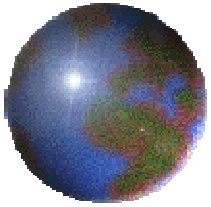
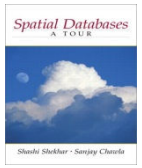
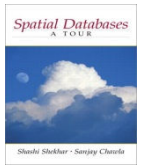


Chapter 5: Query Processing and Optimization



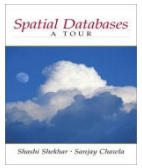
Analogy of Automatic Transmission in Cars

- Manual transmission : automatic :: Java : SQL
- Recall Java program (Section 2.1.6, pp.32-34)
  - Algorithm to answer the query was coded in the program
  - Similar to manual gear change at start and stop in Cars
- In contrast, SQL queries are declarative
  - Users do not specify the procedure to answer it
  - DBMS needs to pick an algorithm to answer query
  - Analogy: automatic transmission choosing gear (1, 2, 3, …)
- Relevant SDBMS component
  - Query processing and optimization (QPO)
    - picks algorithms to process a SQL query
  - Physical data model : QPO :: engine : automatic transmission



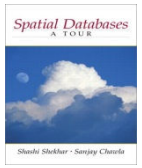
What is Query Processing and Optimization (QPO)?

- Basic idea of QPO
  - In SQL, queries are expressed in high level declarative form
  - QPO translates a SQL query to an execution plan
    - over physical data model
    - using operations on file-structures, indices, etc.
  - Ideal execution plan answers Q in as little time as possible
  - Constraints: QPO overheads are small
    - Computation time for QPO steps << that for execution plan



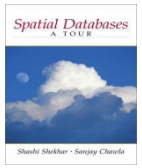
Why Learn about QPO?

- Why learn about automatic transmission in a car?
  - Identify cause of lack of power in a car
    - is it the engine or the transmission ?
  - Solve performance problem with manual override
    - uphill, downhill driving => lower gears
- Why learn about QPO in a SDBMS?
  - Identify performance bottleneck for a query
    - is it the physical data model or QPO ?
  - How to help QPO speed up processing of a query ?
    - providing hints, rewriting query, etc.
  - How to enhance physical data model to speed up queries?
    - add indices, change file- structures, …



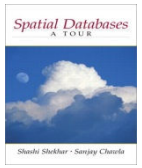
Three Key Concepts in QPO

1. Building blocks
   - Most cars have few motions, e.g. forward, reverse
   - Similar most DBMS have few building blocks:
     - select (point query, range query), join, sorting, ...
   - A SQL query is decomposed in building blocks
2. Query processing strategies for building blocks
   - Cars have a few gears for forward motion: 1st, 2nd, 3rd, overdrive
   - DBMS keeps a few processing strategies for each building block
     - e.g. a point query can be answer via an index or via scanning data-file
3. Query optimization
   - Automatic transmission tries to picks best gear given motion parameters
   - For each building block of a given query, DBMS QPO tries to choose
     - "most efficient" strategy given database parameters
     - parameter examples: table size, available indices, …
     - ex. index search is chosen for a point query if the index is available



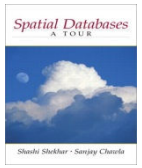
QPO Challenges

- Choice of building blocks
  - SQL queries are based on relational algebra (RA)
  - Building blocks of RA are select, project, join
    - details in section 3.2 (note symbols sigma, pi and join)
  - SQL3 adds new building blocks like transitive closure
    - will be discussed in chapter 6
- Choice of processing strategies for building blocks
  - Constraints: Too many strategies → higher complexity
  - Commercial DBMS have a total of 10 to 30 strategies
    - 2 to 4 strategies for each building block
- How to choose the `best' strategy from among the applicable ones?
  - May use a fixed priority scheme
  - May use a simple cost model based on DBMS parameters



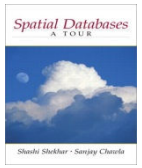
QPO Challenges in SDBMS

- Building Blocks for spatial queries
  - Rich set of spatial data types, operations
  - A consensus on “building blocks” is lacking
  - Current choices include spatial select, spatial join, nearest neighbor
- Choice of strategies
  - Limited choice for some building blocks, e.g. nearest neighbor
- Choosing best strategies
  - Cost models are more complex since
    - spatial queries are both CPU and I/O intensive
    - while traditional queries are I/O intensive
  - Cost models of spatial strategies are not mature



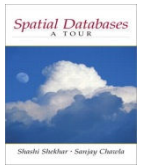
QPO Challenges in SDBMS - Exercise

- Learning Aid
  - Often helpful for readers to try to solve the QPO problem
  - Before looking at the current solutions
  - Particularly when solutions are not mature
- Try following exercise to get an insight into chapter 5 topics
- Exercise:
  - Propose a few additional building blocks for spatial queries
    - besides spatial selection, spatial join and nearest neighbor
    - use GIS operations (Table 1.1, pp.3) as a guide if needed
  - Justify the proposal by listing spatial queries needing the component
  - Detail the proposal by listing a few algorithms for the building block
  - How would one choose between the available algorithms?



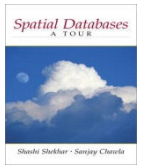
Scope of Discussion

- Chapter 5 will discuss
  - Choice of building blocks for spatial queries
  - Choice of processing strategies for building blocks
  - How to choose the “best” strategy from among the applicable ones?
- Focus on concepts, not procedures
  - Procedures change with change in computer hardware
  - Concepts do not change as often
  - Readers are more likely to remember the concepts after the course



