Databases

Lecture 7

Relational Algebra

The Physical Structure of Databases

Relational Algebra

- *cross product*
  - binary operator
  - notation: $R_1 \times R_2$
  - resulting relation:
    - schema: the attributes of R_1 followed by the attributes of R_2
    - tuples: every tuple r_1 in R_1 is concatenated with every tuple r_2 in R_2
    - equivalent SELECT statement
      - `SELECT * FROM R1 CROSS JOIN R2`

- *union, set-difference, intersection*
  - binary operators
  - notation: $R_1 \cup R_2$, $R_1 - R_2$, $R_1 \cap R_2$
  - R_1 and R_2 must have compatible schemas
  - equivalent SELECT statements
    - `SELECT * FROM R1 UNION ALL SELECT * FROM R2`
    - `SELECT * FROM R1 EXCEPT SELECT * FROM R2`
    - `SELECT * FROM R1 INTERSECT SELECT * FROM R2`

- join operators
  - *condition join* (or *theta join*)
    - notation: $R_1 \otimes_\Theta R_2$
    - result: the records in the cross product of R_1 and R_2 that meet a certain condition
  - definition $\Rightarrow R_1 \otimes_\Theta R_2 = \sigma_\Theta(R_1 \times R_2)$
  - equivalent SELECT statement
    - `SELECT * FROM R1 INNER JOIN R2 ON Θ`

- join operators
  - *natural join*
    - notation: $R_1 * R_2$
    - resulting relation:
      - schema: the union of the attributes of the two relations
      - tuples: obtained from tuples <r_1, r_2>, where r_1 in R_1, r_2 in R_2, and r_1 and r_2 agree on the common attributes of R_1 and R_2
    - let $R_1[\alpha]$, $R_2[\beta]$, $\alpha \cap \beta = \{A_1, A_2, \ldots, A_m\}$; then:

$$R_1 * R_2 = \Pi_{\alpha \cup \beta}(R_1 \otimes_{R_1.A_1 = R_2.A_1 \text{ AND } \ldots \text{ AND } R_1.A_m = R_2.A_m} R_2)$$

    - equivalent SELECT statement
      - `SELECT * FROM R1 NATURAL JOIN R2`

- join operators
  - *left outer join*
    - notation (in these notes): $R_1 \ltimes_C R_2$
    - resulting relation:
      - schema: the attributes of R_1 followed by the attributes of R_2
      - tuples: records from the condition join $R_1 \otimes_C R_2$ + the records in R_1 that were not used in $R_1 \otimes_C R_2$ combined with the *null* value for the attributes of R_2
    - equivalent SELECT statement
      - `SELECT * FROM R1 LEFT OUTER JOIN R2 ON C`

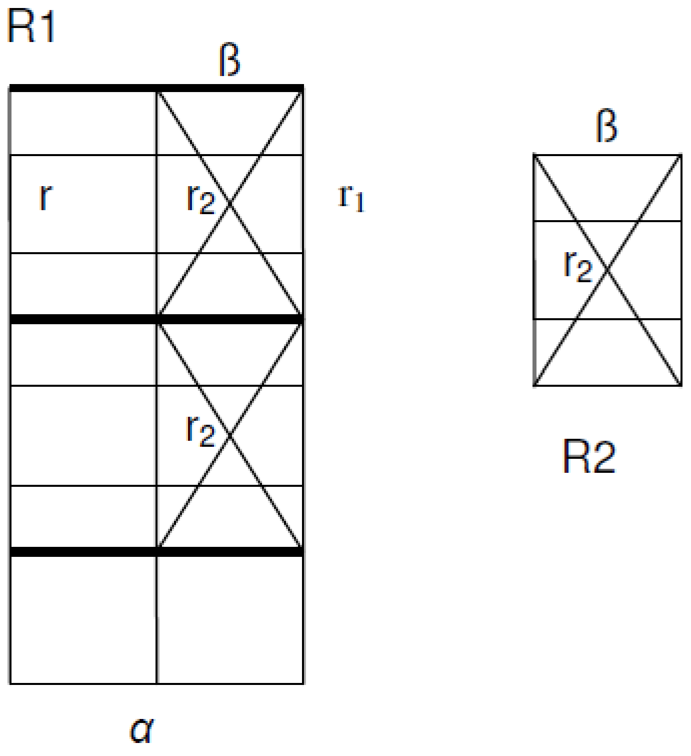
- join operators
  - *right outer join*
    - notation: $R_1 \rtimes_C R_2$
    - resulting relation:
      - schema: the attributes of R_1 followed by the attributes of R_2
      - tuples: records from the condition join $R_1 \otimes_C R_2$ + the records in R_2 that were not used in $R_1 \otimes_C R_2$ combined with the *null* value for the attributes of R_1
    - equivalent SELECT statement
      - `SELECT * FROM R1 RIGHT OUTER JOIN R2 ON C`

