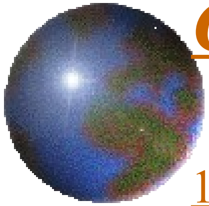
Chapter 1: Introduction to Spatial Databases



1.1 Overview
1.2 Application domains
1.3 Compare a SDBMS with a GIS
1.4 Categories of Users
1.5 An example of an SDBMS application
1.6 A Stroll though a spatial database
    1.6.1 Data Models, 1.6.2 Query Language, 1.6.3 Query Processing,
    1.6.4 File Organization and Indices, 1.6.5 Query Optimization,
    1.6.6 Data Mining

www.spatial.cs.umn.edu/Book/slides/ch1revised.ppt

Learning Objectives

- Learning Objectives (LO)
  - LO1 : Understand the value of SDBMS
    - Application domains
    - users
    - How is different from a DBMS?
  - LO2: Understand the concept of spatial databases
  - LO3: Learn about the Components of SDBMS

- Mapping Sections to learning objectives
  - LO1 - 1.1, 1.2, 1.4
  - LO2 - 1.3, 1.5
  - LO3 - 1.6

Value of SDBMS

- Traditional (non-spatial) database management systems provide:
  - Persistence across failures
  - Allows concurrent access to data
  - Scalability to search queries on very large datasets which do not fit inside main memories of computers
  - Efficient for non-spatial queries, but not for spatial queries
- Non-spatial queries:
  - List the names of all bookstore with more than ten thousand titles.
  - List the names of ten customers, in terms of sales, in the year 2001
- Spatial Queries:
  - List the names of all bookstores with ten miles of Minneapolis
  - List all customers who live in Tennessee and its adjoining states

Value of SDBMS – Spatial Data Examples

- Examples of non-spatial data
  - Names, phone numbers, email addresses of people
- Examples of Spatial data
  - Census Data
  - NASA satellites imagery - terabytes of data per day
  - Weather and Climate Data
  - Rivers, Farms, ecological impact
  - Medical Imaging
- Exercise: Identify spatial and non-spatial data items in
  - A phone book
  - A cookbook with recipes

Value of SDBMS – Users, Application Domains

- Many important application domains have spatial data and queries. Some Examples follow:
  - **Army Field Commander**: Has there been any significant enemy troop movement since last night?
  - **Insurance Risk Manager**: Which homes are most likely to be affected in the next great flood on the Mississippi?
  - **Medical Doctor**: Based on this patient's MRI, have we treated somebody with a similar condition ?
  - **Molecular Biologist**:Is the topology of the amino acid biosynthesis gene in the genome found in any other sequence feature map in the database ?
  - **Astronomer**:Find all blue galaxies within 2 arcmin of quasars.

- Exercise: List two ways you have used spatial data. Which software did you use to manipulate spatial data?

Learning Objectives

- Learning Objectives (LO)
  - LO1 : Understand the value of SDBMS
  - LO2: Understand the concept of spatial databases
    - What is a SDBMS?
    - How is it different from a GIS?
  - LO3: Learn about the Components of SDBMS
- Sections for LO2
  - Section 1.5 provides an example SDBMS
  - Section 1.1 and 1.3 compare SDBMS with DBMS and GIS

What is a SDBMS ?

- A SDBMS is a software module that
  - can work with an underlying DBMS
  - supports spatial data models, spatial abstract data types (ADTs) and a query language from which these ADTs are callable
  - supports spatial indexing, efficient algorithms for processing spatial operations, and domain specific rules for query optimization
- Example: Oracle Spatial data cartridge, ESRI SDE
  - can work with Oracle 8i DBMS
  - Has spatial data types (e.g. polygon), operations (e.g. overlap) callable from SQL3 query language
  - Has spatial indices, e.g. R-trees

SDBMS Example

- Consider a spatial dataset with:
  - County boundary (dashed white line)
  - Census block - name, area, population, boundary (dark line)
  - Water bodies (dark polygons)
  - Satellite Imagery (gray scale pixels)

- Storage in a SDBMS table:

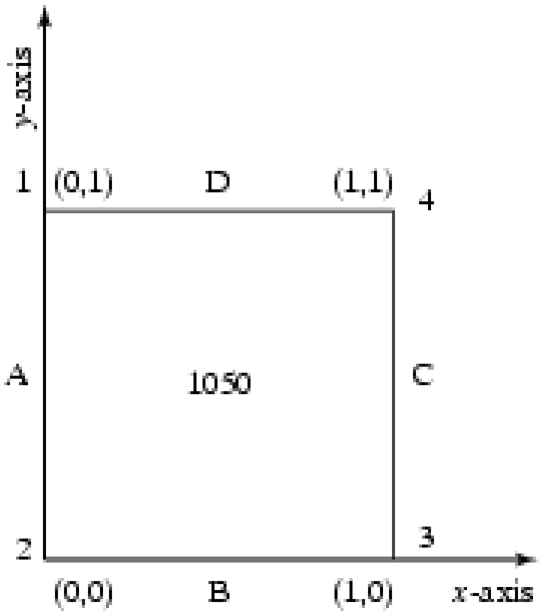
create table **census_blocks** (

name	string,
area	float,
population	number,
boundary	polygon);

Fig 1.2

Modeling Spatial Data in Traditional DBMS

- A row in the table census_blocks (Figure 1.3)
- Question: Is Polyline datatype supported in DBMS?



