
 CMU SCS

15-826: Multimedia Databases and Data Mining


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

 CMU SCS

Reading Material

- Textbook, Chapter 4
- Ramakrishnan+Gehrke, Chapter 28.1-3

15-826 Copyright: C. Faloutsos (2008) 2

 CMU SCS

Outline

Goal: 'Find similar / interesting things'

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

15-826 Copyright: C. Faloutsos (2008) 3

CMU SCS

Indexing - Detailed outline

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

15-826 Copyright: C. Faloutsos (2008) 4

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

15-826 Copyright: C. Faloutsos (2008) 5

CMU SCS

Sec. key indexing

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

15-826 Copyright: C. Faloutsos (2008) 6

CMU SCS

Solution?

15-826 Copyright: C. Faloutsos (2008) 7

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

15-826 Copyright: C. Faloutsos (2008) 8

CMU SCS

Solution

- A#1: eg., with postings lists

salary-index

postings lists

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

15-826 Copyright: C. Faloutsos (2008) 9

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

15-826 Copyright: C. Faloutsos (2008) 10

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

15-826 Copyright: C. Faloutsos (2008) 11

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

15-826 Copyright: C. Faloutsos (2008) 12

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'

15-826 Copyright: C. Faloutsos (2008) 13

CMU SCS

Sec. key indexing

- can create combined indices:
create index sj on EMPLOYEE(salary, job-code);

15-826 Copyright: C. Faloutsos (2008) 14

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
- ...

15-826 Copyright: C. Faloutsos (2008) 15

CMU SCS

Quad-trees

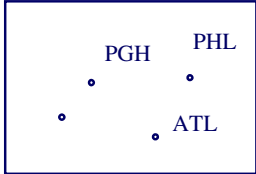
- problem: find cities within 100mi from Pittsburgh
- assumption: all fit in main memory
- Q: how to answer such queries quickly?

15-826 Copyright: C. Faloutsos (2008) 16

CMU SCS

Quad-trees

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

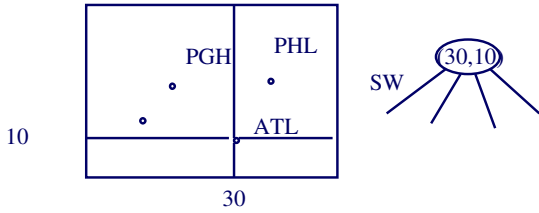


15-826 Copyright: C. Faloutsos (2008) 17

CMU SCS

Quad-trees

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



15-826 Copyright: C. Faloutsos (2008) 18

CMU SCS

Quad-trees

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

15-826 Copyright: C. Faloutsos (2008) 19

CMU SCS

Quad-trees - search?

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

15-826 Copyright: C. Faloutsos (2008) 20

CMU SCS

Quad-trees - search?

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

15-826 Copyright: C. Faloutsos (2008) 21

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);
    }
      
```

15-826 Copyright: C. Faloutsos (2008) 22

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

15-826 Copyright: C. Faloutsos (2008) 23

CMU SCS

Quad-trees - discussion

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

‘adaptive’

‘fixed’

z-ordering (later)

middle

15-826 Copyright: C. Faloutsos (2008) 24

CMU SCS

Quad-trees - discussion

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

15-826 Copyright: C. Faloutsos (2008) 25

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!

15-826 Copyright: C. Faloutsos (2008) 26

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
- ...

15-826 Copyright: C. Faloutsos (2008) 27

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

10

30

SW (30,10) SE NE NW

quad-tree

15-826 Copyright: C. Faloutsos (2008) 28

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

10

30

W (30,10) E

k-d-tree

15-826 Copyright: C. Faloutsos (2008) 29

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

10

30

ATL (30,10)

$x \leq 30$ $x > 30$

15-826 Copyright: C. Faloutsos (2008) 30

CMU SCS

k-d-trees

- Binary trees, with alternating 'discriminators'

15-826 Copyright: C. Faloutsos (2008) 31

CMU SCS

(Several demos/applets, e.g.)

- <http://donar.umiacs.umd.edu/quadtrees/point/s/kdtree.html>

15-826 Copyright: C. Faloutsos (2008) 32

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
- ...

15-826 Copyright: C. Faloutsos (2008) 33

CMU SCS

k-d-trees - insertion

- Binary trees, with alternating 'discriminators'

15-826 Copyright: C. Faloutsos (2008) 34

CMU SCS

k-d-trees - insertion

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

15-826 Copyright: C. Faloutsos (2008) 35

CMU SCS

k-d-trees - deletion

- How?

15-826 Copyright: C. Faloutsos (2008) 36

CMU SCS

k-d-trees - deletion

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

15-826 Copyright: C. Faloutsos (2008) 37

CMU SCS

k-d-trees - range query

15-826 Copyright: C. Faloutsos (2008) 38

CMU SCS

k-d-trees - range query

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

15-826 Copyright: C. Faloutsos (2008) 39

CMU SCS

k-d-trees - k-nn query

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

15-826 Copyright: C. Faloutsos (2008) 40

CMU SCS

k-d-trees - k-nn query

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

15-826 Copyright: C. Faloutsos (2008) 41

CMU SCS

k-d-trees - k-nn query

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

15-826 Copyright: C. Faloutsos (2008) 42

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

15-826 Copyright: C. Faloutsos (2008) 43

CMU SCS

k-d trees - discussion

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

15-826 Copyright: C. Faloutsos (2008) 44

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!)

15-826 Copyright: C. Faloutsos (2008) 45

CMU SCS

Conclusions

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

15-826 Copyright: C. Faloutsos (2008) 46

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>

15-826 Copyright: C. Faloutsos (2008) 47