- join operators
  - *full outer join*
    - notation: $R_1 \bowtie_C R_2$
    - resulting relation:
      - schema: the attributes of R_1 followed by the attributes of R_2
      - tuples: the union of the left and right outer join results
    - equivalent SELECT statement
      - `SELECT * FROM R1 FULL OUTER JOIN R2 ON C`

- join operators
  - *left semi join*
    - notation: $R_1 \rhd R_2$
    - resulting relation:
      - schema: R_1's schema
      - tuples: the records in R_1 that are used in the natural join $R_1 * R_2$

- join operators
    - *right semi join*
        - notation: $R_1 \lhd R_2$
        - resulting relation:
            - schema: R_2's schema
            - tuples: the records in R_2 used in the natural join $R_1 * R_2$

- *division*
  - notation: $R_1 \div R_2$
  - $R_1[\alpha]$, $R_2[\beta]$, $\beta \subset \alpha$
  - resulting relation:
    - schema: $\alpha - \beta$
    - tuples: a record $r \in R_1 \div R_2$ if $\forall r_2 \in R_2, \exists r_1 \in R_1$ such that:
      - $\Pi_{\alpha-\beta}(r_1) = r$
      - $\Pi_{\beta}(r_1) = r_2$
      - i.e., a record r belongs to the result if in R_1 r is concatenated with every record in R_2



- the *renaming* operator

$$\rho(R'(A_1 \rightarrow A_1{}', A_2 \rightarrow A_2{}', A_3 \rightarrow A_3{}'), R)$$

  - the result, relation R', has the same instance as R
  - attributes A_1, A_2, and A_3 are renamed to $A_1{}'$, $A_2{}'$, and $A_3{}'$, respectively
  - an algebra expression can be specified instead of R

An Independent Subset of Operators

- independent set of operators M
  - eliminating any operator *op* from M: there will be a relation that can be obtained using M's operators, but cannot be obtained with the operators in M-{*op*}
- for the previously described query language, with operators:

  $\{\sigma, \Pi, \times, \cup, \cap, -, *, \otimes, \ltimes, \rtimes, \bowtie, \rhd, \lhd, \div\}$

an independent set of operators is $\{\sigma, \Pi, \times, \cup, -\}$

- the other operators are obtained as follows (some expressions have already been introduced):
  - $R_1 \cap R_2 = R_1 - (R_1 - R_2)$
  - $R_1 \otimes_c R_2 = \sigma_c (R_1 \times R_2)$

- the other operators are obtained as follows (some expressions have already been introduced):
  - $R_1[\alpha]$, $R_2[\beta]$, $\alpha \cap \beta = \{A_1, A_2, \dots, A_m\}$, then:

    $R_1 * R_2 = \Pi_{\alpha \cup \beta}(R_1 \otimes_{R_1.A_1 = R_2.A_1 \text{ AND } \dots \text{ AND } R_1.A_m = R_2.A_m} R_2)$

  - $R_1[\alpha]$, $R_2[\beta]$, $R_3[\beta] = \{(\text{null}, \dots, \text{null})\}$, $R_4[\alpha] = \{(\text{null}, \dots, \text{null})\}$

    $R_1 ⟕_C R_2 = (R_1 \otimes_C R_2) \cup [R_1 - \Pi_\alpha(R_1 \otimes_C R_2)] \times R_3$