Census_blocks

Name	Area	Population	Boundary
1050	1	1839	Polyline((0,0),(0,1),(1,1),(1,0))

Figure 1.3

Spatial Data Types and Traditional Databases

- Traditional relational DBMS
  - Support simple data types, e.g. number, strings, date
  - Modeling Spatial data types is tedious
- Example: Figure 1.4 shows modeling of polygon using numbers
  - Three new tables: polygon, edge, points
    - Note: Polygon is a polyline where last point and first point are same
  - A simple unit sqaure represented as 16 rows across 3 tables
  - Simple spatial operators, e.g. area(), require joining tables
  - Tedious and computationally inefficient

- Question. Name post-relational database management systems which facilitate modeling of spatial data types, e.g. polygon.

Mapping "census_table" into a Relational Database

Census_blocks

Name	Area	Population	boundary-ID
340	1	1839	1050

Polygon

boundary-ID	edge-name
1050	A
1050	B
1050	C
1050	D

Edge

edge-name	endpoint
A	1
A	2
B	2
B	3
C	3
C	4
D	4
D	1

Point

endpoint	x-coor	y-coor
1	0	1
2	0	0
3	1	0
4	1	1

Fig 1.4

Evolution of DBMS technology

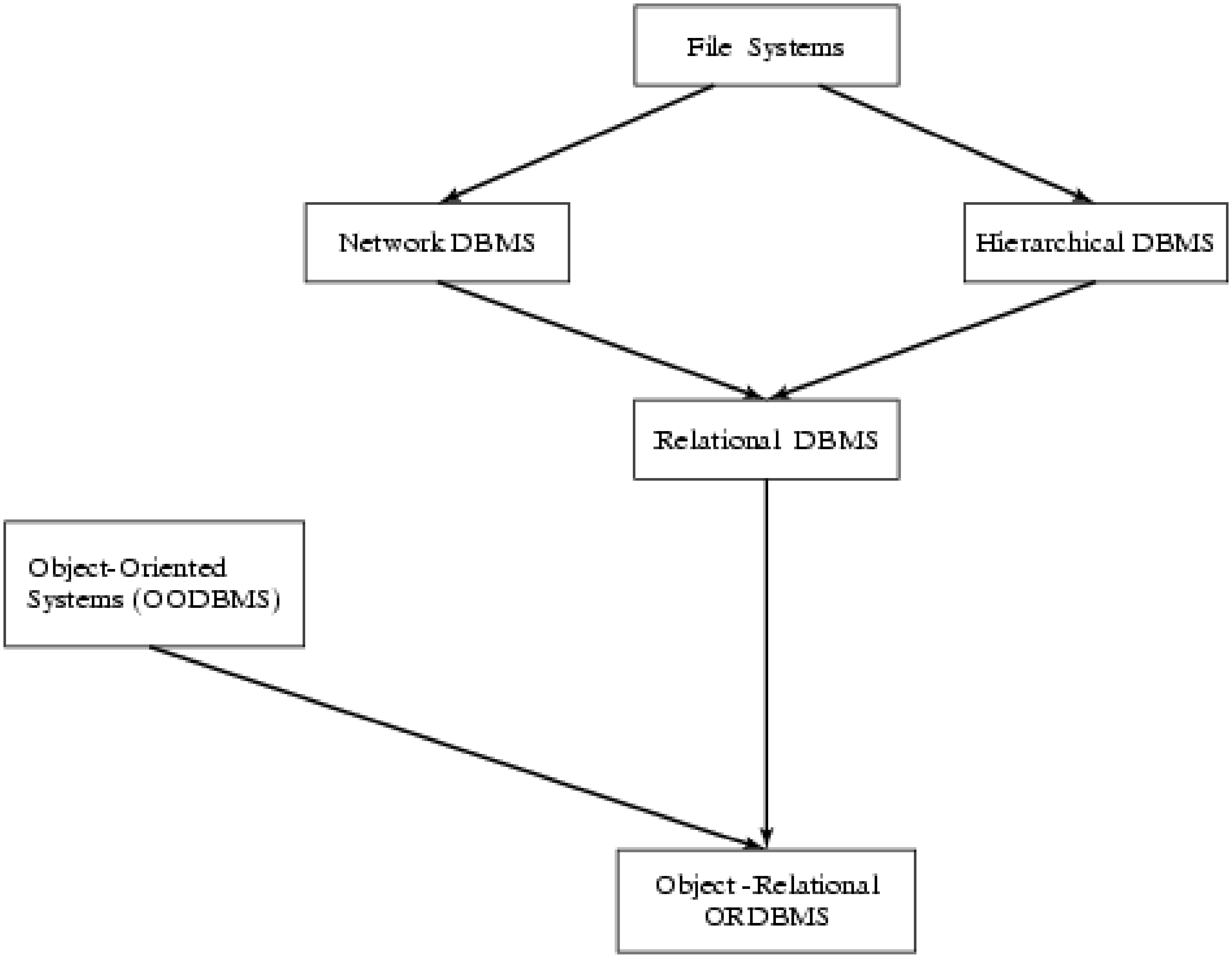


Fig 1.5

Spatial Data Types and Post-relational Databases

- Post-relational DBMS
  - Support user defined abstract data types
  - Spatial data types (e.g. polygon) can be added
- Choice of post-relational DBMS
  - Object oriented (OO) DBMS
  - Object relational (OR) DBMS
- A spatial database is a collection of spatial data types, operators, indices, processing strategies, etc. and can work with many post-relational DBMS as well as programming languages like Java, Visual Basic etc.

