software provides the functions and tools needed to store, analyze, and display geographic information.
- All GIS software generally fit all these requirements, but their on screen appearance (user interface) may be different.

Data:

- Geographic data and related tabular data are the backbone of GIS.
- The digital map forms the basic data input for GIS.
- A GIS will integrate spatial data with other data resources and can even use a DBMS.

Method:

- A successful GIS operates according to a well-designed plan, which are the models and operating practices unique to each task.
- There are various techniques used for map creation and further usage for any project.

People:

- GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work.
- They plan, implement and operate to draw conclusions for decision making.

Network:

- With rapid development of IT, today the most fundamental of these is probably the network, without which no rapid communication or sharing of digital information could occur.
- GIS today relies heavily on the Internet, acquiring and sharing large geographic data sets.

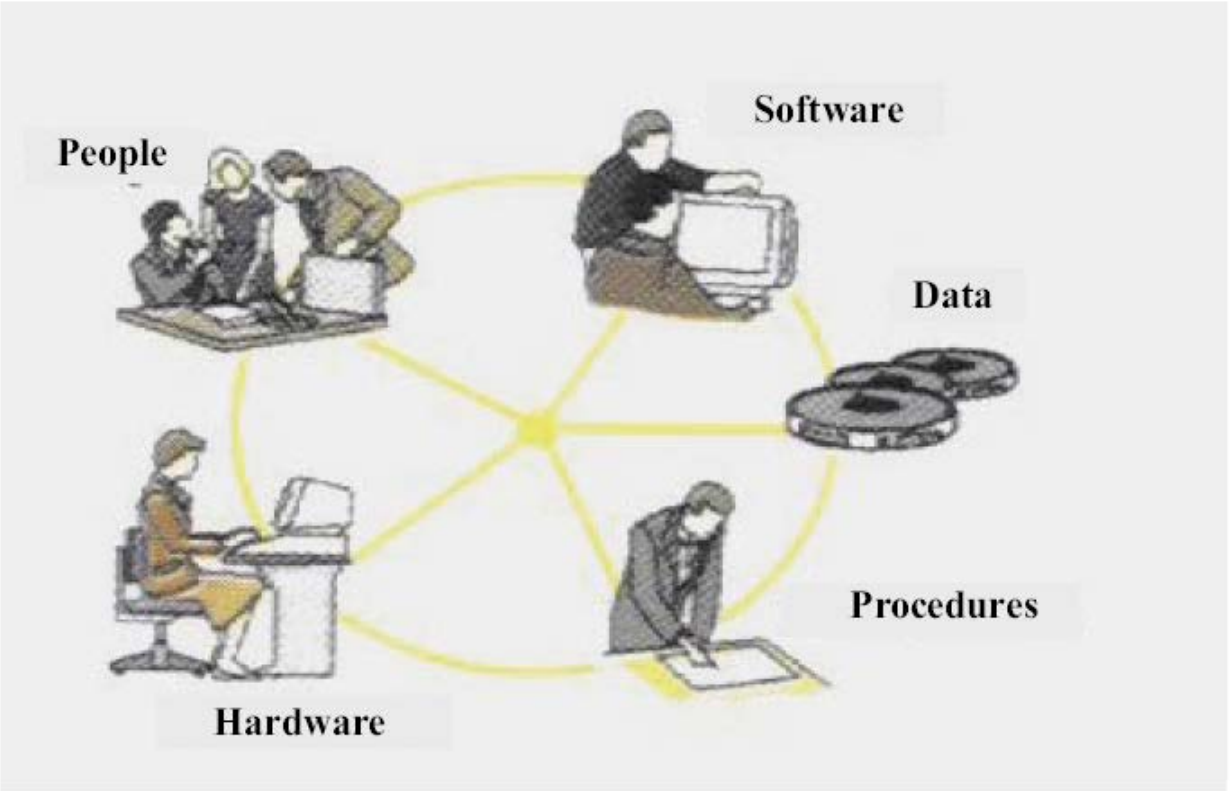


Figure 1.7: Six basic components of GIS.

- These six components of a GIS are interlinked.