Building Blocks for Spatial Queries

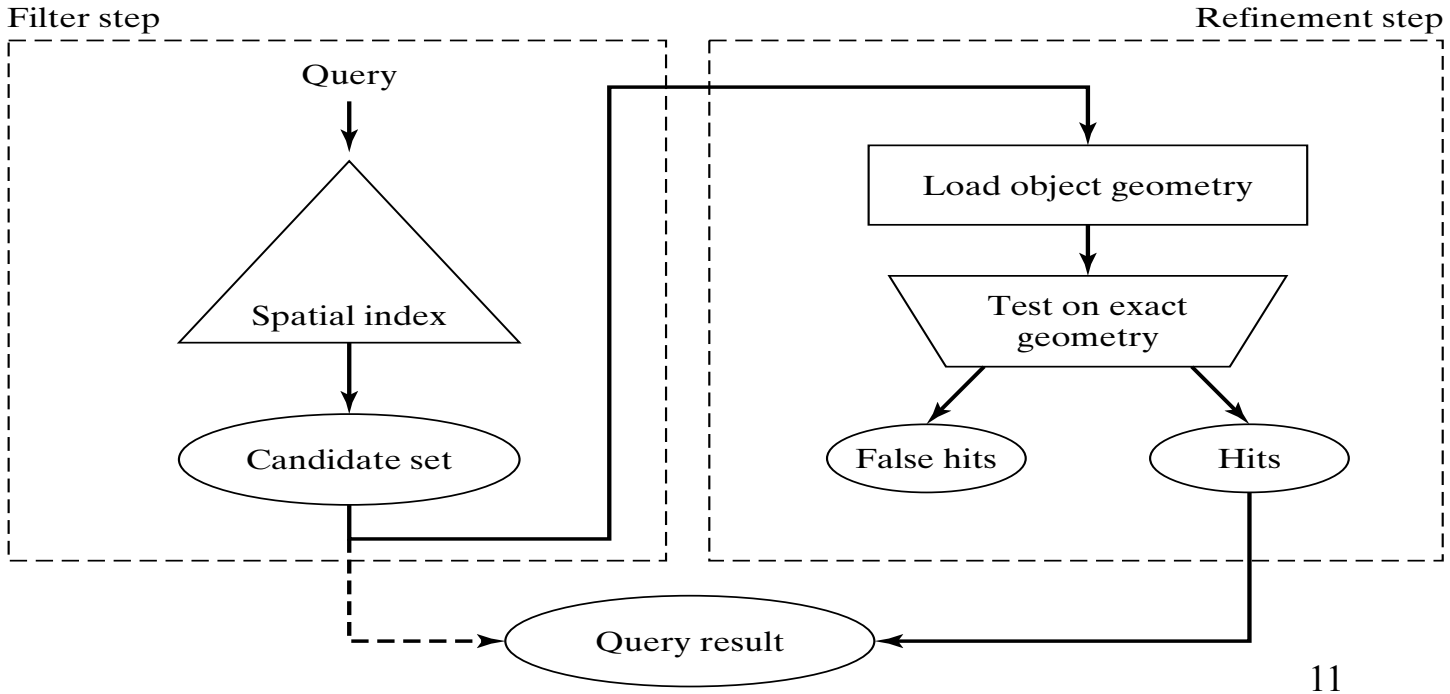
- Challenges in choosing building blocks
  - Rich set of data types - point, line string, polygon, …
  - Rich set of operators - topological, euclidean, set-based, …
  - Large collection of computation geometric algorithms
    - for different spatial operations on different spatial data types
  - Desire to limit complexity of SDBMS
- How to simplify choice of data types and operators?
  - Reusing a Geographic Information System (GIS)
    - which already implements spatial data types and operations
    - however may have difficulties processing large data set on disk
  - SDBMS reduces set of objects to be processed by a GIS
  - SDBMS is used as a filter
  - This is filter and refinement approach

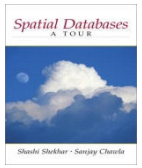


The Filter-Refine Paradigm

- Processing a spatial query Q
  - Filter step : find a superset S of object in answer to Q
    - using approximate of spatial data type and operator
  - Refinement step : find exact answer to Q reusing a GIS to process S
    - using exact spatial data type and operation

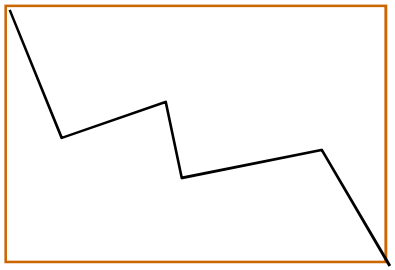
Figure 5.1

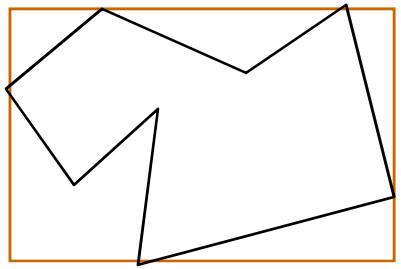


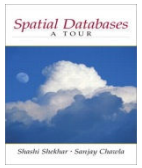


Approximate Spatial Data Types

- Approximating spatial data types
  - Minimum orthogonal bounding rectangle (MOBR or MBR)
    - approximates line string, polygon, …
    - see examples below (black rectangle are MBRs for red objects)
  - MBRs are used by spatial indexes, e.g. R-tree
  - Algorithms for spatial operations MBRs are simple
- Q? Which OGIS operation (Table 3.9, pp.66) returns MBRs ?

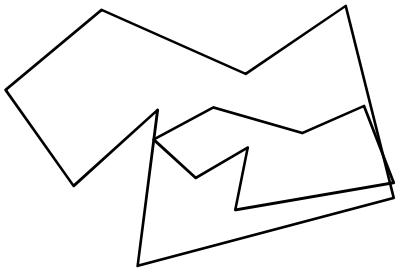


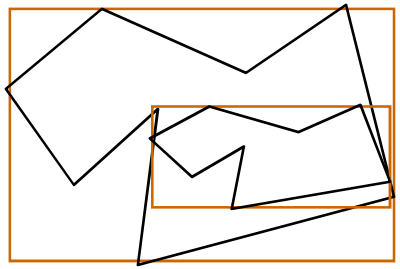


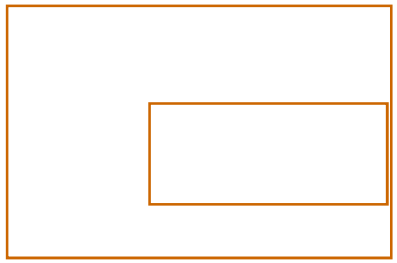


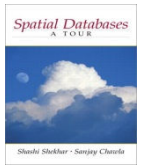
Approximate Spatial Operations

- Approximating spatial operations
  - SDBMS processes MBRs for refinement step
  - Overlap predicate used to approximate topological operations
  - Example: inside(A, B) replaced by
    - overlap(MBR(A), MBR(B)) in filter step
    - see picture below - let A be outer polygon and B be the inner one
    - inside(A, B) is true only if overlap(MBR(A), MBR(B))
    - however overlap is only a filter for inside predicate needing refinement later



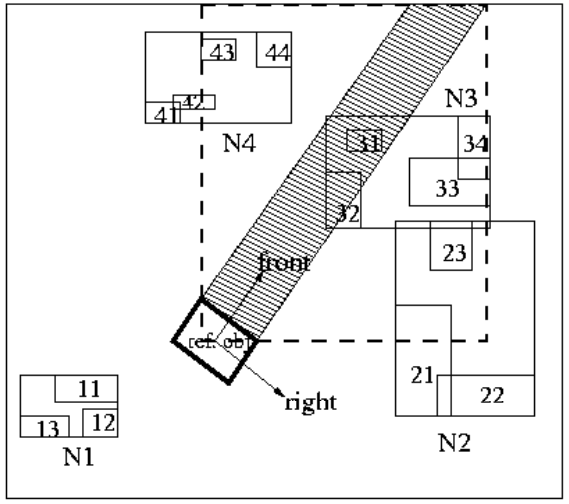




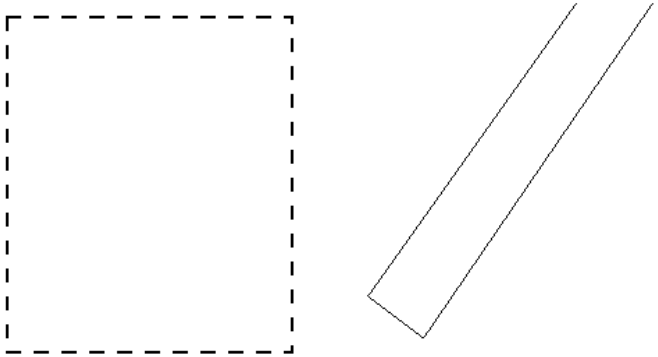


Filter Step Example

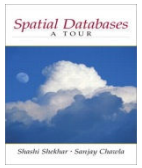
- Query:
  - List objects in front of a viewer V
- Equivalent overlap query
  - Direction region is a polygon
  - List objects overlapping with
    - polygon(front(V))
- Approximate query
  - List objects overlapping with
    - MBR(polygon (front (V)))