How is a SDBMS different from a GIS ?

- GIS is a software to visualize and analyze spatial data using spatial analysis functions such as
  - **Search** Thematic search, search by region, (re-)classification
  - **Location analysis** Buffer, corridor, overlay
  - **Terrain analysis** Slope/aspect, catchment, drainage network
  - **Flow analysis** Connectivity, shortest path
  - **Distribution** Change detection, proximity, nearest neighbor
  - **Spatial analysis/Statistics** Pattern, centrality, autocorrelation, indices of similarity, topology: hole description
  - **Measurements** Distance, perimeter, shape, adjacency, direction
- GIS uses SDBMS
  - to store, search, query, share large spatial data sets

How is a SDBMS different from a GIS ?

- SDBMS focusses on
  - Efficient storage, querying, sharing of large spatial datasets
  - Provides simpler set based query operations
  - Example operations: search by region, overlay, nearest neighbor, distance, adjacency, perimeter etc.
  - Uses spatial indices and query optimization to speedup queries over large spatial datasets.
- SDBMS may be used by applications other than GIS
  - Astronomy, Genomics, Multimedia information systems, ...
- Will one use a GIS or a SDBM to answer the following:
  - How many neighboring countries does USA have?
  - Which country has highest number of neighbors?

Evolution of acronym "GIS"

- Geographic Information Systems (1980s)
- Geographic Information Science (1990s)
- Geographic Information Services (2000s)

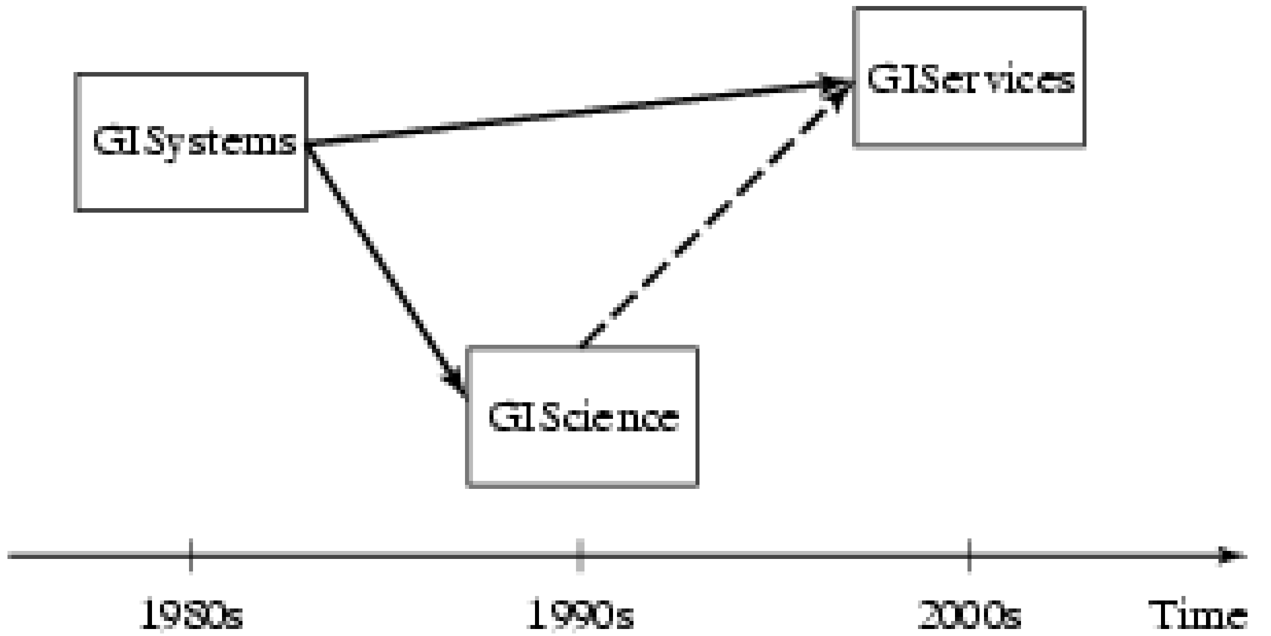


Fig 1.1

Three meanings of the acronym GIS

- Geographic Information Services
  - Web-sites and service centers for casual users, e.g. travelers
  - Example: Service (e.g. AAA, mapquest) for route planning
- Geographic Information Systems
  - Software for professional users, e.g. cartographers
  - Example: ESRI Arc/View software
- Geographic Information Science
  - Concepts, frameworks, theories to formalize use and development of geographic information systems and services
  - Example: design spatial data types and operations for querying
- Exercise: Which meaning of the term GIS is closest to the focus of the book titled “Spatial Databases: A Tour”?