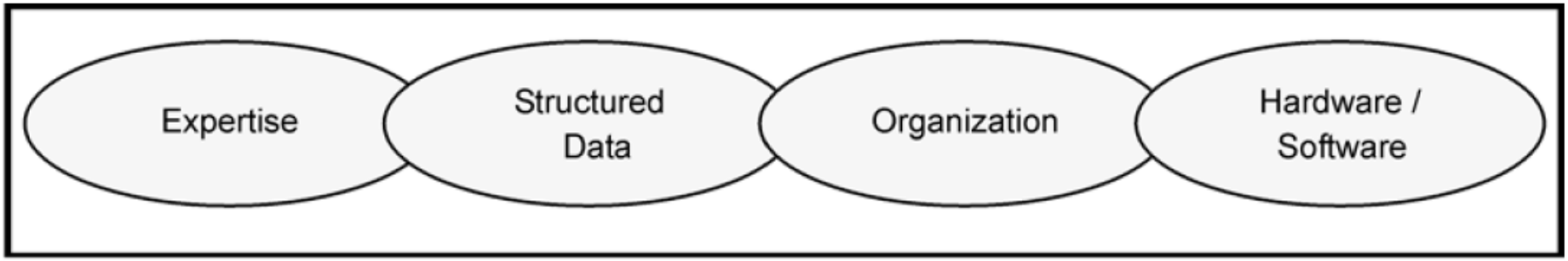


Figure 1.8: A GIS chain – Equal role of the above links in GIS organization.

- Although it is very easy to purchase the constituent parts of a GIS (the computer hardware and basic software), the system functions only when the requisite expertise is available, the data are compiled, the necessary routines are organized, and the programs are modified to suit the application.

- The hardware and software functions of a GIS include:
  - Compilation
  - Storage
  - Updating and changing
  - Management and exchange
  - Manipulation
  - Retrieval and presentation
  - Acquisition and verification
  - Analysis and combination

- All of these actions and operations are applied by a GIS to the geographical data that form its database.

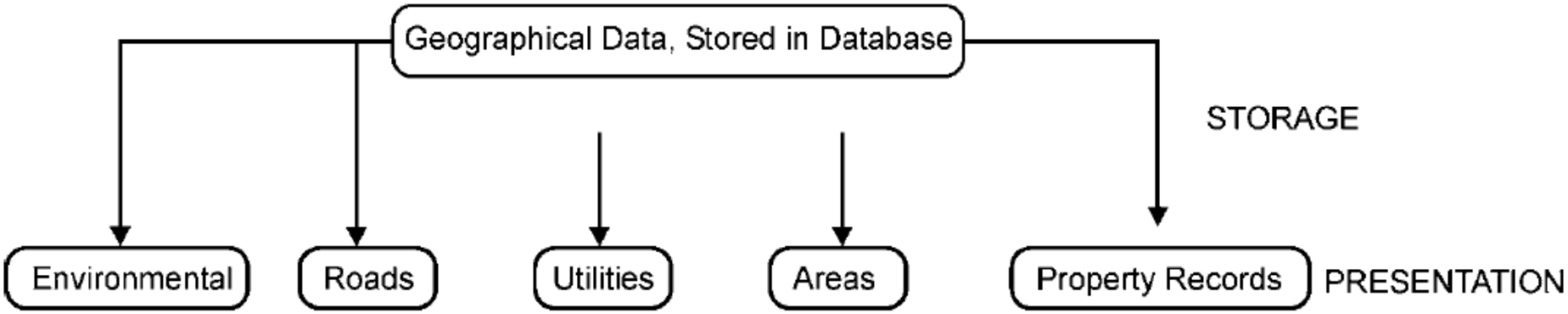


Figure 1.9: A map can be a presentation medium and a storage medium. GIS manipulates data to produce results.

- Geographical information attaches a variety of qualities and characteristics to geographical locations (Figure 1.10).
  - These qualities may be physical parameters such as ground elevation, soil moisture level, or classifications according to the type of vegetation, ownership of land, zoning, and so on. Such occurrences as accidents, floods, or landslides may also be included.
  - We use the general term *attributes* to refer to the qualities or characteristics of places.
  - Attributes are one of the two basic elements of geographical information, along with locations.