(a) World Boundary

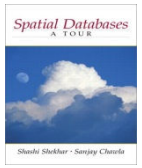


(b) Range Query (c) Direction region



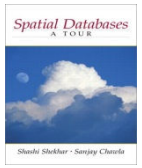
Approximate Spatial Operations - 2

- Exercise: Approximate following using overlap predicate
  - Cross(A, B), Touch(A, B), Disjoint(A, B)
  - See Table 3.9, pp.66 for definition of these operations.
- Exercise: Given MBRs R and S, provide conditions to test
  - Overlap(A, B)
  - Use coordinates of left-lower and upper-right corners of MBRs



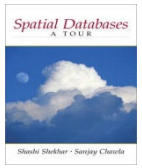
Choice of Building Blocks

- Choice of building blocks
  - Varies across software vendors and products
  - Representative building blocks are listed here
- List of building blocks
  - Point Query: Name a highlighted city on a digital map
    - return one spatial object out of a table
  - Range Query: List all countries crossed by the river Amazon
    - returns several objects within a spatial region from a table
  - Spatial Join: List all pairs of overlapping rivers and countries
    - return pairs from 2 tables satisfying a spatial predicate
  - Nearest Neighbor: Find the city closest to Mount Everest
    - return one spatial object from a collection



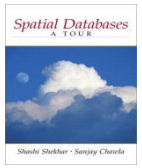
Strategies for Each Building Block

- Choice of strategies
  - Varies across software vendors and products
  - Representative strategies are listed here
  - Some strategies need special file-structures or indices
- Description of strategies
  - Main message: there are multiple strategies for each building block!
  - Focus on concepts rather than procedures
  - Readers interested in procedural details (e.g. algorithms)
    - refer to papers in Bibliographic notes
    - note: better algorithms appear in literature every year!



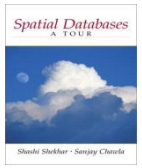
Strategies for Point Queries

- Recall Point Query Example
  - Name a highlighted city on a digital map
  - Return one spatial object out of a table
- List of strategies
  - Scan all B disk sectors of the data file
  - If records are ordered using space filling curve (say Z-order)
    - then use binary search on the Z-order of search point
    - to examine about $\log_2 B$ disk sectors
  - If an index is available on spatial location of data objects,
    - then use find() operation on the index
    - number of disk sector examined = index depth (typically 4 to 5)



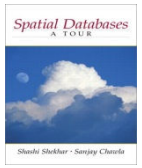
Strategies for Range Queries

- Recall Range Query Example
  - List all countries crossed by of the river Amazon
  - Returns several objects within a spatial region from a table
- List of strategies
  - Scan all B disk sectors of the data file
  - If records are ordered using space filling curve (say Z-order)
    - then determine range of Z-order values satisfying range query
    - use binary search to get lowest Z-order within query answer
    - scan forward in the data file till the highest Z-order satisfying query
  - If an index is available on spatial location of data objects,
    - then use range-query operation on the index



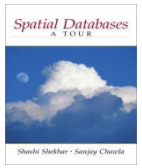
Strategies for Spatial Joins

- Recall Spatial Join Example:
  - List all pairs of overlapping rivers and countries.
  - Return pairs from 2 tables satisfying a spatial predicate
- List of strategies
  - Nested loop:
    - test all possible pairs for spatial predicate
    - all rivers are paired with all countries
  - Space Partitioning:
    - test pairs of objects from common spatial regions only
    - rivers in Africa are tested with countries in Africa only!
  - Tree Matching
    - hierarchical pairing of object groups from each table
  - Other, e.g. spatial-join-index based, external plane-sweep, …



Strategies for Nearest Neighbor Queries

- Recall Nearest Neighbor Example
  - Find the city closest to Mount Everest
  - Return one spatial object from city data file C
- List of strategies
  - Two phase approach
    - fetch C's disk sector(s) containing the location of Mt. Everest
    - M = minimum distance(Mt. Everest, cities in fetched sectors)
    - test all cities within distance M of Mt. Everest (Range Query)
  - Single phase approach
    - recursive algorithm for R-tree
    - eliminate candidates dominated by some other candidate



Query Processing and Optimizer Process

- A site-seeing trip
  - Start : a SQL Query
  - End: an execution plan
  - Intermediate Stopovers
    - query trees
    - logical tree transforms
    - strategy selection

- What happens after the journey?
  - Execution plan is executed
  - Query answer returned

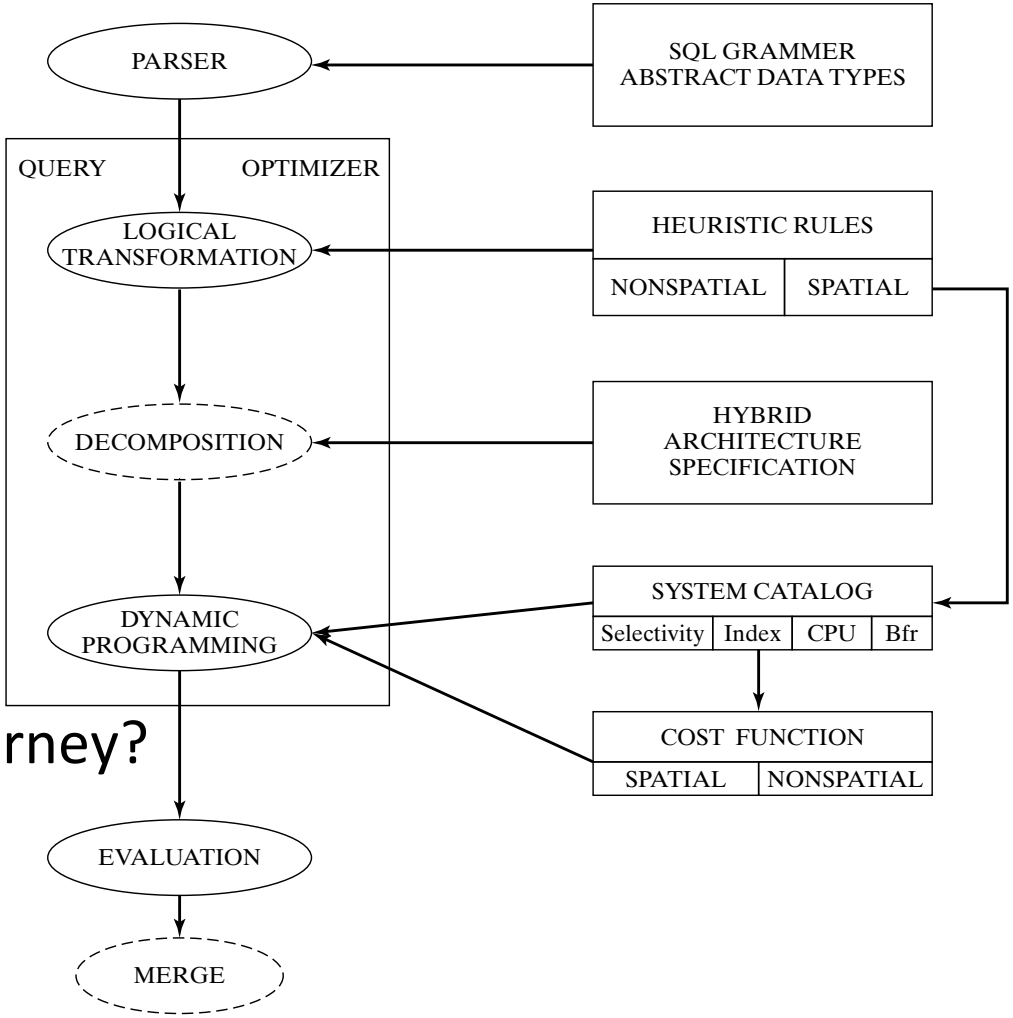
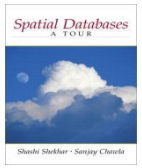