Learning Objectives

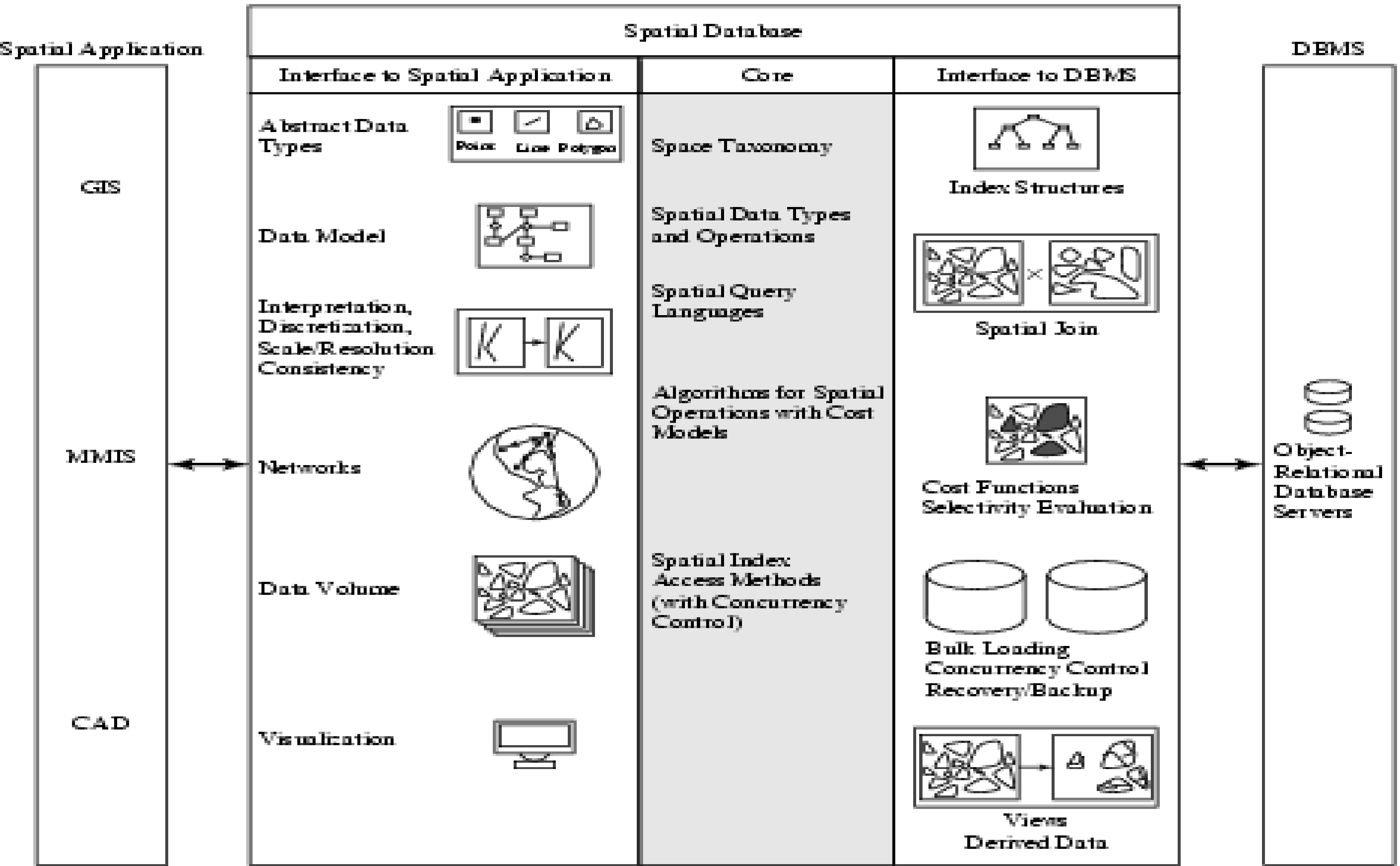
- Learning Objectives (LO)
  - LO1 : Understand the value of SDBMS
  - LO2: Understand the concept of spatial databases
  - LO3: Learn about the Components of SDBMS
    - Architecture choices
    - SDBMS components:
      - data model, query languages,
      - query processing and optimization
      - File organization and indices
      - Data Mining
- Chapter Sections
  - 1.5 second half
  - 1.6 – entire section

Components of a SDBMS

- Recall: a SDBMS is a software module that
  - can work with an underlying DBMS
  - supports spatial data models, spatial ADTs and a query language from which these ADTs are callable
  - supports spatial indexing, algorithms for processing spatial operations, and domain specific rules for query optimization
- Components include
  - spatial data model, query language, query processing, file organization and indices, query optimization, etc.
  - Figure 1.6 shows these components
  - We discuss each component briefly in chapter 1.6 and in more detail in later chapters.

