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Chapter 9 – MM/Search Extensions for Object-Relational DBMS

Digital Libraries and Content Management

(OR-)DBMS-Support for Content-based Search

- Search engine coupling
  - separate, external search engine for content-based retrieval
- Integrated search support
  - utilization of "conventional" index support (e.g., b*-trees)
    - "high-level indexing"
  - specialized (multi-dimensional) index support
- Extensible indexing support

Coupling of External Search Engines

- Shallow Integration
  - Loose coupling of DB search and content-specific search/retrieval
    - content search engine is not integrated into DBMS
    - well-defined interfaces and interaction
  - Index data for media objects may still reside outside the DBMS
    - index is accessed during query evaluation by calling out to external search engine
  - Location/storage of media objects is not impacted
    - inside the DB, or outside (e.g., as a file)
- Motivation
  - lack of appropriate index support in the DBMS
    - adding new index support is complex, expensive
  - optimized external search engine exists
    - costly migration
- Potential problems
  - integrity
  - usability (in search and administration)
  - performance

Example: DB2 Text Extender

- Text is stored in char column (long varchar, CLOB, ...) or anything that can be used to "produce" character strings
  - structured type (SQL/MM)
  - external storage
- Search using scalar UDFs
  - CONTAINS
  - SCORE
  - NUMBER_OF_MATCHES
- Remember: preprocessing is expensive!
  - CONTAINS function always needs to access an external text index
    - performance issues
  - updates, inserts on text columns become expensive
    - asynchronous index updates
    - decoupled from column update

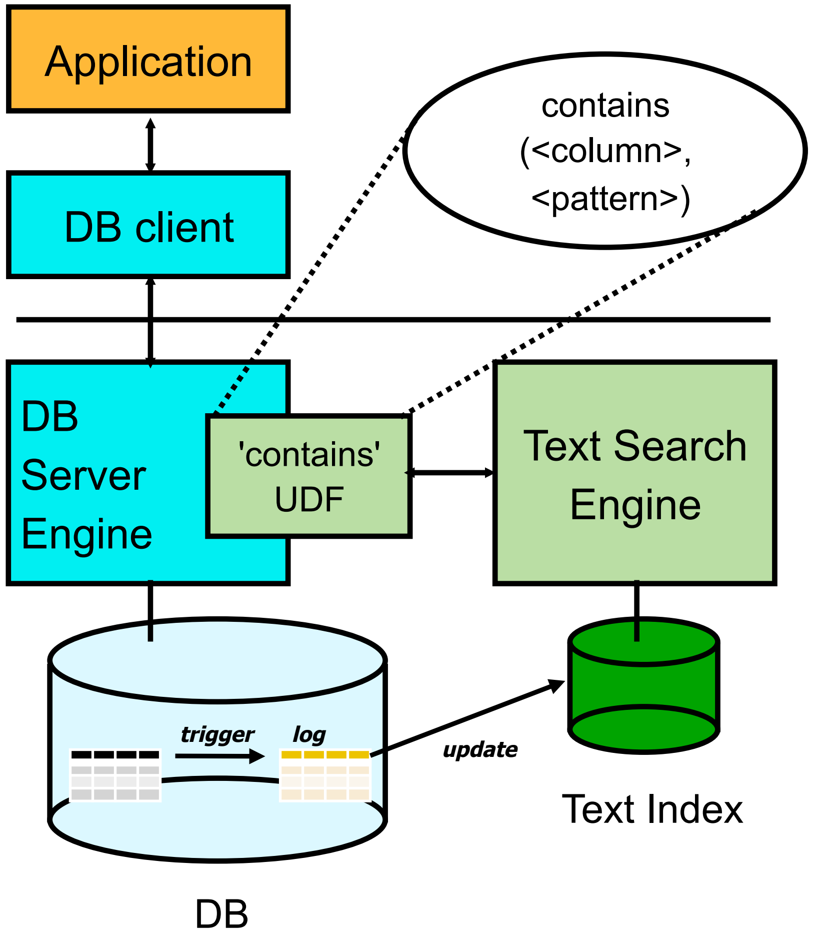
Projects

proj-no	title	budget	description
123	'....'	200000	'This project ..'
456	'....'	400000	'Objects are...'
789	'....'	700000	'A database...'

```
SELECT proj-no, title
FROM compschema.projects
WHERE contains (description,
    ' "database"
      IN SAME SENTENCE AS
     "object-relational" ') = 1
```

Text Extender System Architecture

- Text index is stored outside the DB under control of text search engine (TSE)
  - index scope: all documents in a text column
  - primary key of table used as document id
- Separate TSE process for building and incrementally updating the text index
  - configuration of update interval, etc.
- Each index has a log table in the DB
  - holds information about updates that need to be reflected in the index
  - populated using DB-triggers
  - used by asynchronous index update process
- Search UDF (implemented as a C function) calls text engine, which returns a list of doc-ids
  - may "miss" the latest updates!



