CMU SCS

15-826: Multimedia Databases and Data Mining

Lecture #4: Multi-key and Spatial Access Methods - I

C. Faloutsos

CMU SCS

Must-Read Material

- Textbook, Chapter 4
- [Bentley75] J.L. Bentley: *Multidimensional Binary Search Trees Used for Associative Searching*, CACM, 18,9, Sept. 1975.
- Ramakrinshan+Gehrke, Chapter 28.1-3

CMU SCS

Outline

Goal: 'Find similar / interesting things'

- Intro to DB
- Indexing - similarity search
- Data Mining

CMU SCS

Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
- spatial access methods
- text
- ...

CMU SCS

Sec. key indexing

- attributes w/ duplicates (eg., EMPLOYEES, with 'job-code')
- Query types:
  - exact match
  - partial match
    - 'job-code'= 'PGM' and 'dept'='R&D'
  - range queries
    - 'job-code'='ADMIN' and salary < 50K

CMU SCS

Sec. key indexing

- Query types - cont'd
  - boolean
    - 'job-code'='ADMIN' or salary>20K
  - nn
    - salary ~ 30K

CMU SCS

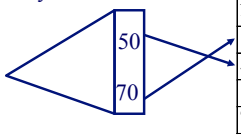
Solution?

CMU SCS

Solution?

- Inverted indices (usually, w/ B-trees)
- Q: how to handle duplicates?

salary-index



Name	Job-code	Salary	Dept
Smith	PGM	70	R&D
Jones	ADMIN	50	R&D
….			
Tomson	ENG	50	SALES

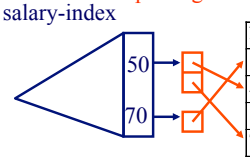
CMU SCS

Solution

- A#1: eg., with postings lists

postings lists

salary-index



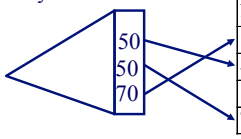
Name	Job-code	Salary	Dept
Smith	PGM	70	R&D
Jones	ADMIN	50	R&D
….			
Tomson	ENG	50	SALES

CMU SCS

Solution

- A#2: modify B-tree code, to handle dup's

salary-index



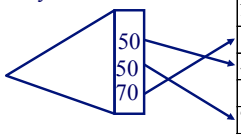
Name	Job-code	Salary	Dept
Smith	PGM	70	R&D
Jones	ADMIN	50	R&D
….			
Tomson	ENG	50	SALES

CMU SCS

How to handle Boolean Queries?

- eg., 'sal=50 AND job-code=PGM'?

salary-index



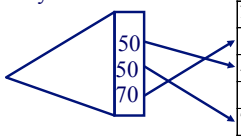
Name	Job-code	Salary	Dept
Smith	PGM	70	R&D
Jones	ADMIN	50	R&D
….			
Tomson	ENG	50	SALES

CMU SCS

How to handle Boolean Queries?

- from indices, find lists of qual. record-ids
- merge lists (or check real records)

salary-index



Name	Job-code	Salary	Dept
Smith	PGM	70	R&D
Jones	ADMIN	50	R&D
….			
Tomson	ENG	50	SALES

CMU SCS

Sec. key indexing

- easily solved in commercial DBMS:

```
create index sal-index on
  EMPLOYEE (salary);
select * from EMPLOYEE
   where salary > 50 and
   job-code = 'ADMIN'
```


CMU SCS

Sec. key indexing

- can create combined indices:

```
create index sj on EMPLOYEE
  ( salary, job-code);
```


CMU SCS

Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
  - main memory: quad-trees
  - main memory: k-d-trees
- spatial access methods
- text
- ...

CMU SCS

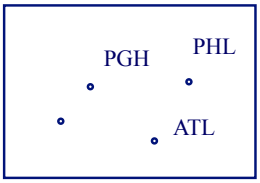
Quad-trees

- problem: find cities within 100mi from Pittsburgh
- assumption: all fit in main memory
- Q: how to answer such queries quickly?

CMU SCS

Quad-trees

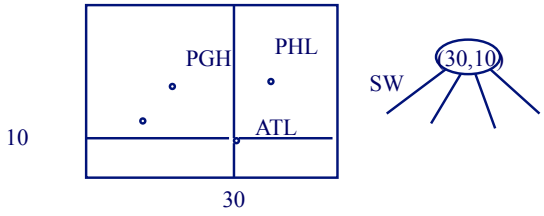
- A: recursive decomposition of space, e.g.:



CMU SCS

Quad-trees

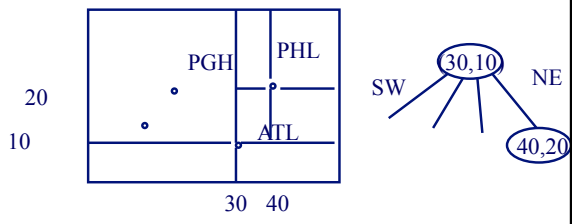
- A: recursive decomposition of space, e.g.:



CMU SCS

Quad-trees

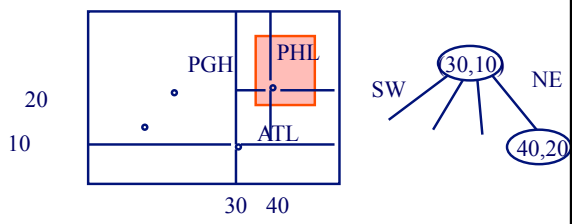
- A: recursive decomposition of space, e.g.:



CMU SCS

Quad-trees - search?