Figure 5.2



Query Trees

- Nodes = building blocks of (spatial) queries
  - See section 3.2 (pp.55) for symbols sigma, pi and join
- Children = inputs to a building block
- Leafs = Tables
- Example SQL query and its query tree follows:

```
SELECT   L.Name
FROM     Lake L, Facilities Fa
WHERE    Area(L.Geometry) > 20 AND
         Fa.Name = 'campground' AND
         Distance(Fa.Geometry, L.Geometry) < 50
```

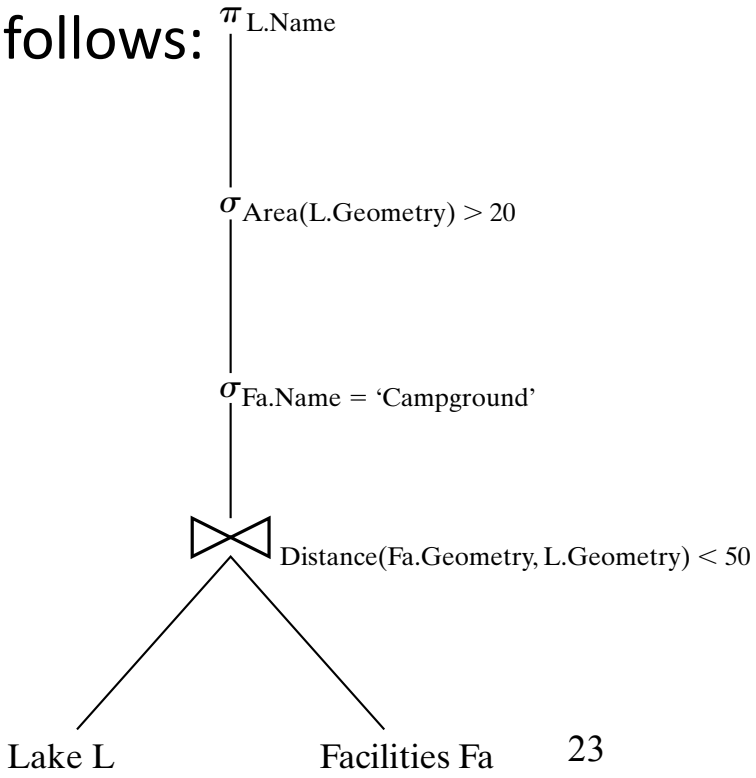
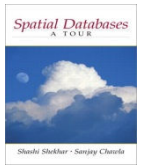


Figure 5.3



Logical Transformation of Query Trees

- Motivation
  - Transformation do not change the answer of the query
  - But can reduce computational cost by
    - reducing data produced by sub-queries
    - reducing computation needs of parent node
- Example Transformation
  - Push down select operation below join
  - Example: Figure 5.4 (compare with Figure 5.3)
  - Reduces size of table for join operation
- Other common transformations
  - Push project down
  - Reorder join operations
  - ...

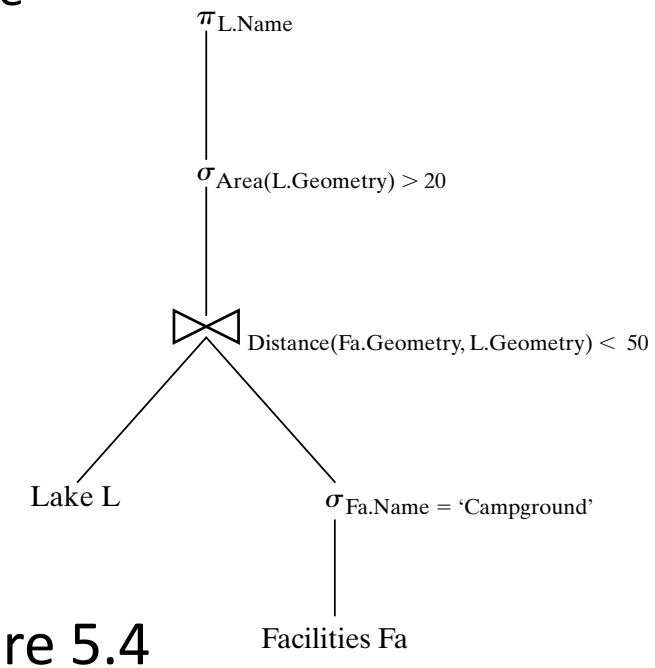
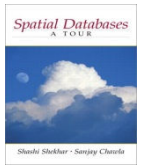


Figure 5.4



Logical Transformation and Spatial Queries

- Traditional logical transform rules
  - For relational queries with simple data types and operations
    - CPU costs are much smaller and I/O costs
  - Need to be reviewed for spatial queries
    - complex data types, operations
    - CPU cost is higher
- Example:
  - Push down spatial selection below join
  - May not decrease cost if
    - area() is costlier than distance()

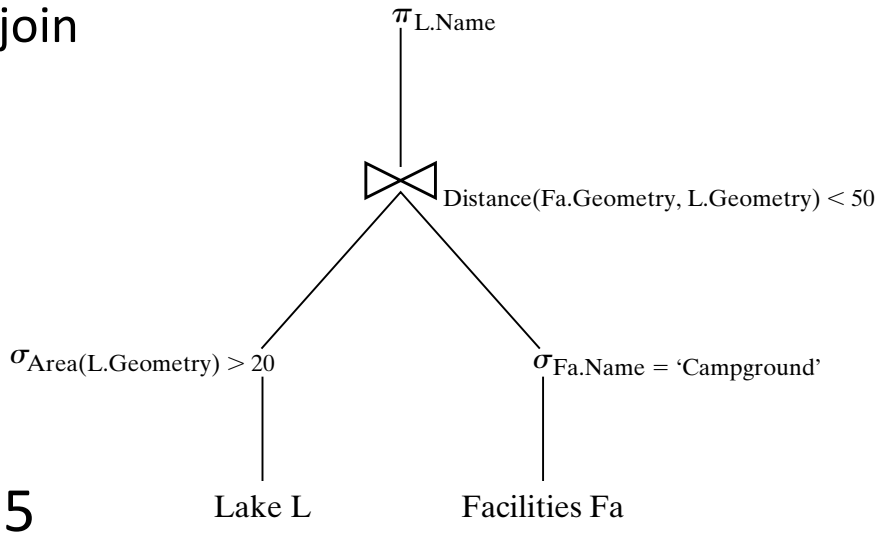
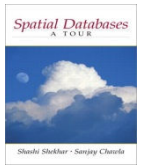