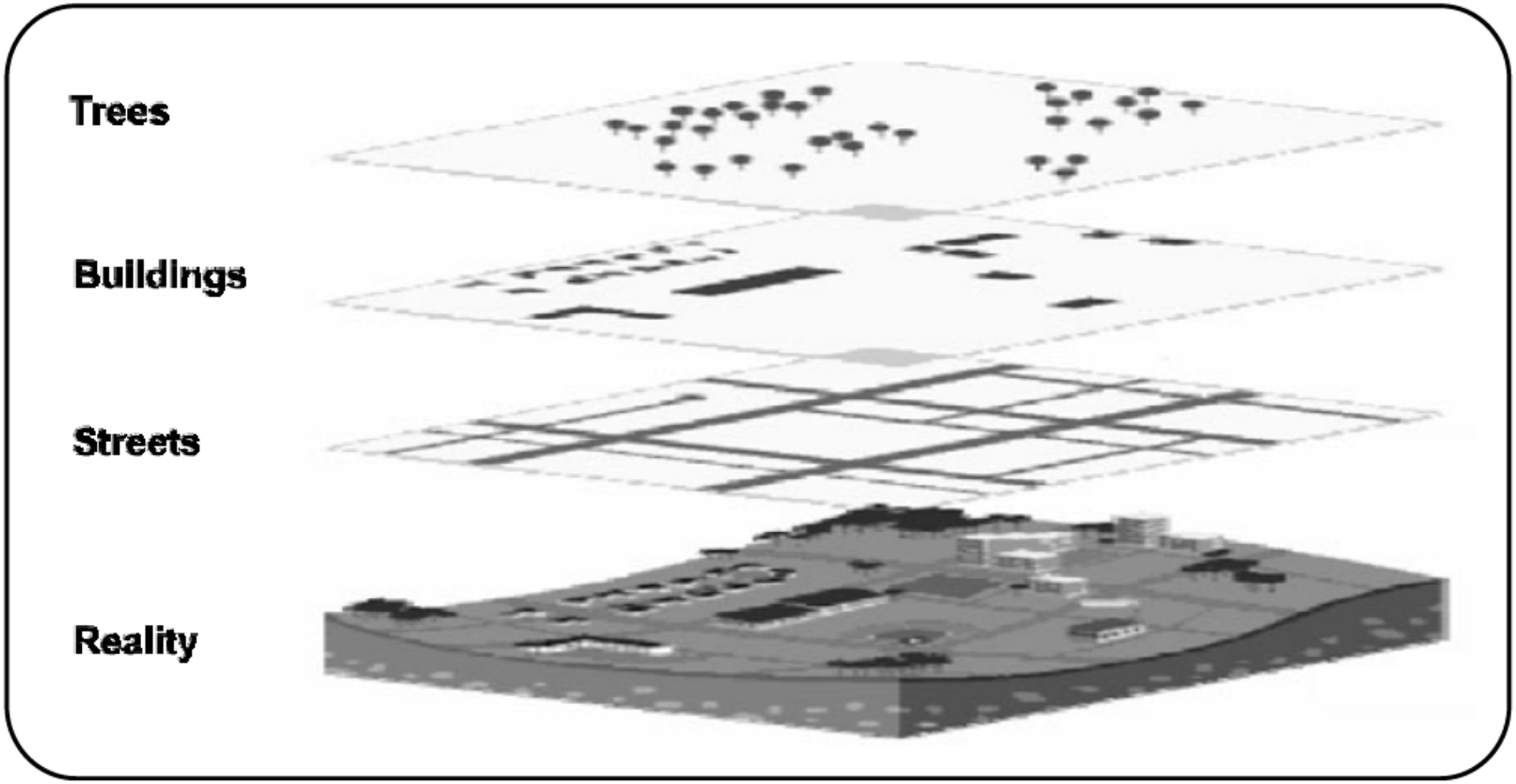


Figure 1.10: GIS stores data in different theme layers in the computer, each layer is linked to a common referencing system.

- The ability of a GIS to store relationships between features in addition to feature locations and attributes is one of the most important sources of the power and flexibility of this technology.