Search – Performance Problems

- Scalar UDFs (contains, etc.)
  - calls text search engine to retrieve search result list
  - checks whether the document id is in that list
    - or returns the score, #of matches
  - for each tuple in PROJECTS!
- First (big) improvement:
  - UDF can 'buffer' the result list to reduce text engine API calls
  - TSE API only needs to be invoked for the first tuple in PROJECTS
- But: the DB engine still calls the UDF for every row!
  - table scan
  - invocation overhead

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Search Using Table Functions

- Table function (TF)
  - (user-defined) function that returns a table structure instead of a single scalar value
  - can be invoked in the FROM clause of a SELECT statement using special syntax
- Text search TF interacts with TSE, returns search results for specific index
  - input parameters for
    - scope of the text search (external index name or name of indexed table, column)
    - text search pattern
    - optional parameters for limiting the result set
  - result table has columns holding
    - primary key value (document id)
    - score (optional), number of matches (optional)
- Example

```
SELECT p.pro-no, p.title
FROM compschema.projects p,
  TABLE(containstable('COMPSCHEMA', 'PROJECTS', 'DESCRIPTION,
          ' "database" IN SAME SENTENCE AS "object-relational" ')) AS restab
WHERE p.proj-no = restab.primarykey
```

Table Functions - Evaluation

- Advantages
  - performance!
    - avoids table scan
- Disadvantages: usability!
  - asks end-user to make choice for the optimizer
    - in some situations, using the scalar function results in a better plan
  - lack of transparency
    - two different syntax alternatives for the same query
  - use of table functions
    - not "intuitive" to write
    - requires join of function result with document table, complicating the queries
    - potential lack of support by query tools, data access tools
  - view transparency lost
    - view definition may access multiple tables with text columns
      - involves multiple indexes, based on the base table columns
    - user has to know view definitions

Query Rewrite/Optimization Support

- Optimizer is made aware of additional rewrite options
  - users continue to use scalar functions for better usability
  - internally, the query is rewritten to exploit table function for better performance
- Based on correspondences
  - scalar function to table function
  - parameter correspondences
    - search argument
    - document/primary key columns
  - meta data
    - table/columns names as TF parameters
  - either hard-wired, or through syntax extensions in "CREATE FUNCTION"
- Further optimization opportunities
  - multiple scalar functions in the same query mapped to the same TF
  - predicate/sorting "push-down"