Three Layer Architecture

Fig 1.6



1.6.1 Spatial Taxonomy, Data Models

- Spatial Taxonomy:
  - multitude of descriptions available to organize space.
  - Topology models homeomorphic relationships, e.g. overlap
  - Euclidean space models distance and direction in a plane
  - Graphs models connectivity, Shortest-Path
- Spatial data models
  - rules to identify identifiable objects and properties of space
  - Object model help manage identifiable things, e.g. mountains, cities, land-parcels etc.
  - Field model help manage continuous and amorphous phenomenon, e.g. wetlands, satellite imagery, snowfall etc.
- More details in chapter 2.

1.6.2 Spatial Query Language

- Spatial query language
  - Spatial data types, e.g. point, linestring, polygon, …
  - Spatial operations, e.g. overlap, distance, nearest neighbor, …
  - Callable from a query language (e.g. SQL3) of underlying DBMS

```
SELECT    S.name
FROM      Senator S
WHERE     S.district.Area() > 300
```

- Standards
  - SQL3 (a.k.a. SQL 1999) is a standard for query languages
  - OGIS is a standard for spatial data types and operators
  - Both standards enjoy wide support in industry
  - More details in chapters 2 and 3

Multi-scan Query Example

- Spatial join example

  SELECT S.name FROM Senator S, Business B

  WHERE S.district.Area() > 300 AND Within(B.location, S.district)

- Non-Spatial Join example

  SELECT S.name FROM Senator S, Business B

  WHERE S.soc-sec = B.soc-sec AND S.gender = ‘Female’

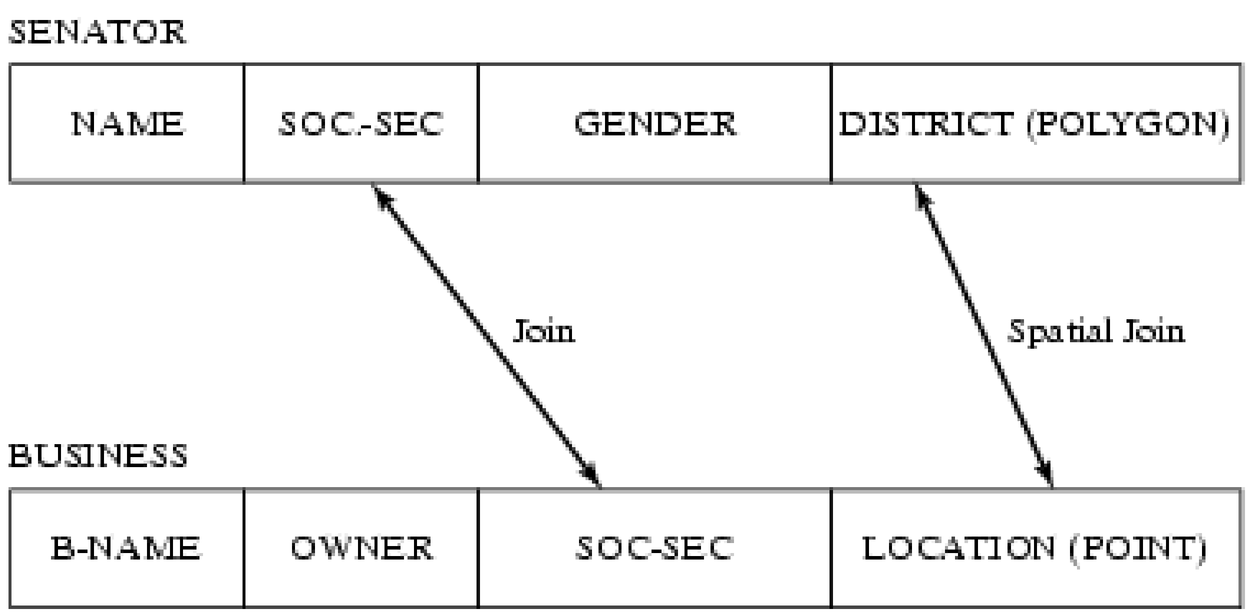


Fig 1.7

1.6.3 Query Processing

- Efficient algorithms to answer spatial queries
- Common Strategy - filter and refine
  - Filter Step:Query Region overlaps with MBRs of B,C and D
  - Refine Step: Query Region overlaps with B and C