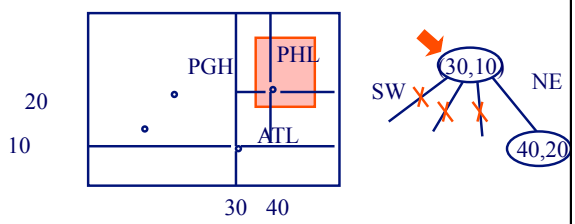
- find cities with (35<x<45, 15<y<25):



CMU SCS

Quad-trees - search?

- find cities with (35<x<45, 15<y<25):



CMU SCS

Quad-trees - search?

- pseudocode:

```
range-query( tree-ptr, range)
  if (tree-ptr == NULL) exit;
  if (tree-ptr->point within range){
   print tree-ptr->point}
  for each quadrant {
   if ( range intersects quadrant ) {
     range-query( tree-ptr->quadrant-ptr, range);
   }
```


CMU SCS

Quad-trees - k-nn search?

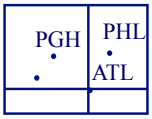
- k-nearest neighbor algo - more complicated:
  - find 'good' neighbors and put them in a stack
  - go to the most promising quadrant, and update the stack of neighbors
  - until we hit the leaves

CMU SCS

Quad-trees - discussion

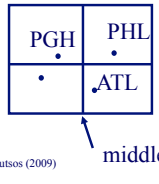
- great for 2- and 3-d spaces
- several variations, like fixed decomposition:

'adaptive'



'fixed'

z-ordering (later)



CMU SCS

Quad-trees - discussion

- but: unsuitable for higher-d spaces (why?)

CMU SCS

Quad-trees - discussion

- but: unsuitable for higher-d spaces (why?)
- A: 2^d pointers, per node!
- Q: how to solve this problem?
- A: k-d-trees!

CMU SCS

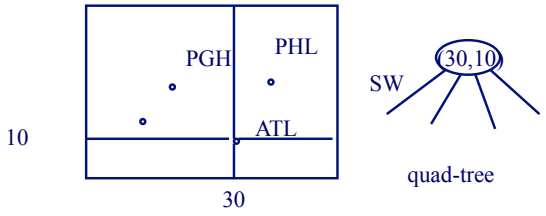
Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
  - – main memory: quad-trees
  - – main memory: k-d-trees
- spatial access methods
- text
- ...

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

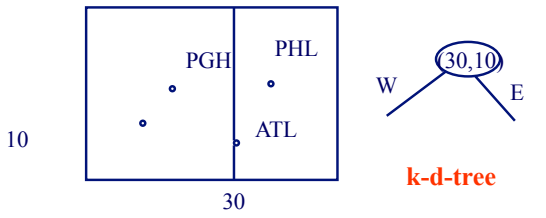


quad-tree

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

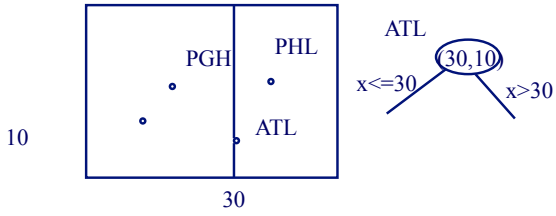


k-d-tree

CMU SCS

k-d-trees

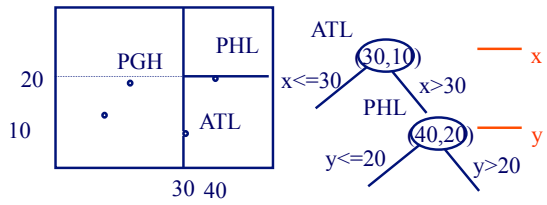
- Binary trees, with alternating 'discriminators'



CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'



CMU SCS

(Several demos/applets, e.g.)

- http://donar.umiacs.umd.edu/quadtree/points/kdtree.html

CMU SCS

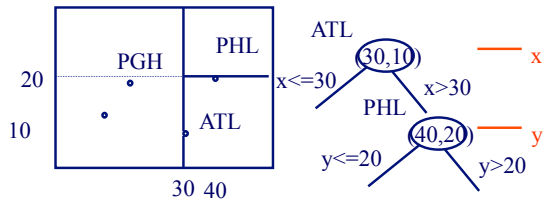
Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
  - – main memory: quad-trees
  - – main memory: k-d-trees
    - insertion; deletion
    - range query; k-nn query
- spatial access methods
- text
- ...