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WHERE contains (description,
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        'DESCRIPTION',
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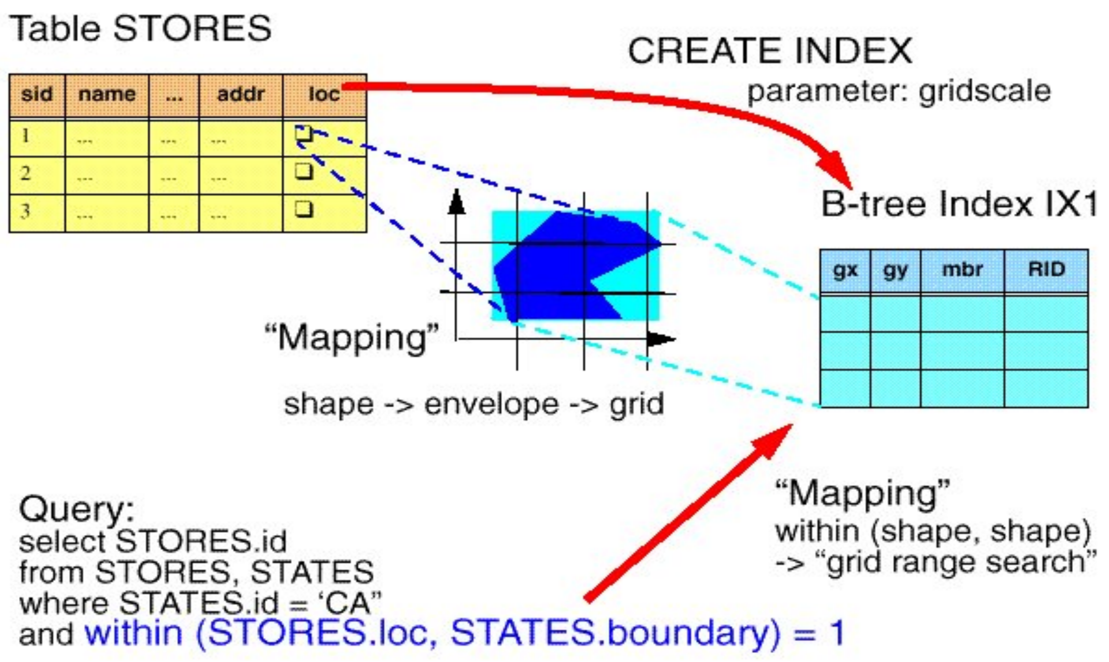
          "object-relational" ')) AS restab
WHERE p.proj-no = restab.primarykey
```

High-Level Indexing - Motivation

- Existing DB index mechanisms (e.g., b*-tree) may not support content search predicates directly (e.g., within (shape, shape), overlaps (shape, shape) for spatial)
- But it may be possible to exploit them to a certain degree
- Example: spatial search
  - define a coordinate grid
  - b*-tree index entries for shape
    - grid cell coordinates
    - min. bound. rectangle (mbr)
  - for each cell touched by mbr
- Search can be done in stages
  - compute grid cells, mbr for search argument ('CA')
  - search index with cell coordinates as arguments
  - filter false positives based on mbr, eliminate duplicates
  - compute final result using exact shape



Query:
select STORES.id
from STORES, STATES
where STATES.id = 'CA'
and within (STORES.loc, STATES.boundary) = 1

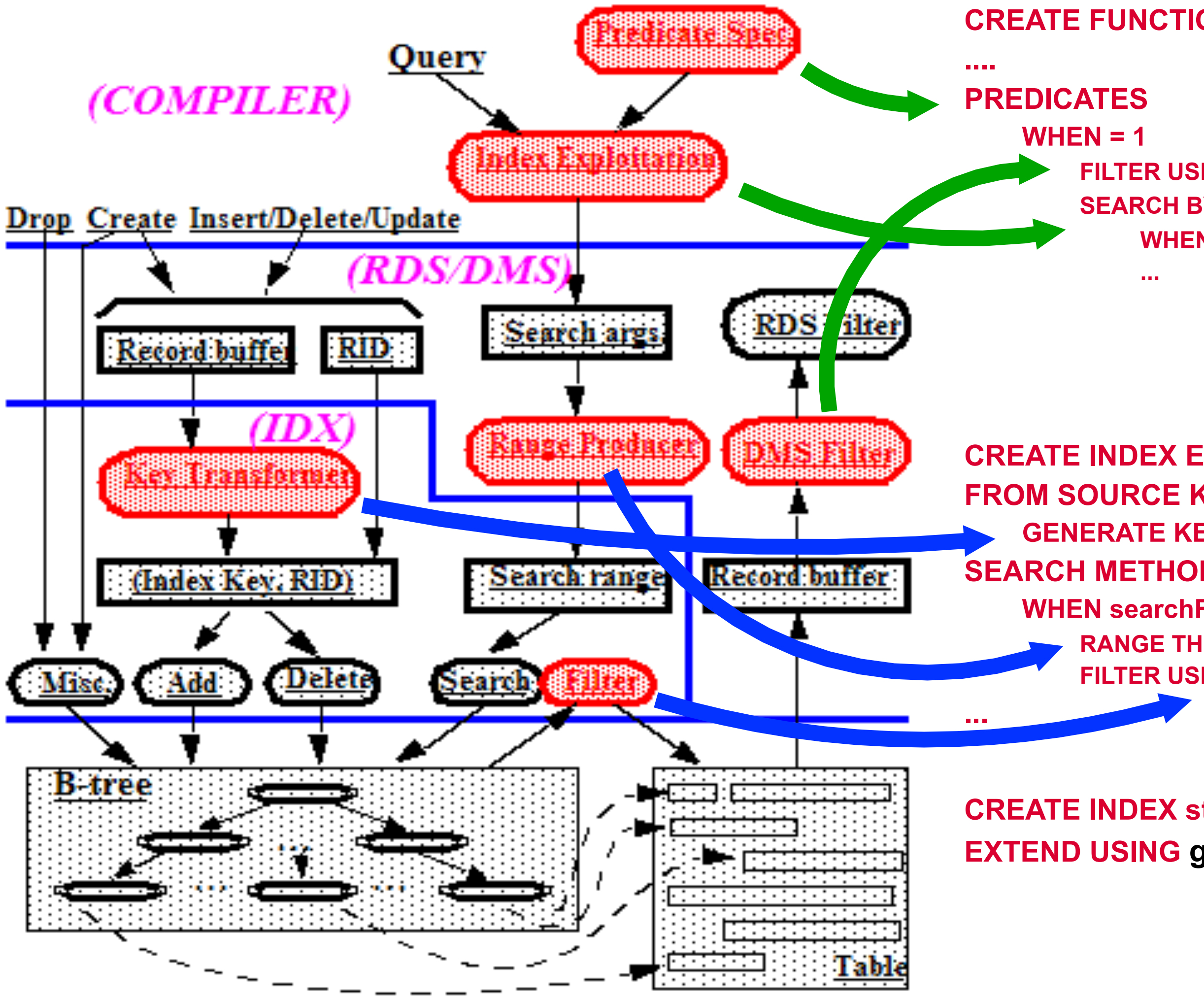
Spatial Indexing Requirements

- Index type for 'reuse' in index creation
- Index entries
  - Not useful to store complete shape object in the index
  - Should contain information extracted from a shape object
    - grid cell coordinates
    - minimum bounding rectangle information
  - Multiple index entries for a single shape object have to be supported