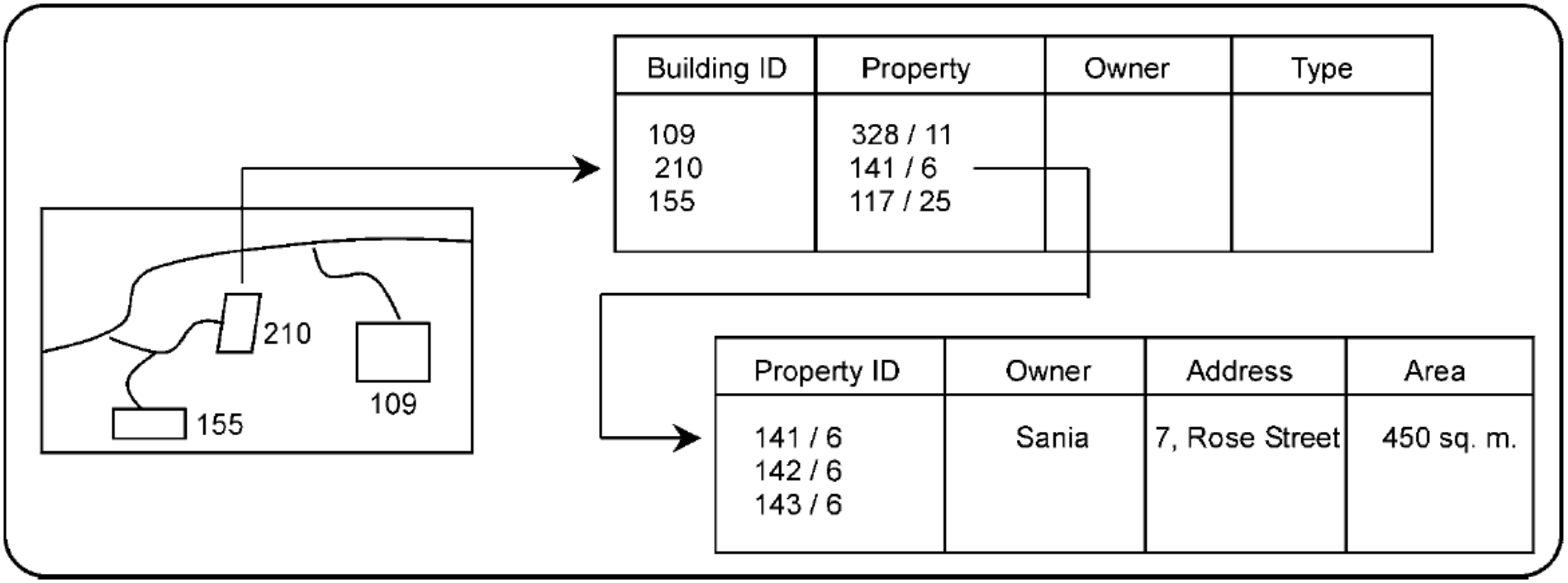


Figure 1.11: GIS functions on the interaction between digital map data and its attribute informations.

- Data integration is one of the most valuable functions of a GIS.