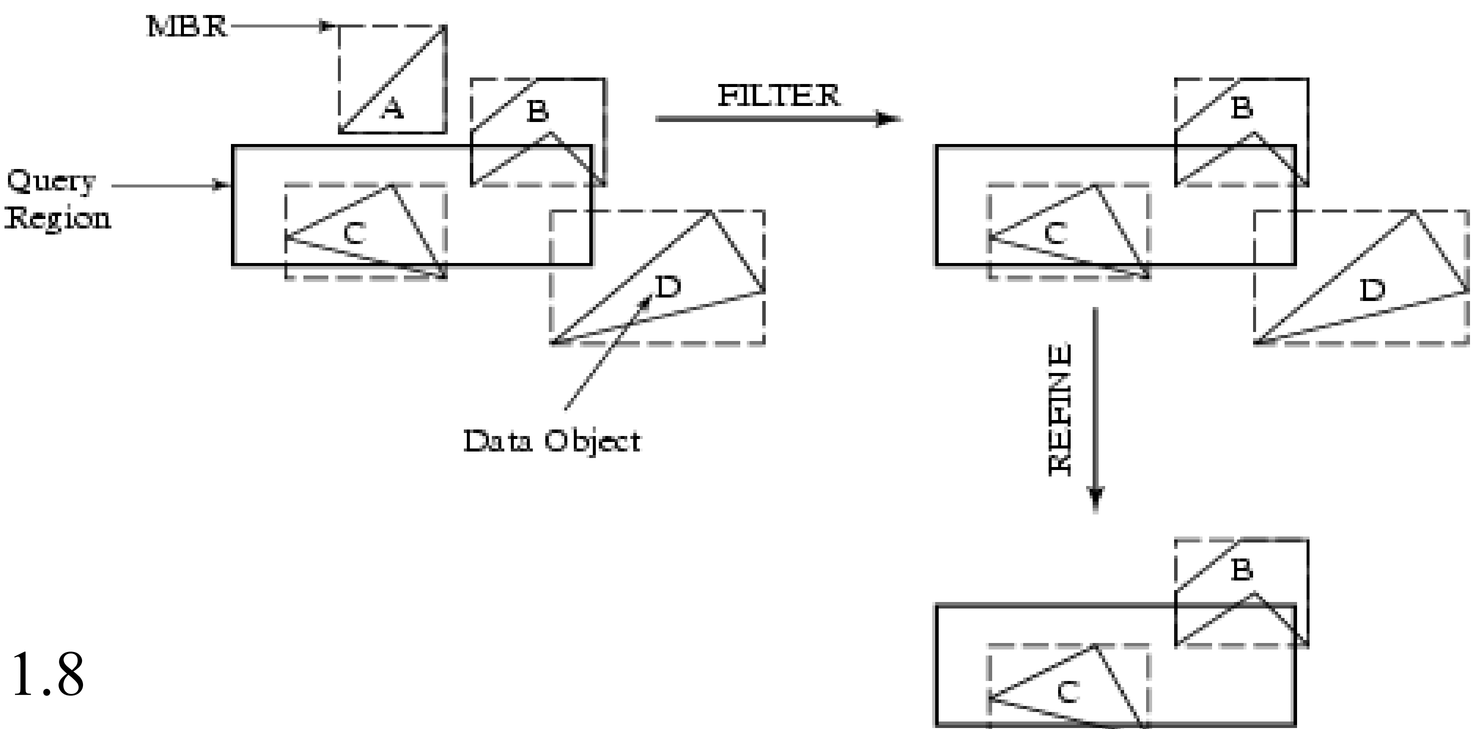


Fig 1.8

Query Processing of Join Queries

- Example - Determining pairs of intersecting rectangles
  - (a):Two sets R and S of rectangles, (b): A rectangle with 2 opposite corners marked, (c): Rectangles sorted by smallest X coordinate value
  - Plane sweep filter identifies 5 pairs out of 12 for refinement step
  - Details of plane sweep algorithm on page 15