    - a shape object may 'appear' in multiple grid cells
- Index exploitation (search)
  - flexible search method for mapping a 'query shape' to a range search on the index
  - multiple levels of search (result set filtering)
    - grid coordinate match
    - mbr overlap or containment
    - full geometric overlap or containment
  - multiple search methods for the same index extension
    - overlap or containment
- Index parameters
  - grid levels (determines granularity of the grid)
  - grid levels may vary for individual indexes

Index Extension Support

- Builds on top of existing B-Tree support
  - index plug-ins
- DDL for creating named index extensions
  - define parameters to be supplied at ‘create index’ time
  - specify mapping of UDT to (multiple) index entries (Key Transformer)
  - define search methods that map a 'query literal' to a set of ranges over the index (Range Producers)
  - provide filter functionality that further reduces answer set during index lookup (IDX Filter)
- Specify how search UDFs can be mapped to search methods of the index extension
  - extended CREATE FUNCTION syntax to provide Predicate Specification, Index Exploitation
  - provide filter functionality that further reduces answer set during DMS predicate evaluation (DMS Filter)
- Extended ‘CREATE INDEX’ to allow usage of index extensions
  - create index using an index extension
  - supply required parameters (e.g., grid scale)

Index Extension Architecture - DDL

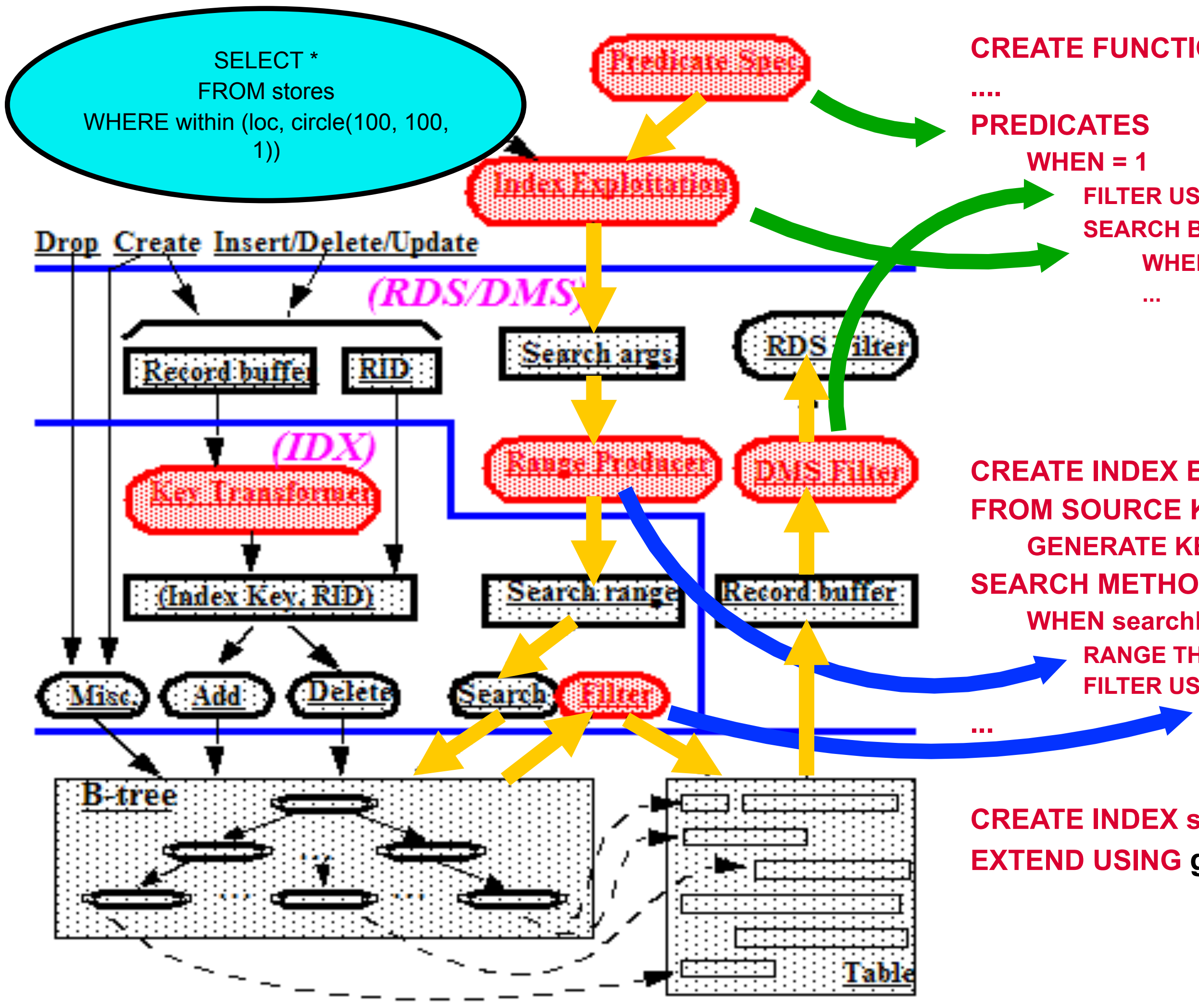