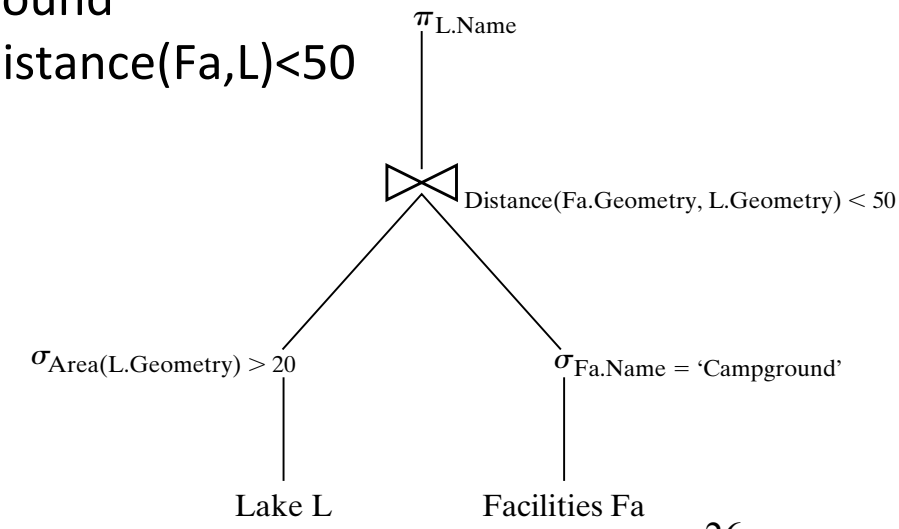
Figure 5.5

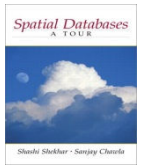


Execution Plans

- An execution plan has 3 components
  - A query tree
  - A strategy selected for each non-leaf node
  - An ordering of evaluation of non-leaf nodes
- Example
  - Strategies for Query tree in Figure 5.5
    - use scan for Area(L.Geometry)>20
    - use index for Fa.Name='Campground'
    - use space-partitioning join for Distance(Fa,L)<50
    - use on-the-fly for projection
  - Ordering
    - as listed above

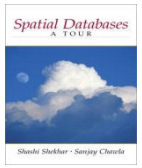
Figure 5.5





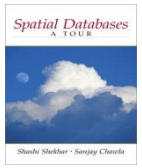
Choosing Strategies for Building Blocks

- A priority scheme
  - Check applicability of each strategies given file-structures and indices
  - Choose highest priority strategy
  - This procedure is fast, used for complex queries
- Rule based approach
  - System has a set of rules mapping situations to strategy choices
  - Example: Use scan for range query if result size > 10 % of data file
- Cost based approach
  - See next slide



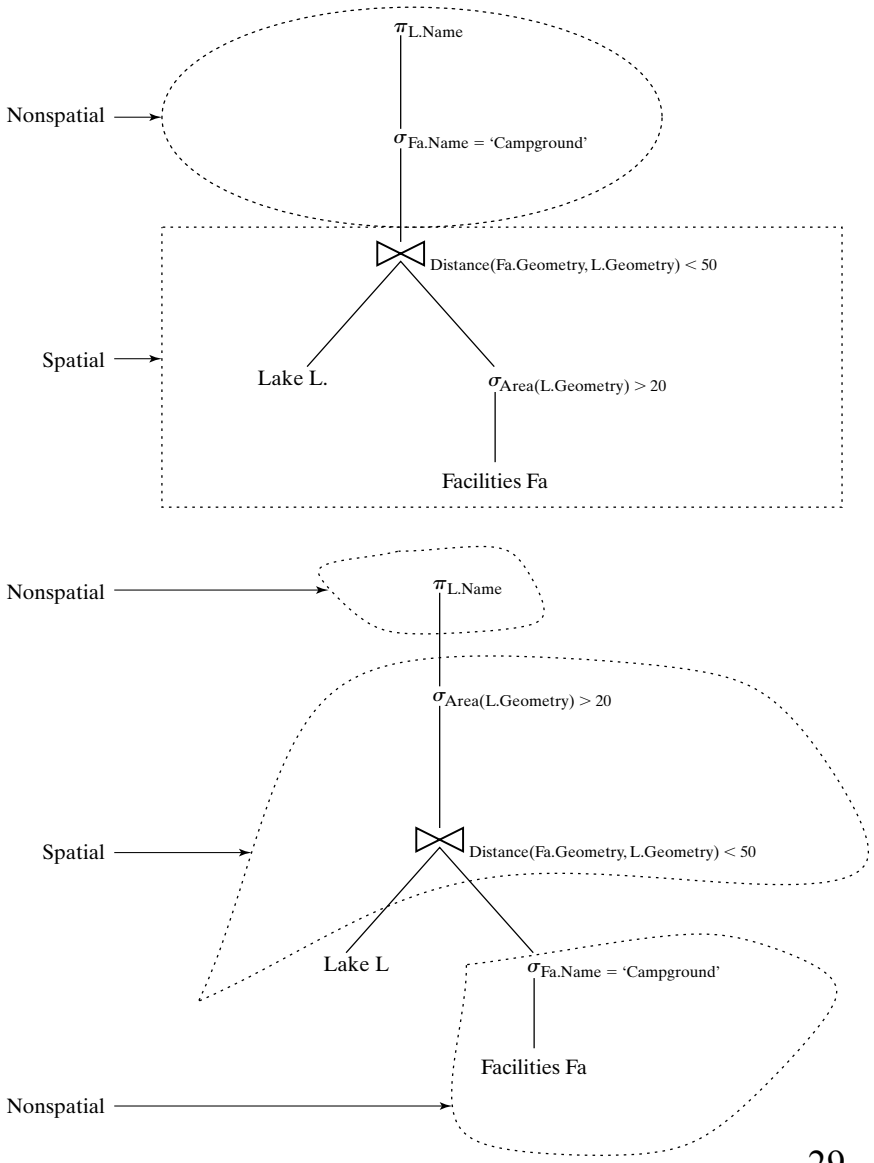
Choosing Strategies for Building Blocks - 2

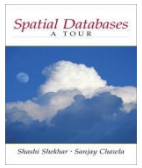
- Cost model based approach
  - Single building block
    - use formulas to estimate cost of each strategy, given table size etc.
    - choose the strategy with least cost
    - example cost models for spatial operation in section 5.3
  - A query tree
    - least cost combination of strategy choices for non-leaf nodes
    - dynamic programming algorithm
- Commercial practice
  - RDBMS use cost based approach for relational building blocks
  - But cost models for spatial strategies are not mature
  - Rule based approach is often used for spatial strategies



Query Decomposition

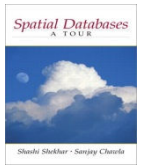
Figure 5.8





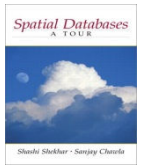
Trends in Query Processing and Optimization