    $R_1 ⟖_C R_2 = (R_1 \otimes_C R_2) \cup R_4 \times [R_2 - \Pi_\beta(R_1 \otimes_C R_2)]$

    $R_1 ⟗_C R_2 = (R_1 ⟕_C R_2) \cup (R_1 ⟖_C R_2)$

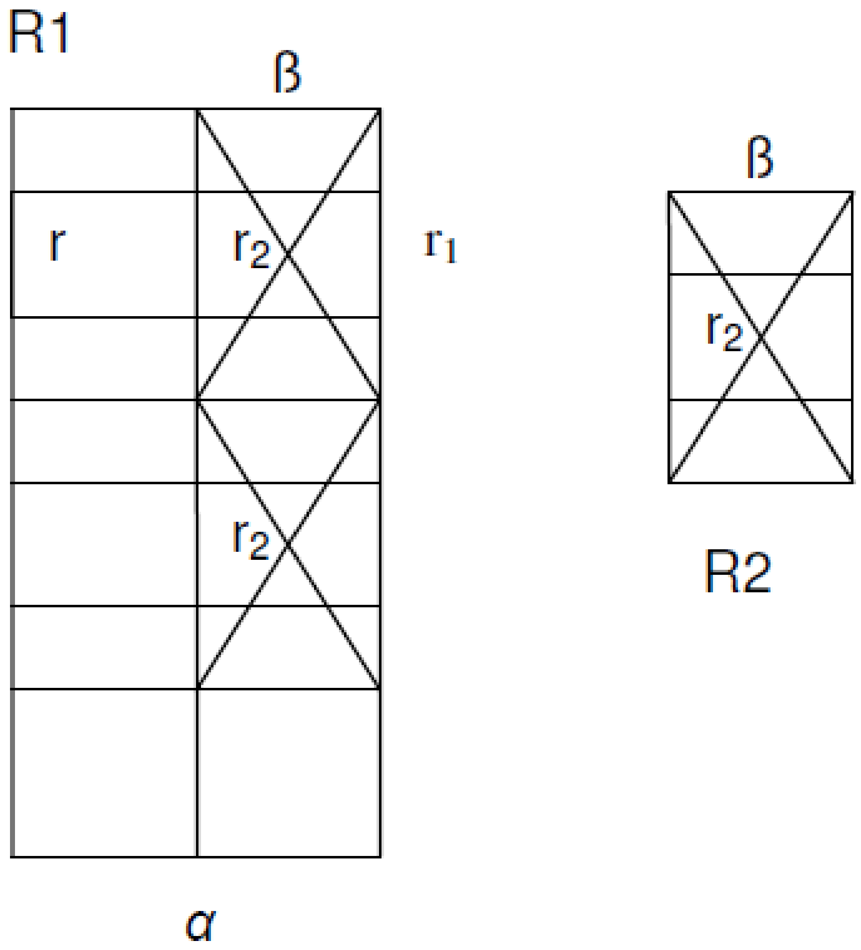
  - $R_1[\alpha]$, $R_2[\beta]$

    $R_1 \rhd R_2 = \Pi_\alpha(R_1 * R_2)$

    $R_1 \lhd R_2 = \Pi_\beta(R_1 * R_2)$

- the other operators are obtained as follows (some expressions have already been introduced):
    - if $R_1[\alpha]$, $R_2[\beta]$, $\beta \subset \alpha$, then $r \in R_1 \div R_2$ if $\forall r_2 \in R_2, \exists r_1 \in R_1$ such that: $\Pi_{\alpha - \beta}(r_1) = r$ and $\Pi_{\beta}(r_1) = r_2$.
    - hence r is in $\Pi_{\alpha - \beta}(R_1)$, but not all the elements in $\Pi_{\alpha - \beta}(R_1)$ are in the result
    - $(\Pi_{\alpha - \beta}(R_1)) \times R_2$ contains all the elements with one part in $\Pi_{\alpha - \beta}(R_1)$ and the second part in R_2
    - to obtain values that are disqualified, R_1 is eliminated from $(\Pi_{\alpha - \beta}(R_1)) \times R_2$, and the result is projected on $\alpha - \beta$
    - the final expression:

$$R_1 \div R_2 = \Pi_{\alpha - \beta}(R_1) - \Pi_{\alpha - \beta}((\Pi_{\alpha - \beta}(R_1)) \times R_2 - R_1)$$