```
CREATE FUNCTION within (x shape, y shape) ..
....
PREDICATES
    WHEN = 1
        FILTER USING mbrWithin(...)
        SEARCH BY INDEX EXTENSION grid
            WHEN KEY(x) USE searchFirst(y)
            ...
```

```
CREATE INDEX EXTENSIONS grid (scale VARCHAR ...)
FROM SOURCE KEY (shapeCol shape)
    GENERATE KEY USING (gridEntry ( .... ) ) ...
SEARCH METHODS
    WHEN searchFirst(searchArg shape)
        RANGE THROUGH gridRange( ... )
        FILTER USING checkDuplicates( ... )
...
```

```
CREATE INDEX store_loc ON stores(loc)
EXTEND USING grid('10 100 1000')
```

Index Extension Architecture - Query



CREATE FUNCTION within (x shape, y shape) ..
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PREDICATES
    WHEN = 1
        FILTER USING mbrWithin(...)
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            WHEN KEY(x) USE searchFirst(y)
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CREATE INDEX EXTENSIONS grid (scale VARCHAR ...)
FROM SOURCE KEY (shapeCol shape)
    GENERATE KEY USING (gridEntry (....)) ...
SEARCH METHODS
    WHEN searchFirst(searchArg shape)
        RANGE THROUGH gridRange(...)
        FILTER USING checkDuplicates(...)
...

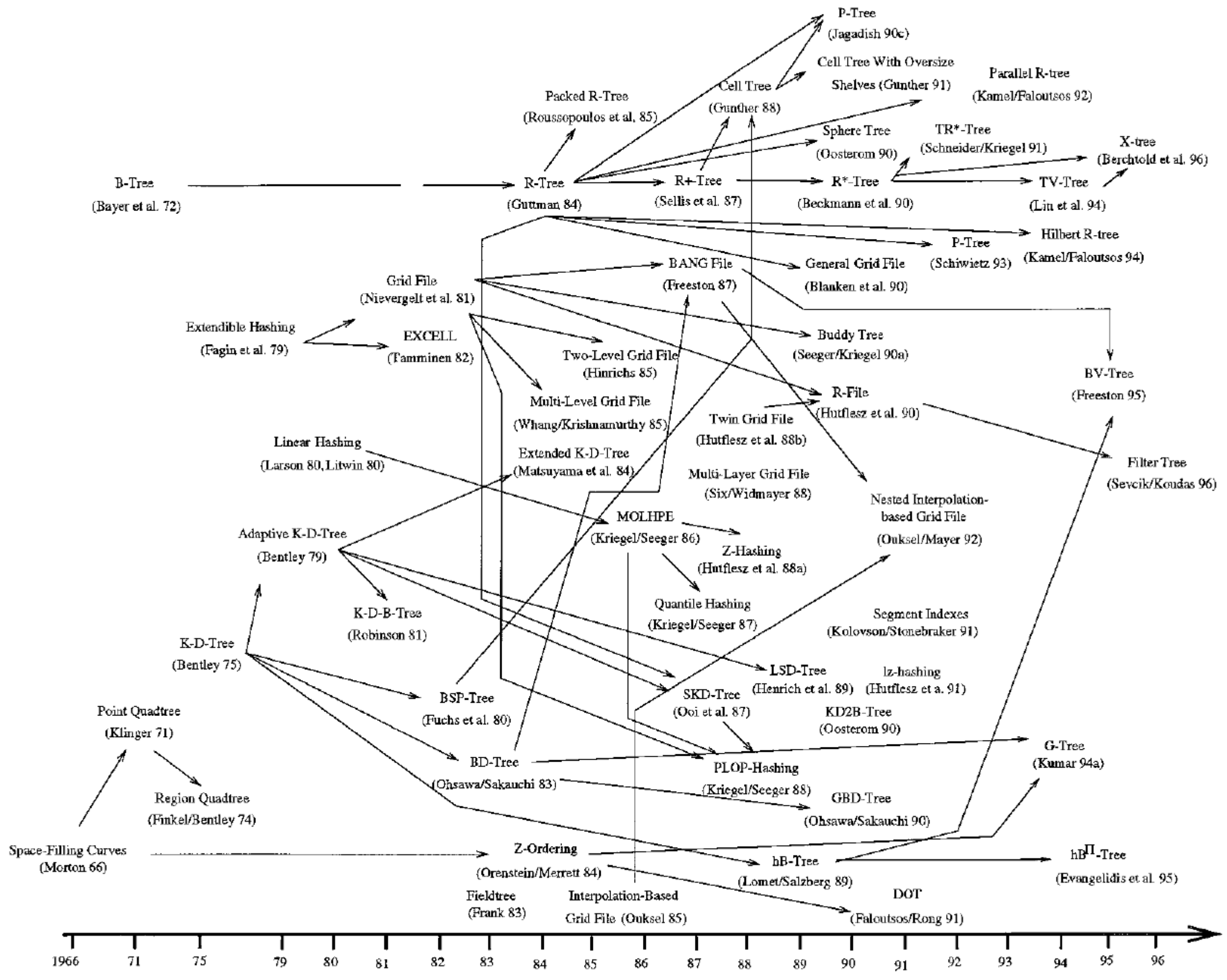
CREATE INDEX store_loc ON stores(loc)
EXTEND USING grid('10 100 1000')

Specialized Index Support

- Most interesting queries over media objects are
  - range queries, or
  - nearest-neighbor queries (top-k) involving similarity/distance measure
  - involving multiple dimensions
- "Classic" index structures in DBMS (e.g., B-tree)
  - limited to a single dimension
  - can be leveraged only in a restricted manned, not suitable for high-dimensional space
- Multi-dimensional index methods
  - large number of methods proposed over the last years
  - no clear winner
    - complexity (hard to understand/compare)
    - numerous criteria for optimality, performance
    - strong dependency on data/query
  - commercial systems
    - optimized, highly tuned implementation of a simple and robust index method
    - most popular: R-tree
- More details: course on realization of database systems

Multi-dimensional Access Methods - History

Gaede, V., Günther, O.:
Multidimensional Access Methods
ACM Computing Survey 30:2, 1998


P-Tree (Jagadish 90c)
Cell Tree With Oversize Shelves (Gunther 91)
Parallel R-tree (Kamel/Faloutsos 92)
Packed R-Tree (Roussopoulos et al. 85)
Cell Tree (Gunther 88)
Sphere Tree (Oosterom 90)
TR*-Tree (Schneider/Kriegel 91)
X-tree (Berchtold et al. 96)
B-Tree (Bayer et al. 72)
R-Tree (Guttman 84)
R+-Tree (Sellis et al. 87)
R*-Tree (Beckmann et al. 90)
TV-Tree (Lin et al. 94)
Hilbert R-tree (Kamel/Faloutsos 94)
P-Tree (Schiwietz 93)
Grid File (Nievergelt et al. 81)
BANG File (Freeston 87)
General Grid File (Blanken et al. 90)
Extendible Hashing (Fagin et al. 79)
EXCELL (Tamminen 82)
Buddy Tree (Seeger/Kriegel 90a)
Two-Level Grid File (Hinrichs 85)
BV-Tree (Freeston 95)
R-File (Hutflesz et al. 90)
Multi-Level Grid File (Whang/Krishnamurthy 85)
Twin Grid File (Hutflesz et al. 88b)
Linear Hashing (Larson 80, Litwin 80)
Extended K-D-Tree (Matsuyama et al. 84)
Multi-Layer Grid File (Six/Widmayer 88)
Filter Tree (Sevcik/Koudas 96)