- Motivation
  - SDBMS and GIS are invaluable to many organizations
  - Price of success is to get new requests from customers
    - to support new computing hardware and environment
    - to support new applications
- New computing environments
  - Distributed computing (Section 5.4)
  - Internet and web (Section 5.4)
  - Parallel computers (Section 5.5)
- New applications
  - Location based services, transportation (Chapter 6)
  - Data Mining (Chapter 7)
  - Raster data (Chapter 8)



Distributed Spatial Databases

- Distributed Environments
  - Collection of autonomous heterogeneous computers
  - Connected by networks
  - Client-server architectures
    - server computer provides well-defined services
    - client computers use the services
- New issues for SDBMS
  - Conceptual data model -
    - translation between heterogeneous schemas
  - Logical data model
    - naming and querying tables in other SDBMSs
    - keeping copies of tables (in other SDBMs) consistent with original table
  - Query Processing and Optimization
    - cost of data transfer over network may dominate CPU and I/O costs
    - new strategies to control data transfer costs



Distributed SDBMS - 2

- Data-transfer strategies for joining 2 table at different sites
  - Transfer one table to the other site
  - Semi-join strategy
    - transfer join column of one table to the other site
    - transfer back the matching rows of the other table back to first site
  - Semi-join often is cheaper than transferring a table to other site
    - detailed Example in section 5.4.2 (pp.135)

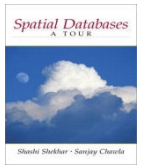
Figure 5.9: Two tables at different sites to be joined on overlap of D_MBR overlap FARM_MBR

FARM

FID (10 bytes)	OWNER_NAME (10 bytes)	FARM_BOUNDARY (2000 bytes)	FARM_MBR (16 bytes)

DISEASE_MAP

MAP-ID (10 bytes)	DISEASE_NAME (20 bytes)	DISEASE_BOUNDARY (2000 bytes)	D_MBR (16 bytes)



Internet and (World-wide-) web

- Internet and Web Environments
  - Very popular medium of information access in last few years
  - A distributed environment
  - Web servers, web clients
    - common data formats (e.g. HTML, XML)
    - common communication protocols (e.g. http)
    - naming - uniform resource locator (url), e.g. www.cs.umn.edu
- New issues for SDBMS
  - Offer SDBMS service on web
  - Use Web data formats, communication protocols etc.
    - example on next slide
  - Evaluate and improve web for SDBMS clients and servers

Web-based Spatial Database Systems

- SDBMS on web
  - MapServer case study
  - SDBMS talks to a web server
  - web server talks to web clients
- Commercial practice
  - Several web based products
  - Web data formats for spatial data
    - GML
    - WMS

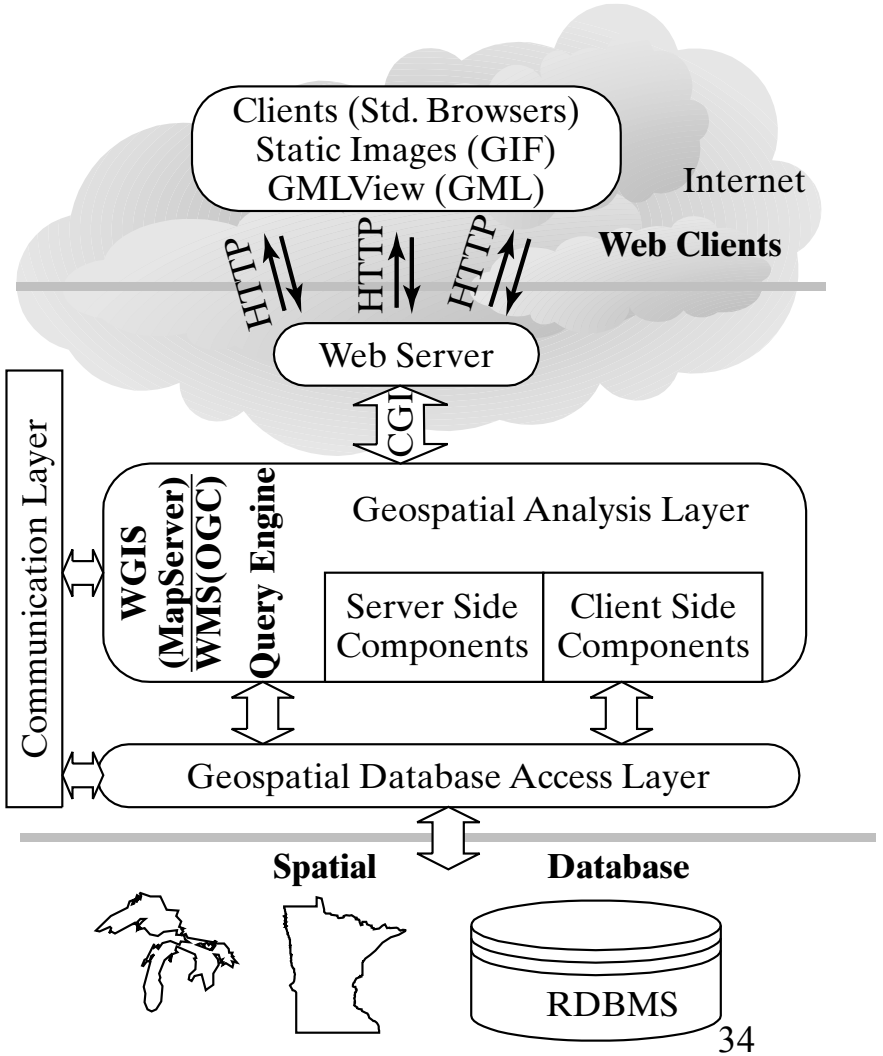
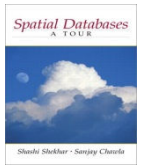


Figure 5.10



Parallel Spatial Databases

- Parallel Environments
  - Computer with multiple CPUs, Disk drives (Figure 5.11 for examples)
  - All CPUs and disk available to a SDBMS
  - Can speed-up processing of spatial queries!