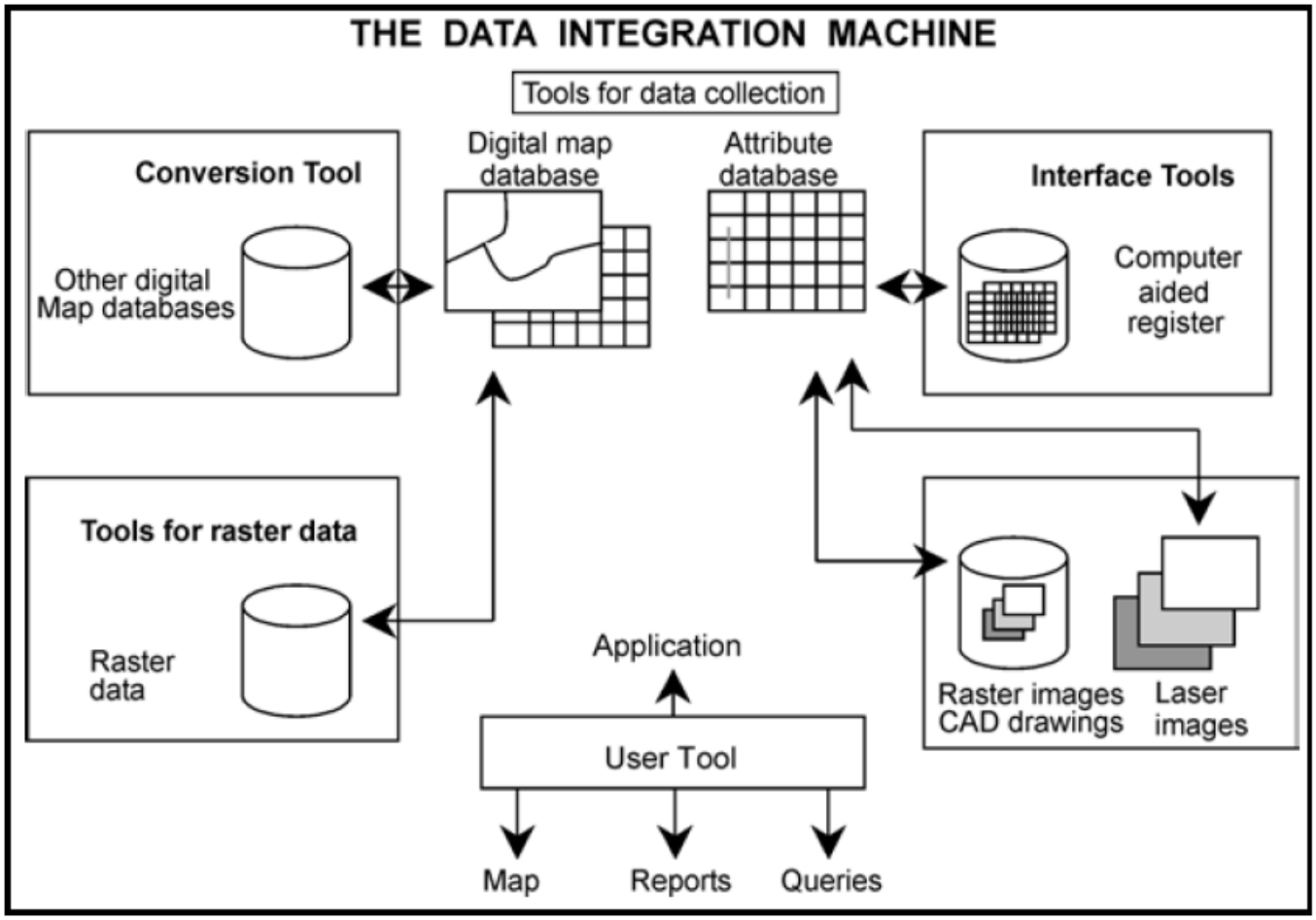


Figure 1.12: GIS is a typical data integration machine. It receives, process and transmits data.

- Technically, a GIS organizes and exploits digital geographical data stored in databases.