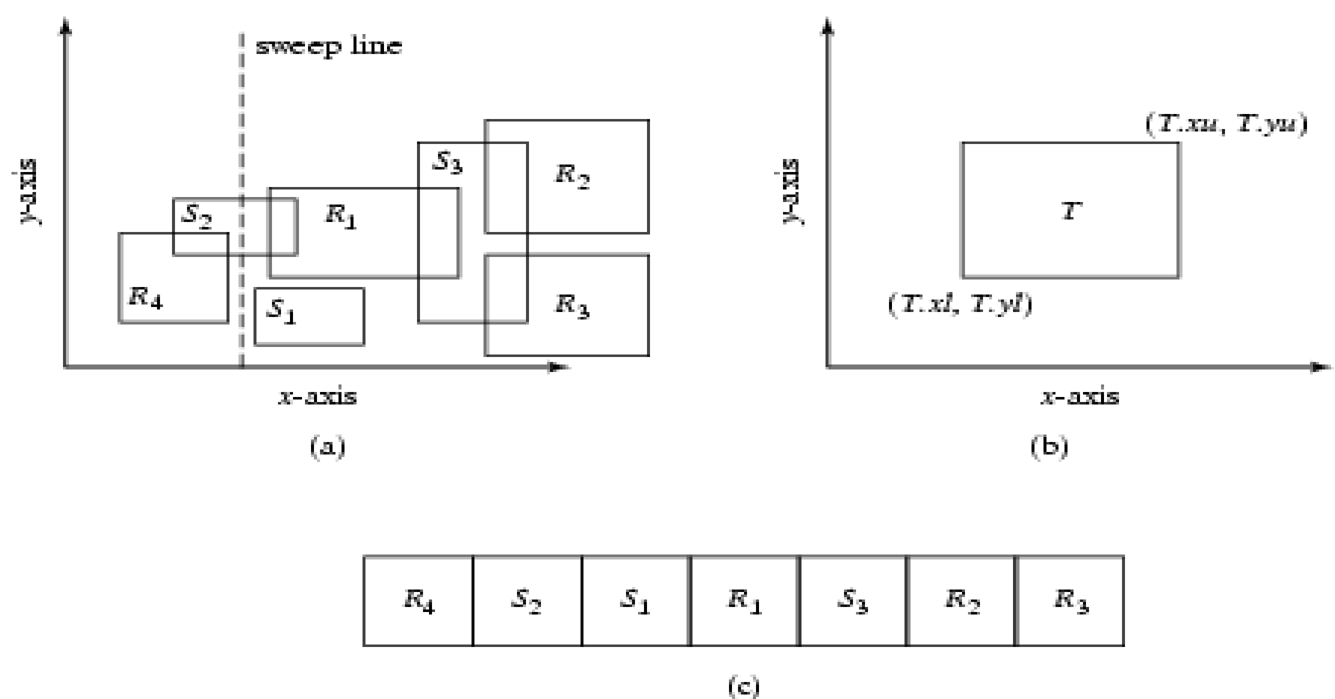


Fig 1.9

1.6.4 File Organization and Indices

- A difference between GIS and SDBMS assumptions
  - GIS algorithms: dataset is loaded in main memory (Fig. 1.10(a))
  - SDBMS: dataset is on secondary storage e.g disk (Fig. 1.10(b))
  - SDBMS uses space filling curves and spatial indices
    - to efficiently search disk resident large spatial datasets

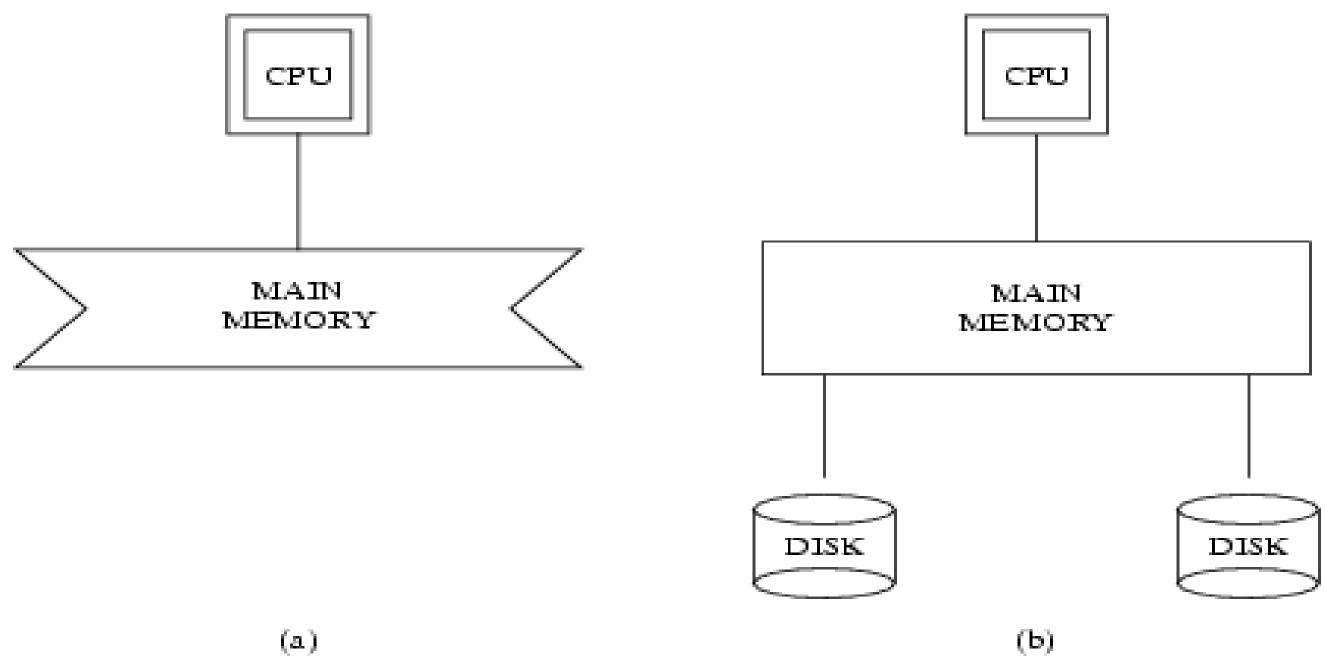


Fig 1.10

Organizing spatial data with space filling curves

- Issue:
  - Sorting is not naturally defined on spatial data
  - Many efficient search methods are based on sorting datasets
- Space filling curves
  - Impose an ordering on the locations in a multi-dimensional space
  - Examples: row-order (Fig. 1.11(a), z-order (Fig 1.11(b))
  - Allow use of traditional efficient search methods on spatial data

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

(a)

7	8	14	16
5	6	13	15
2	4	10	12
1	3	9	11

(b)

Fig 1.11

Spatial Indexing: Search Data-Structures

- Choice for spatial indexing:
  - B-tree is a hierarchical collection of ranges of linear keys, e.g. numbers
  - B-tree index is used for efficient search of traditional data
  - B-tree can be used with space filling curve on spatial data
  - R-tree provides better search performance yet!
  - R-tree is a hierarchical collection of rectangles
  - More details in chapter 4