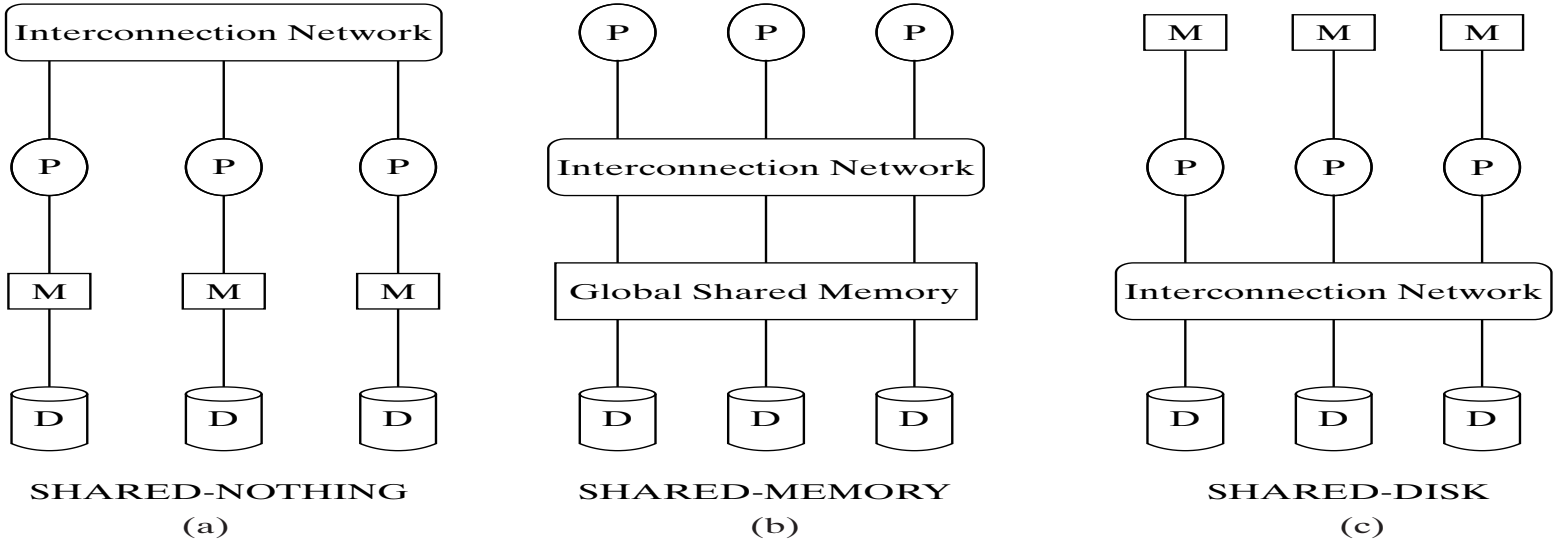
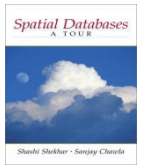
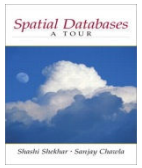


Figure 5.11



Parallel Spatial Databases - 2

- New issues for DBMS
  - Physical Data Model
    - declustering: how to partition tables, indices across disk drives?
  - Query Processing and Optimization
    - query partitioning: how to divide queries among CPUs?
    - cost model of strategies on parallel computers
- Example: Techniques for declustering (Figure 5.12)
  - Simple technique: round robin based on an order (space filling curve)
  - Disk



Declustering for Data Partitioning

- Example
  - A Simple Techniques for declustering (Figure 5.12)
    1. Order the spatial objects using a space filling curve
    2. Allocate to disk drives in a round robin manner
  - Effective for point objects, e.g. pixels in an image
  - Many queries, e.g. large MBRs are parallelized well
    - Example: consider a query to retrieve data in bottom-left quarter of the space
      - two data points retrieved from each disk drive for Z-curve

3	4	5	6	7	0	1	2
6	7	0	1	2	3	4	5
1	2	3	4	5	6	7	0
4	5	6	7	0	1	2	3
7	0	1	2	3	4	5	6
2	3	4	5	6	7	0	1
5	6	7	0	1	2	3	4
0	1	2	3	4	5	6	7

Linear Method
disk-id =
(x + 5y) mod 8

7	0	1	2	3	4	5	6
6	7	0	1	2	3	4	5
5	6	7	0	1	2	3	4
4	5	6	7	0	1	2	3
3	4	5	6	7	0	1	2
2	3	4	5	6	7	0	1
1	2	3	4	5	6	7	0
0	1	2	3	4	5	6	7

CMD Method
disk-id =
(x + y) mod 8

42	43	46	47	58	59	62	63
40	41	44	45	56	57	60	61
34	35	38	39	50	51	54	55
32	33	36	37	48	49	52	53
10	11	14	15	26	27	30	31
8	9	12	13	24	25	28	29
2	3	6	7	18	19	22	23
0	1	4	5	16	17	20	21

→

2	3	6	7	2	3	6	7
0	1	4	5	0	1	4	5
2	3	6	7	2	3	6	7
0	1	4	5	0	1	4	5
2	3	6	7	2	3	6	7
0	1	4	5	0	1	4	5
2	3	6	7	2	3	6	7
0	1	4	5	0	1	4	5

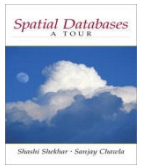
Z-Curve Method -> disk-id = Z(x, y) mod 8

63	62	49	48	47	44	43	42
60	61	50	51	46	45	40	41
59	56	55	52	33	34	39	38
58	57	54	53	32	35	36	37
5	6	9	10	31	28	27	26
4	7	8	11	30	29	24	25
3	2	13	12	17	18	23	22
0	1	14	15	16	19	20	21

→

7	6	1	0	7	4	3	2
4	5	2	3	6	5	0	1
3	0	7	4	1	2	6	5
2	1	6	5	0	3	1	2
5	6	1	2	7	4	3	2
4	7	0	3	6	5	0	1
3	2	5	4	1	2	7	6
0	1	6	7	0	3	4	5

Hilbert Method -> disk-id = H(x, y) mod 8



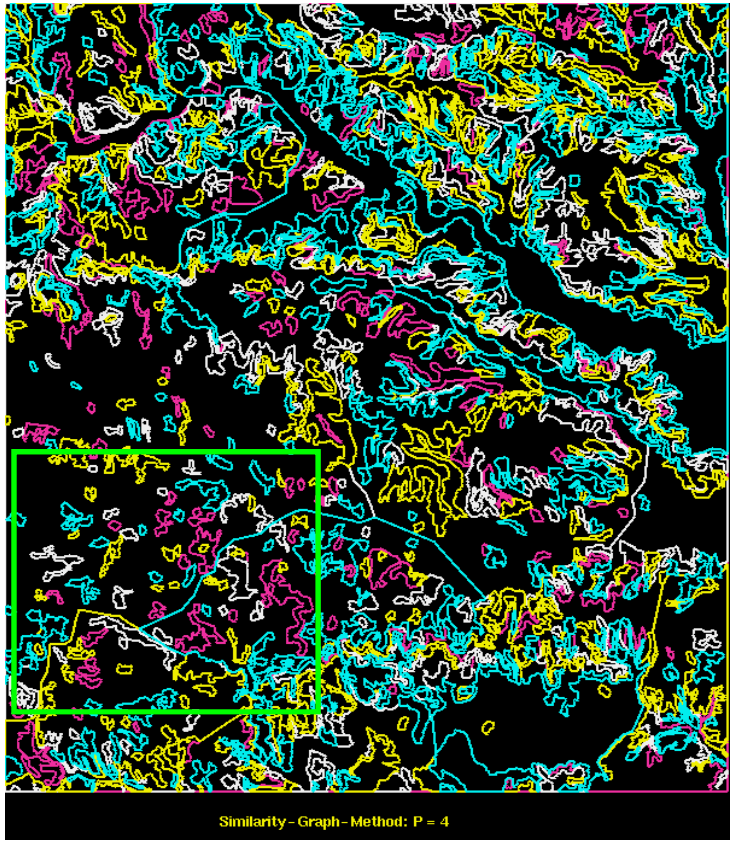
A Case Study: High Performance GIS

Goal: Meet the response time constraint for real time battlefield terrain visualization in flight simulator.

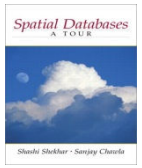
Methodology:

- Data-partitioning approach
- Evaluation on parallel computers,
  - e.g. Cray T3D, SGI Challenge.