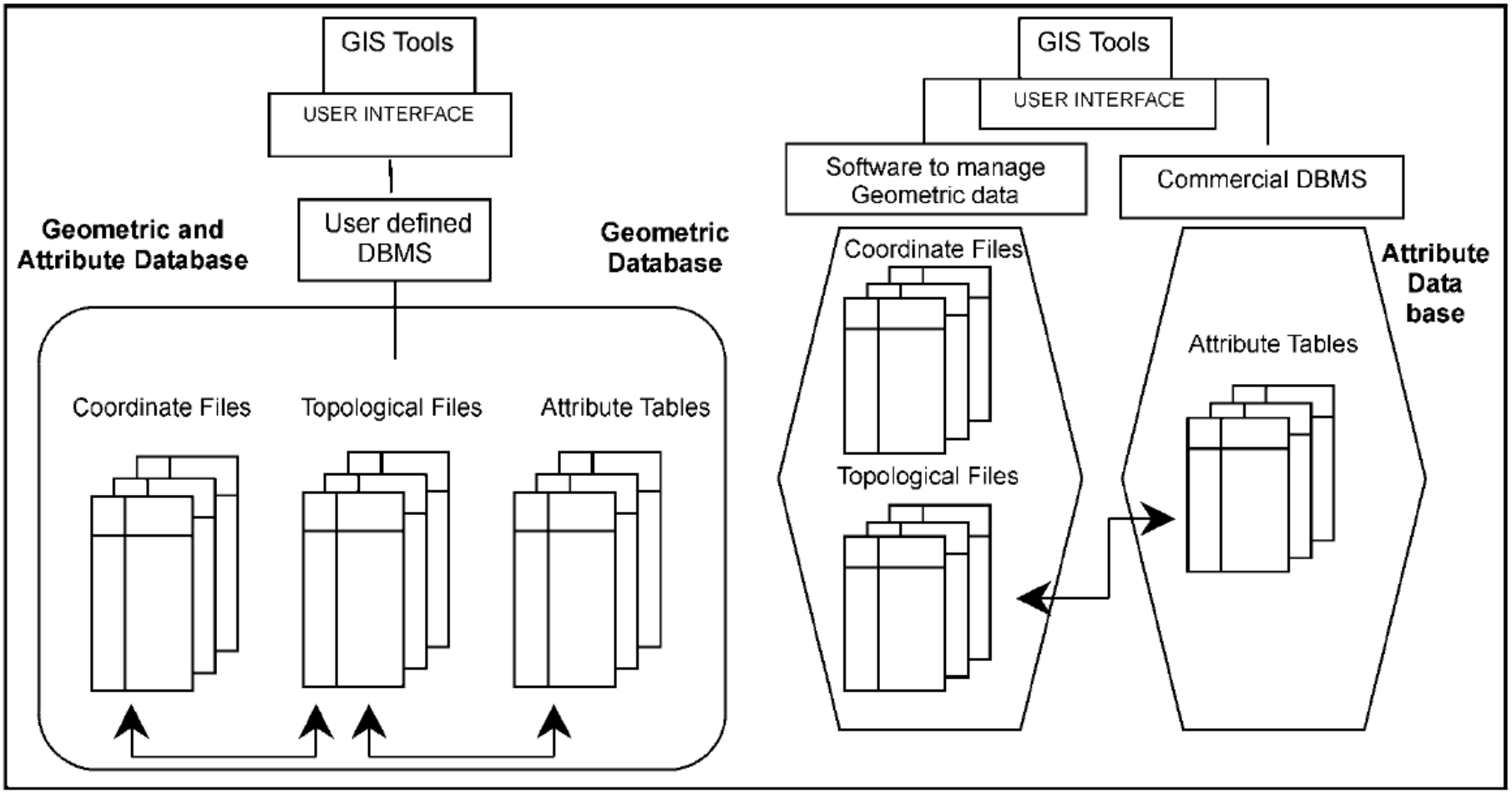


Figure 1.13: DBMS solution for GIS.

- Databases are vital in all geographical information systems. They ensure that data are:
  - Stored and maintained in one place
  - Stored in a uniform, structured, and controlled manner than can be documented
  - Accessible to many users at once, each of whom has the same understanding of the database’s contents
  - Easily updated with new data

- This contrasts with the traditional way of organizing and storing data on paper in filing cabinets, in which data are often:
  - Stored in ways that are understandable to one person only
  - Easily corrupted by use, or edited in ways that are meaningful only to the editor
  - Inaccessible to anyone other than the creator of the system
  - Stored in formats and at scales that are so diverse that they cannot be compared or collated
  - Difficult to update

GIS Diversity

- Although the general definition of GIS given here is quite valid, in practice the diversity of GIS has spawned various definitions.
  - First, users have contrived working definitions suited to their own specific uses.
  - Second, those with a more theoretical approach may use definitions that are different from those used in practical applications.

- There are many views of GISs, including:
  - A data processing system designed for map production or visualization
  - A data analysis system for examining conflicts over plans or optimizing the design of transport systems
  - An information system for responding to queries about land ownership or soil type
  - A management system to support the operations of a utility company, helping it to maintain its distribution network of pipes or cables
  - A planning system to aid the design of road systems, excavations, or forest harvest operations
  - An electronic navigation system for use in land or sea transport.