Nested Interpolation-based Grid File (Ouksel/Mayer 92)
MOLHPE (Kriegel/Seeger 86)
Adaptive K-D-Tree (Bentley 79)
Z-Hashing (Hutflesz et al. 88a)
Quantile Hashing (Kriegel/Seeger 87)
Segment Indexes (Kolovson/Stonebraker 91)
K-D-B-Tree (Robinson 81)
K-D-Tree (Bentley 75)
LSD-Tree (Henrich et al. 89)
lz-hashing (Hutflesz et a. 91)
SKD-Tree (Ooi et al. 87)
KD2B-Tree (Oosterom 90)
Point Quadtree (Klinger 71)
BSP-Tree (Fuchs et al. 80)
G-Tree (Kumar 94a)
BD-Tree (Ohsawa/Sakauchi 83)
PLOP-Hashing (Kriegel/Seeger 88)
Region Quadtree (Finkel/Bentley 74)
GBD-Tree (Ohsawa/Sakauchi 90)
Space-Filling Curves (Morton 66)
Z-Ordering (Orenstein/Merrett 84)
hB-Tree (Lomet/Salzberg 89)
hB$^{\Pi}$-Tree (Evangelidis et al. 95)
Fieldtree (Frank 83)
Interpolation-Based Grid File (Ouksel 85)
DOT (Faloutsos/Rong 91)
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Extensibility – User-defined Access Methods

- ORDBMS provides support for user-defined access methods
  - primary access methods
    - relational table interface for direct read/write access
    - data may be stored outside the DB
  - secondary access methods
    - index structure to support key-based retrieval of rows in a table
    - index entries may reside outside the DB
- Based on generic interfaces
  - developers can supply their own implementation of access method APIs
  - implementation may utilize storage services of the DBMS (e.g., BLOB storage)
- Example: IBM Informix Dynamic Server virtual tables/indexes
  - pioneered in POSTGRES DBMS
  - Oracle (Data Options) offers similar capabilities

Virtual Indexes in Informix Dynamic Server

- Virtual Index Interface
  - purpose functions
    - functionality to build, connect to, populate, query, and update the index
      - includes cost information for the optimizer
    - called by DBMS server to pass SQL statement specifications to the access method
    - example: CREATE INDEX …
    - to be implemented by the access method developer
  - descriptors
    - predefined data types used to exchange information
      - e.g., qualification descriptor contains a data structure describing the content of the WHERE-clause
    - parameters for API calls
  - accessor functions
    - obtain specific information from the descriptors
    - supplied by the DBMS
- Programmer is responsible for implementing
  - index functionality (see above)
  - concurrency control on index
  - logging/recovery, unless index data resides in DB BLOBs

Important Purpose Functions - Overview

Invoking Statement	**Purpose Function**
all	am_open(MI_AM_TABLE_DESC *) am_close(MI_AM_TABLE_DESC *)
CREATE INDEX	am_create(MI_AM_TABLE_DESC *) am_insert(MI_AM_TABLE_DESC *, MI_ROW *, MI_AM_ROWID_DESC *)
DROP INDEX	am_drop(MI_AM_TABLE_DESC *)
INSERT	am_insert(MI_AM_TABLE_DESC *, MI_ROW *, MI_AM_ROWID_DESC *)
DELETE	am_delete(MI_AM_TABLE_DESC *, MI_ROW *, MI_AM_ROWID_DESC *)

SELECT
INSERT, UPDATE, DELETE
WHERE...
	am_scancost(MI_AM_TABLE_DESC *, MI_AM_QUAL_DESC *)
	am_beginscan(MI_AM_SCAN_DESC *)
	am_getnext(MI_AM_SCAN_DESC *, MI_ROW **, MI_AM_ROWID_DESC *)
	am_endscan(MI_AM_SCAN_DESC *)

SELECT with join	am_rescan(MI_AM_SCAN_DESC *)
UPDATE	am_update(MI_AM_TABLE_DESC *, MI_ROW *, MI_AM_ROWID_DESC *, MI_ROW *,MI_AM_ROWID_DESC *)