CMU SCS

k-d-trees - insertion

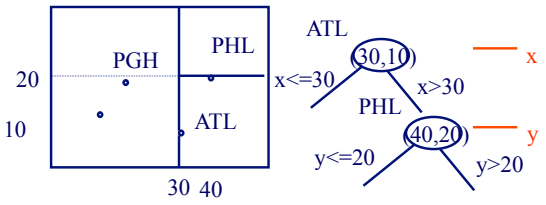
- Binary trees, with alternating 'discriminators'



CMU SCS

k-d-trees - insertion

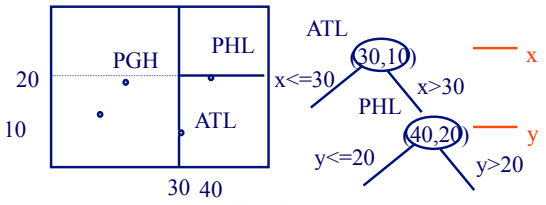
- discriminators: may cycle, or ....
- Q: which should we put first?



CMU SCS

k-d-trees - deletion

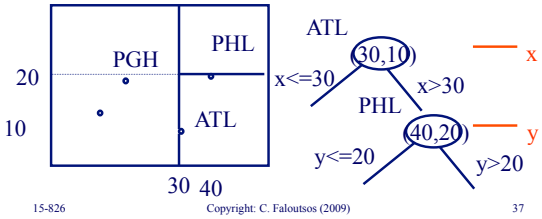
- How?



CMU SCS

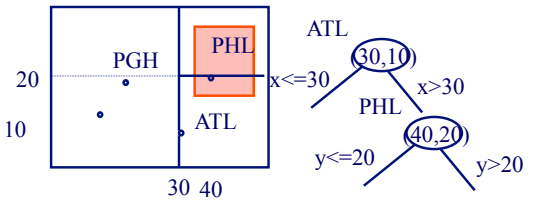
k-d-trees - deletion

- Tricky! 'delete-and-promote' (or 'mark as deleted')



CMU SCS

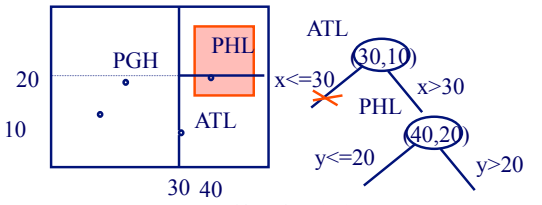
k-d-trees - range query



CMU SCS

k-d-trees - range query

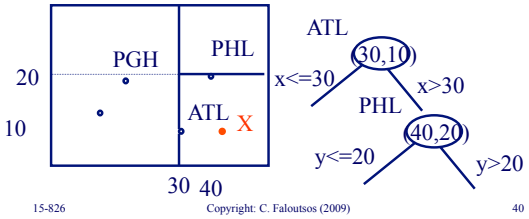
- similar to quad-trees: check the root; proceed to appropriate child(ren).



CMU SCS

k-d-trees - k-nn query

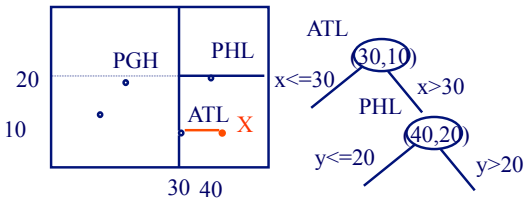
- e.g., 1-nn: closest city to 'X'



CMU SCS

k-d-trees - k-nn query

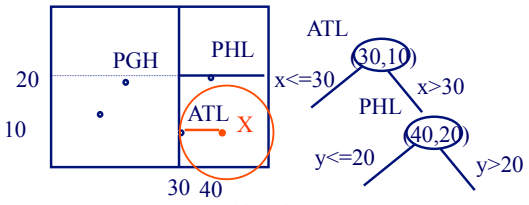
- A: check root; put in stack; proceed to child (ren)



CMU SCS

k-d-trees - k-nn query

- A: check root; put in stack; proceed to child (ren)



CMU SCS

Indexing - Detailed outline

- primary key indexing
- secondary key / multi-key indexing
  - – main memory: quad-trees
  - – main memory: k-d-trees
    - insertion; deletion
    - range query; k-nn query
    - discussion
- spatial access methods
- text
- ...

CMU SCS

k-d trees - discussion

- great for main memory & low 'd' (~<10)
- Q: what about high-d?
- A:
- Q: what about disk
- A:

CMU SCS

k-d trees - discussion

- great for main memory & low 'd' (~<10)
- Q: what about high-d?
- A: most attributes don't ever become discriminators
- Q: what about disk?
- A: Pagination problems, after ins./del. (solutions: next!)

CMU SCS

Conclusions

- sec. keys: B-tree indices (+ postings lists)
- multi-key, main memory methods:
  - quad-trees
  - k-d-trees

CMU SCS

References

- [Bentley75] J.L. Bentley: *Multidimensional Binary Search Trees Used for Associative Searching*, CACM, 18,9, Sept. 1975.
- [Finkel74] R.A. Finkel, J.L. Bentley: *Quadtrees: A data structure for retrieval on composite keys*, ACTA Informatica,4,1, 1974
- Applet: eg., http://donar.umiacs.umd.edu/quadtree/points/kdtree.html