- GISs are often designated according to application.
  - land information systems (LISs)
  - urban information systems (UISs)
  - natural resource information systems (NRISs)
  - automatic mapping/facility management (AM/FM)
- The software capabilities required for a GIS often overlap those needed by other computer applications, particularly image processing and computer-assisted design (CAD).
  - Today, the distinction between image processing and GIS is becoming increasingly blurred as images become more and more important sources of GIS data.
  - The distinction between CAD and GIS has become increasingly blurred in recent years; by adding appropriate features, many former vendors of CAD systems are now able to compete effectively in the GIS market.

BENEFITS OF COMPUTERIZING INFORMATION

- GIS offers its users the ability to process quantities of data far beyond the capacities of manual systems.
  - Data in GIS are stored in a uniform, structured manner, as opposed to manual systems in which data are stored in archives and files, in agencies, on file cards, on maps, or in long reports.
  - Data may be retrieved from GIS databases and manipulated far more rapidly and reliably than data in manual systems.
  - In addition, data are quickly compiled into documents using techniques that include automatic mapmaking and direct report printouts.
  - The potential gains from switching from manually prepared maps and ordinary files to computerized GIS are considerable, in both the public and private sectors.

- Benefits are often related to objectives and that the following benefit/cost ratios may be attained by introducing GIS (Figure 1.14):
  - 1. If computerized GIS is used for automated production and maintenance of maps, the benefit/cost ratio is 1:1.
  - 2. If the system is also used for other internal tasks such as work manipulation and planning, the benefit/cost ratio may be 2:1.
  - 3. The full benefit of the system is first realized when information is shared among various users. The benefit/cost ratio may then be 4:1.
- Nonetheless, it is obvious that investment in GIS is at least as productive as investment in other sectors.

Objective	GIS Operation	Production of Data	Use of Data
Task	• Storage • Update • Manipulation • Maintenance • Retrieval	• Analysis of Data • Map Production • Planning • Project Management	• Map Production • Coordination of Tasks • Information Updating • Information Sharing • Management & Planning • Execution of Task
Benefit / Cost Ratio	**1:1**	**2:1**	**4:1**

Figure 1.14: The benefit/cost ratio of GIS data is significantly high.

- Measurable benefits
  - Improved efficiency due to more work being performed by the same staff, or the same work performed by a smaller staff
  - Reduction in direct operating costs through better bases for financial management, less costly maintenance of facilities, and joint uses of available data
  - Increases in income due to increased sales, or sales of new products and services

- Intangible benefits
  - Improved public and private decision making in administration, planning, and operations
  - Improved information and service to the public
  - Increased safety, and reduction in the impact of disasters through better planned evacuation and more efficient management of emergency services
  - An improved environment for future generations
  - Better presentation of plans and their associated effects
  - Improved decisions regarding new development, and better analysis of market and site conditions

Users of GIS

- Users of GIS naturally fall into two groups: professional operators of GIS and management and decision-making groups.
- Professional operators of GIS
  - They spend much of their lives working with the technology in their jobs.
  - They are well trained in the particular software they use and are well aware of its capabilities.
  - In many cases they do not use the results of their work themselves, but pass them to end users.
- Management and decision-making groups
  - They may maintain a GIS capability on their personal workstation in order to produce an occasional map, to find a park in an unfamiliar city, to plan a driving route for a vacation, or to carry out analysis of map data in connection with a research project.

- The GIS must be simple and easy to use.
- This second group also comprises end users and primary users who make professional decisions based on GIS products.
- The group includes:
  - Operation and maintenance engineers; a typical decision may be whether to replace or repair a damaged water main.
  - Regional planners; characteristic tasks involve presentations of plans to municipal authorities in a realistic, varied, visual manner.
  - Building authority functionaries; representative jobs include processing building permit applications involving access roads, water supply, or sewage.
  - Revenue officials, typically dealing with tax assessment and taxpayer addresses.
  - Road engineers, whose responsibilities include locating new roads to minimize cut-and-fill operations.

- Information officers; information produced may include complete packages to newly established firms with details on industrial areas, schools, and transportation.
- Local officials, who may require updated overviews on the effects of effluents on water quality at municipal hand pumps.
- Fire brigades, for whom rapid, reliable information on the locations of fires and the presence of hazards such as explosives would be invaluable.
- Forest managers planning harvest operations, computing volumes of annual growths, estimating road costs and identifying sensitive wildlife areas.