UPDATE STATISTICS	am_stats(MI_AM_TABLE_DESC *,MI_AM_ISTATS_DESC *)

Operator Classes

- Operator class connects SQL operators, predicates, data types to an access method
  - which data types can be indexed using a specific secondary access method?
  - what predicates can be supported by the index?
  - how can the optimizer be provided with statistics?
- Two types of functions
  - strategy functions
    - needed for optimizer to decide whether an index can be used for a specific operation on a data type
    - lists operators that appear in SQL (e.g., "=", "contains", …) and are supported by the index
  - support functions
    - called by the access method, e.g., to traverse the index and obtain the results
    - example: "compare keys" for a B-tree index
- Similar to high-level indexing for B-trees, but supports user-defined access methods as well!

Extensibility – Generalized Search Trees

- Generalized Search Tree (GiST)
  - generalization of tree-based index structures
    - e.g., B*-tree, R-tree can be seen as special cases
  - framework
    - provides implementation of common, generic index functionality
    - adapted by providing/registering a *key class* implementation with six methods
- Common GiST properties
  - balanced tree, high fanout
  - internal nodes are used as a directory
    - series of keys, pointers
  - leaf nodes point to the actual data
    - linked list storage
  - search for tuples that match a query predicate:
    - starting at the root, for each pointer on the node,
      if the associated key is consistent with the query predicate,
      then traverse the subtree
    - requirement: key must match every data item (transitively) stored "below" it

may be an arbitrary 'predicate' that holds for each datum below the key, e.g., an integer range, or a bounding box

GiST Key Methods and Tree Methods

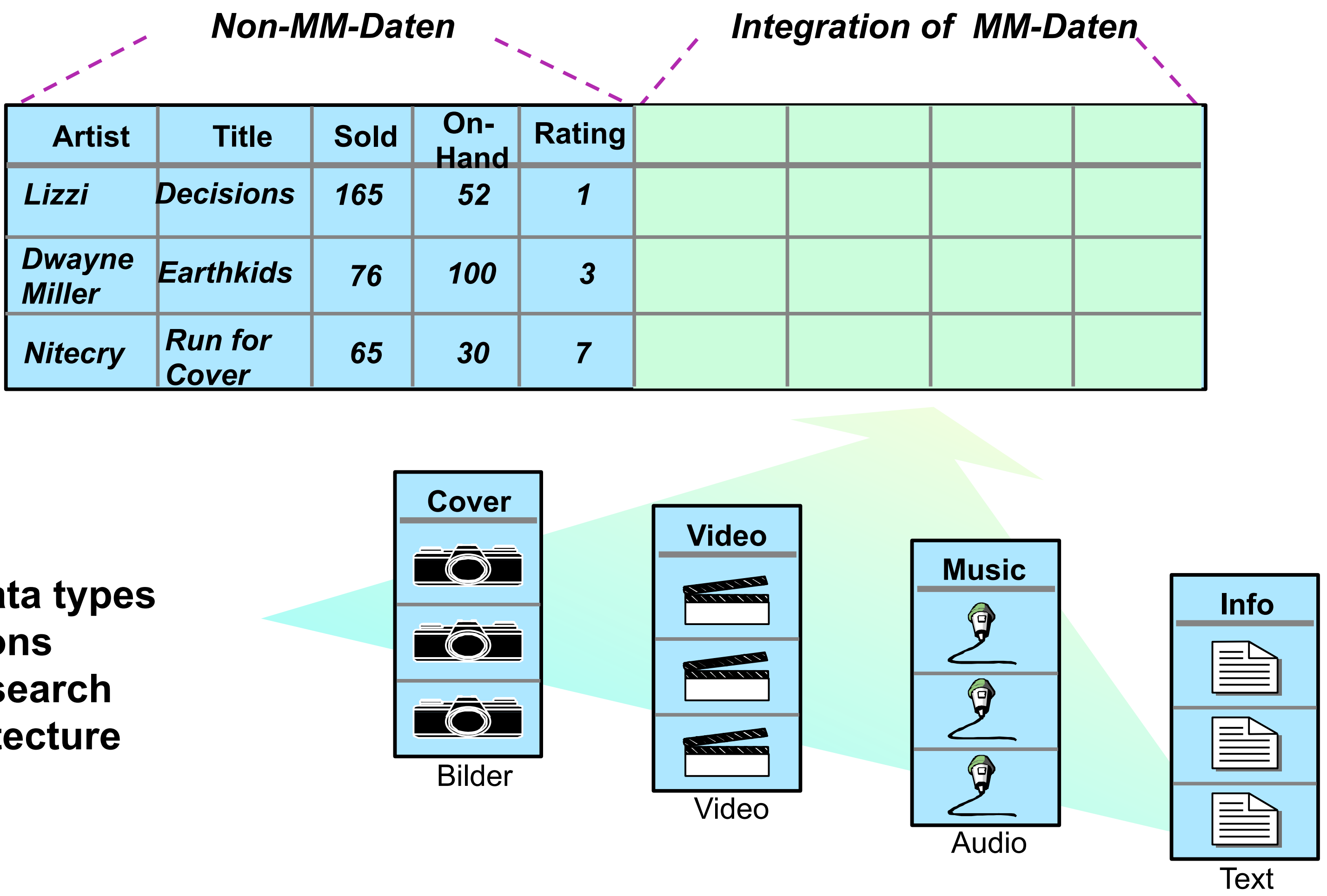
- Key Methods (to be provided as an extension)
  - consistent (entry, predicate)
    - false, if conjunction of key and query predicate is unsatisfiable
    - may return false positives
  - union (set of entries)
    - return predicate that holds for the union of all tuples stored 'below' all of the entries
  - penalty (entry1, entry2)
    - domain-specific cost (penalty) for inserting entry2 into entry 1 subtree
    - aids split and insert algorithms
  - picksplit (set of entries)
    - splits set of entries into two sets of entries
  - compress
  - decompress

- Tree methods (provided by framework)
  - search
    - uses "consistent()"
  - search in linear ordered domains (findMin, Next)
    - uses "consistent()"
    - requires further ordering guarantees, "compare" method implementation
  - insert (insert, chooseSubtree, split, adjustKeys)
    - uses "penalty", "pickSplit", "union"
    - maintains tree balance
  - delete
    - uses "union"

Commercial Systems

- Database Extenders (IBM DB2)
  - data types and functions
    - Text Search, Net Search Extender
    - Image, Audio, Video Extender
    - Spatial Extender (ESRI)
  - utilize search engine coupling, high-level indexing approaches
- Data Blades (Illustra, IBM Informix Universal Server)