Significance: A major improvement in capability of geographic information systems for determining the subset of terrain polygons within the view point (Range Query) of a soldier in a flight simulator using real geographic terrain data set.

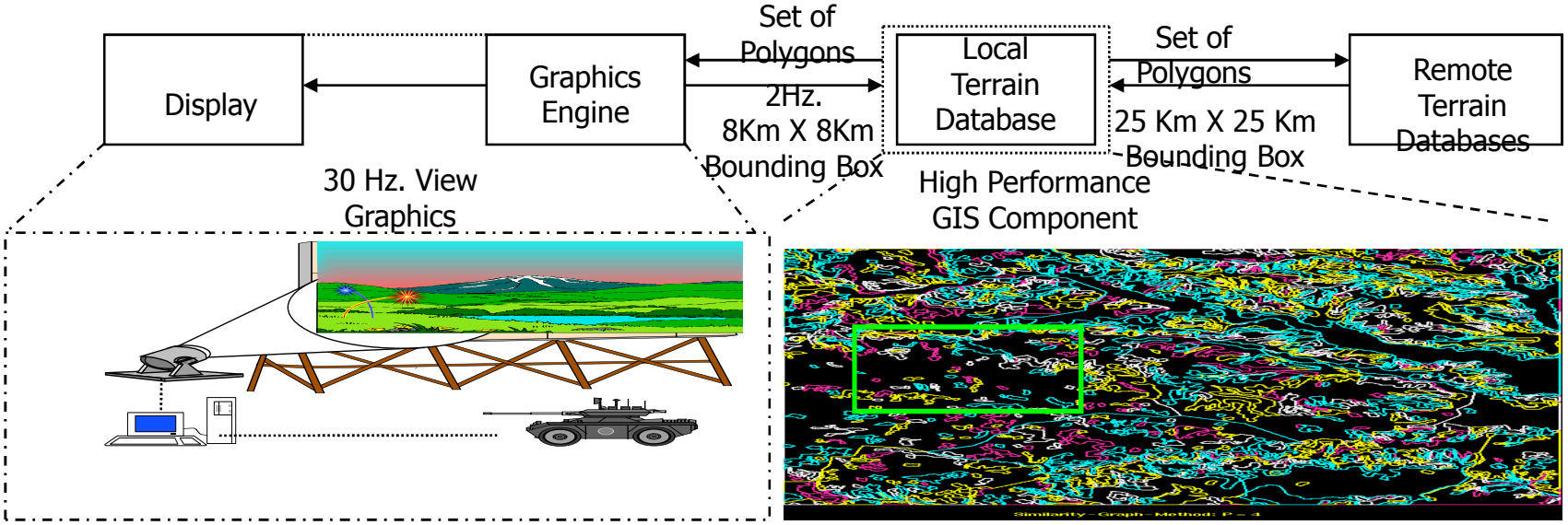


Dividing a Map among 4 processors. Polygons within a processor have common color

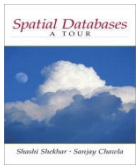


A Case Study: High Performance GIS

- (1/30) second Response time constraint on Range Query
- Parallel processing necessary since best sequential computer cannot meet requirement
- Green rectangle = a range query, Polygon colors shows processor assignment



Dividing a Map among 4 processors. Polygons within a processor have common color



Real Time Visualization: A Case Study

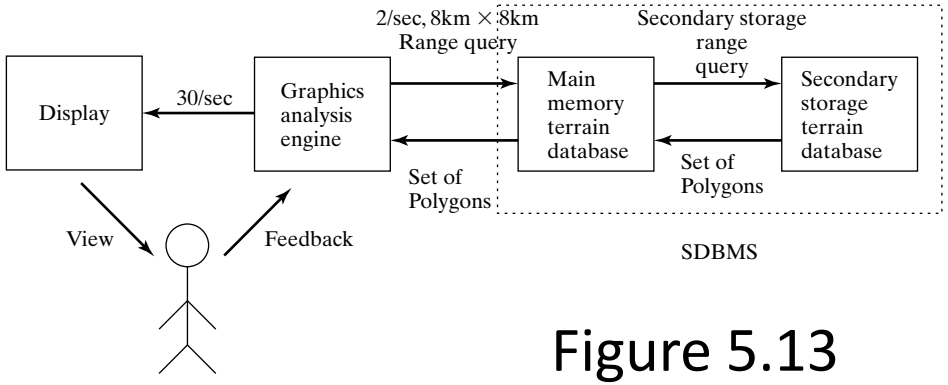


Figure 5.13

Options for Dividing the Polygon Data

Options for Dividing Bounding Box

	No Division	Subsets of polygons	Subsets of small polygons	Subsets of edges
No Division	I	II	III	IV
Divide into small boxes	III	III	III	IV
Divide into edges	IV	IV	IV	IV

Figure 5.16

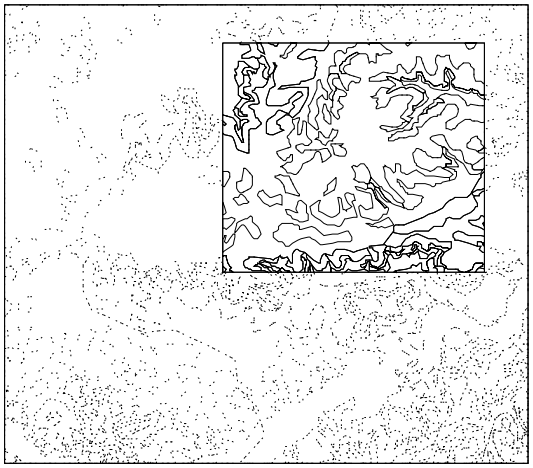


Figure 5.14 Range Query

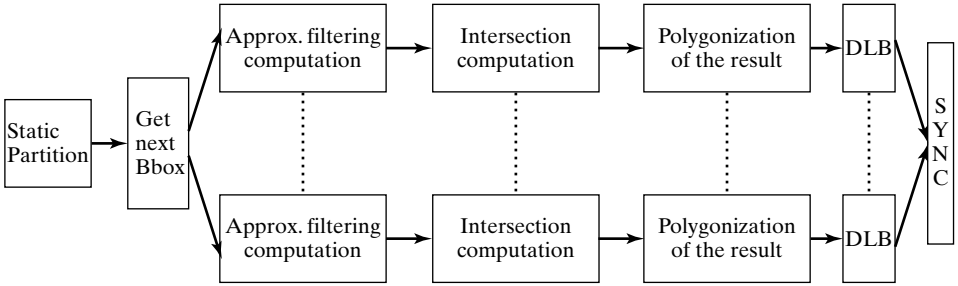
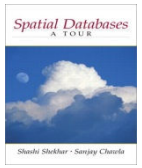


Figure 5.15



Summary

- Query processing and optimization (QPO)
  - translates SQL Queries to execution plan
- QPO process steps include
  - Creation of a query tree for the SQL query
  - Choice of strategies to process each node in query tree
  - Ordering the nodes for execution
- Key ideas for SDBMS include
  - Filter-Refine paradigm to reduce complexity
  - New building blocks and strategies for spatial queries