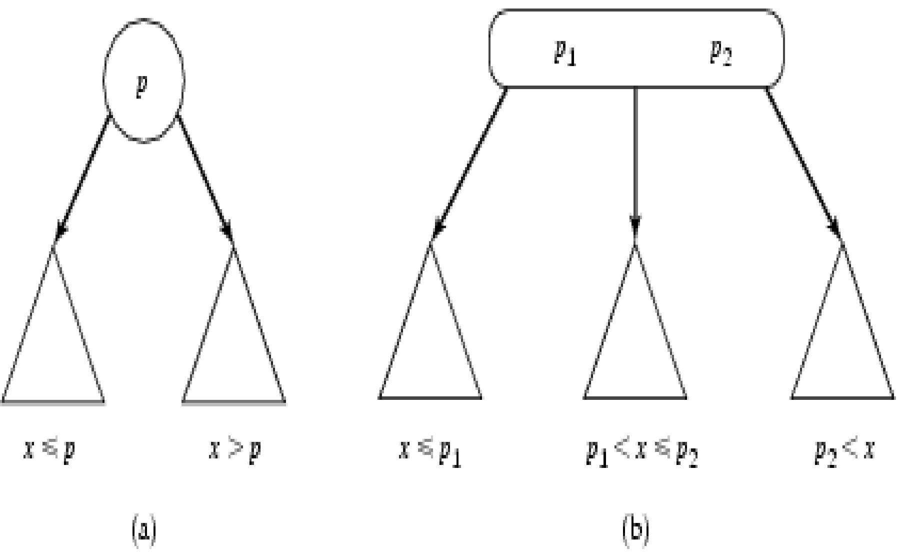


Fig 1.12: B-tree

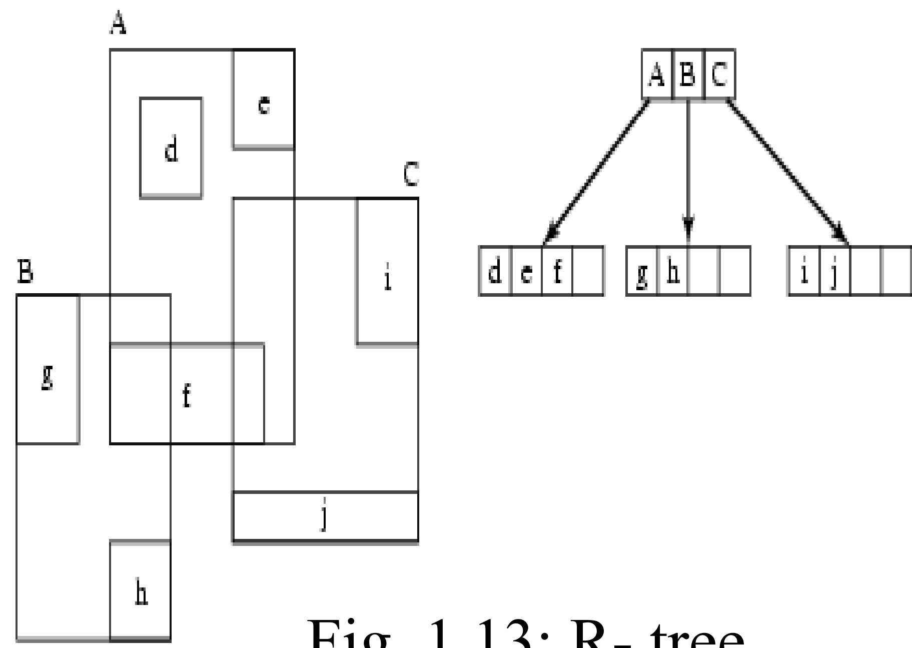


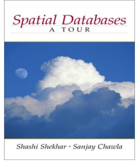
Fig. 1.13: R- tree

1.6.5 Query Optimization

- Query Optimization
  - A spatial operation can be processed using different strategies
  - Computation cost of each strategy depends on many parameters
  - Query optimization is the process of
    - ordering operations in a query and
    - selecting efficient strategy for each operation
    - based on the details of a given dataset
- Example Query:

  SELECT S.name FROM Senator S, Business B

  WHERE S.soc-sec = B.soc-sec AND S.gender = 'Female'
- Optimization decision examples
  - Process (S.gender = 'Female') before (S.soc-sec = B.soc-sec)
  - Do not use index for processing (S.gender = 'Female')



1.6.6 Data Mining

- Analysis of spatial data is of many types
  - Deductive Querying, e.g. searching, sorting, overlays
  - Inductive Mining, e.g. statistics, correlation, clustering,classification, …
- Data mining is a systematic and semi-automated search for interesting non-trivial patterns in large spatial databases

- Example applications include
  - Infer land-use classification from satellite imagery
  - Identify cancer clusters and geographic factors with high correlation
  - Identify crime hotspots to assign police patrols and social workers

1.7 Summary

- SDBMS is valuable to many important applications
- SDBMS is a software module
  - works with an underlying DBMS
  - provides spatial ADTs callable from a query language
  - provides methods for efficient processing of spatial queries
- Components of SDBMS include
  - spatial data model, spatial data types and operators,
  - spatial query language, processing and optimization
  - spatial data mining
- SDBMS is used to store, query and share spatial data for GIS as well as other applications