  - collection of data types and associated functions
    - Text, Spatial, Geodetic, Image Foundation, Video Foundation, Visual Information Retrieval (Virage)
  - utilize virtual indexes, operator classes, R-tree specialized index structure
  - largely provided by business partners, certified by IBM/Informix
- Data Options (Oracle)
  - interMedia (text, image, audio, video), Spatial, Visual Information Retrieval
  - utilize virtual index approach
- Status
  - similar functionality, but only partial standardization

DB2 Extender – Application View



Artist	Title	Sold	On-Hand	Rating				
Lizzi	*Decisions*	*165*	*52*	*1*				
Dwayne Miller	*Earthkids*	*76*	*100*	*3*				
Nitecry	*Run for Cover*	*65*	*30*	*7*				

- **Complex data types**
- **New functions**
- **Integrated search**
- **Open architecture**

Extended Data Model (Example: Image Extender)

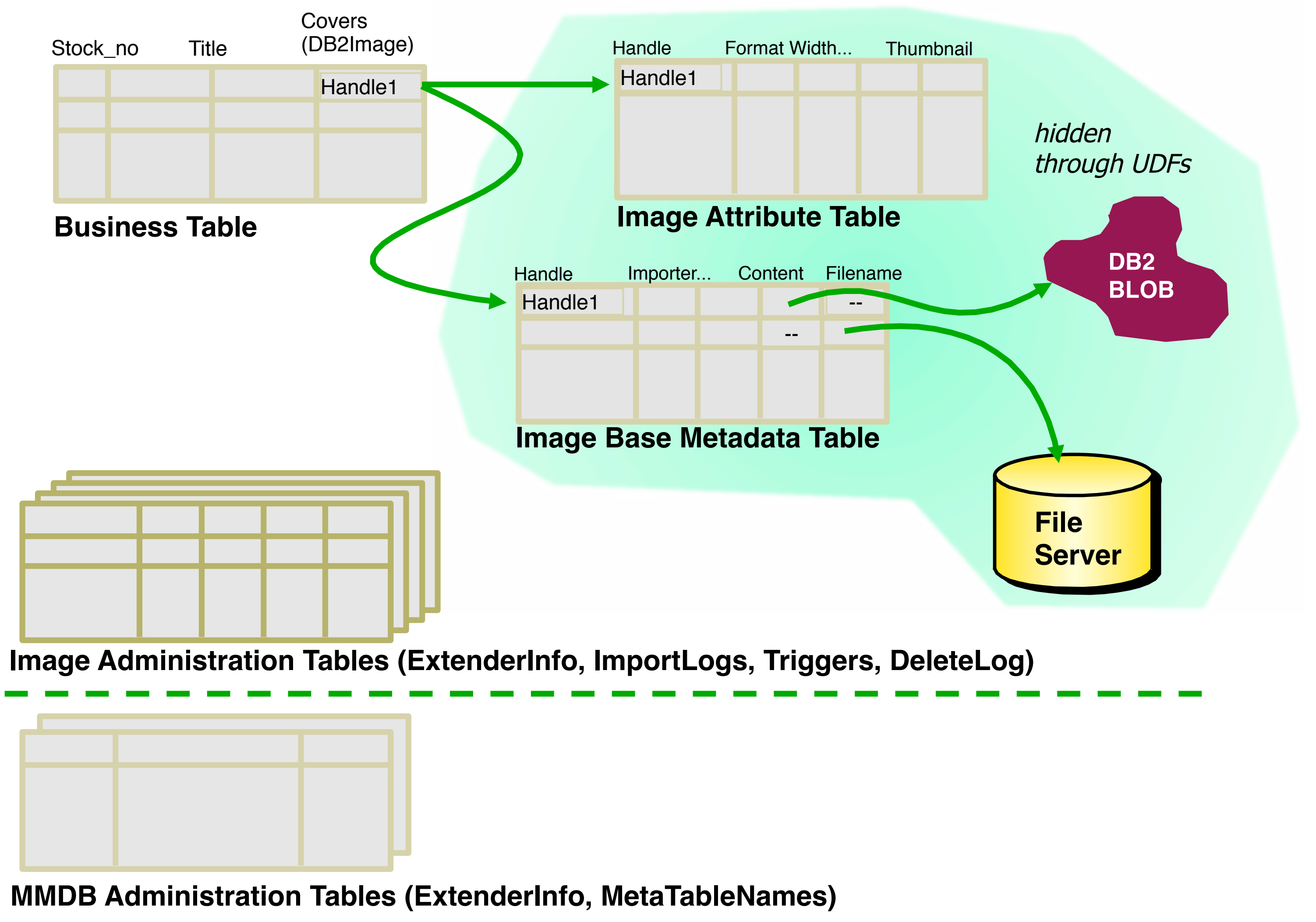


Image Extender: Overview

- Attributes stored in side tables, accessible through UDFs
  - format, thumbnail, length, width, ...
- Support for common image formats
  - (BMP, EPS, EP2, GIF, IMG, IPS, JPG, PCX, PGM, PS, PSC, PS2, TIF, YUG, ...)
- Format conversion routines
- Support for internal and external storage of media objects
- Utilizes the Query by Image Content (QBIC) search engine
  - average color, color histogram, positional color, texture
  - features are extracted in an explicit catalog run, then available for search
- Ranking (scoring) of search results

Video Extender: Overview

- Supported (searchable) attributes:
  - format, duration, number of frames, ...
- Support for AVI, MPEG1, MPEG2, QT
- DB-storage for store-and-forward playback
- External media-server storage for realtime playback
- Import, export and update of videos
- Support for Video Shot Change Detection
  - shot detection, management of a shot catalog in the DB, extraction of frames
- In combination with QBIC:
  - "Find the sunset shot in the video most similar to a given image and start playback at that shot"

Summary

- ORDBMS architectures and support for MM-search
  - cannot be limited to provision of data types and functions
  - requires additional infrastructure for efficient content-based search
- Search engine coupling
  - separate, external search engine for content-based retrieval
    - cost, utilization and protection of competitive, optimized search engines
    - table functions, query rewrite approaches for performance/usability improvements
- Integrated search support
  - utilization of "conventional" index support (e.g., b*-trees)
    - "high-level indexing" that provides mapping of UDTs and predicated to index capabilities
    - multi-level search
  - specialized (multi-dimensional) index support
- Extensible indexing support
  - virtual indexes/access methods
    - need to implement "purpose functions" for index operations, index maintenance
      - rather complex undertaking (locking, recovery, …)
    - most powerful and flexible approach
  - generalized search trees (GiST)
    - reduced programming effort through search tree framework, class library
- Commercial ORDBMS support
  - IBM DB2 Extenders, IBM Informix Data Blades, Oracle Data Options