- see lecture examples (at the board) with algebra queries:

\- selection

\- projection

\- division

\- selection & projection

\- natural join with multiple tables, selection, projection

\- set-difference, natural join, selection, projection

\- different algebra expressions producing the same result (optimization - reducing the size of intermediate relations)

- the next examples use the statements below
- assignment:

  R[list] := expression

  - the expression's result, i.e., a relation, is assigned to a variable R[list], specifying the name of the relation [and the names of its columns]
- eliminating duplicates from a relation

  δ(R)
- sorting records in a relation

  $S_{\{list\}}$(R)
- grouping - an extension for projection

  $\gamma_{\{\mathrm{list1}\}\ \mathrm{group\ by}\ \{\mathrm{list2}\}}(\mathrm{R})$

  - R's records are grouped by the columns in *list2*
  - for each group of records, *list1* (that can contain aggregate functions) is evaluated

```
students [id, name, sgroup, gpa, dob]

groups [id, year, program]

schedule [day, starthour, endhour, activtype, room, sgroup, faculty_id]

faculty [id, name]
```

1. The names of students in a given group:

$$R \coloneqq \Pi_{\{name\}}\left(\sigma_{sgroup='222'}(students)\right)$$

```
SELECT name
FROM students
WHERE sgroup='222'
```

2. The students in a given program (alphabetical list, by groups):

$$G \coloneqq \Pi_{\{id\}}\left(\sigma_{program='IG'}(groups)\right)$$
$$R \coloneqq S_{\{sgroup,name\}}\left(\sigma_{sgroup\ is\ in\ G}(students)\right)$$

```
SELECT *
FROM students
WHERE sgroup IN
  (SELECT id
  FROM groups
  WHERE program='IG')
ORDER BY sgroup, name
```

3. The number of students in every group of a given program:

$$ST \coloneqq \sigma_{sgroup\ is\ in\left(\Pi_{\{id\}}\left(\sigma_{program='IG'}(groups)\right)\right)}(students)$$

$$NR \coloneqq \gamma_{\{sgroup,\, count(*)\}\ group\ by\ \{sgroup\}}(ST)$$

```
SELECT sgroup, COUNT(*)
FROM (SELECT *
     FROM students
     WHERE sgroup IN
        (SELECT id
         FROM groups
         WHERE program='IG')
      ) t
GROUP BY sgroup
```

4. A student's schedule (the student is given by name):

$$T := \sigma_{sgroup\ is\ in\left(\Pi_{\{sgroup\}}\left(\sigma_{name='Ionescu'}(students)\right)\right)}(schedule)$$

5. The number of hours per week for every group:

$$F(no, sgroup) := \Pi_{\{endhour-starthour, sgroup\}}(schedule)$$
$$NoHours(sgroup, nohours) := \gamma_{\{sgroup, sum(no)\}\ group\ by\ \{sgroup\}}(F)$$

6. The faculty members (their names) who teach a given student:

$$A := (\sigma_{name='Ionescu'}(students)) \otimes_{students.sgroup=schedule.sgroup}(schedule)$$
$$B := \Pi_{\{faculty\_id\}}(A)$$
$$C := faculty \otimes_{faculty.id=B.faculty\_id}(B)$$
$$D := \Pi_{\{name\}}(C)$$

7. The faculty members with no teaching assignments (i.e., not on the schedule):

$$C \coloneqq \Pi_{\{name\}}(faculty) - \Pi_{\{name\}}(schedule \otimes_{schedule.faculty\_id=faculty.id} faculty)$$

* is there a problem if 2 different faculty members have the same name?

8. Students with school activities on every day of the week (all days with school activities considered):

$$A \coloneqq \delta\left(\Pi_{\{day\}}(schedule)\right)$$

$$B \coloneqq students \otimes_{students.sgroup=schedule.sgroup} schedule$$

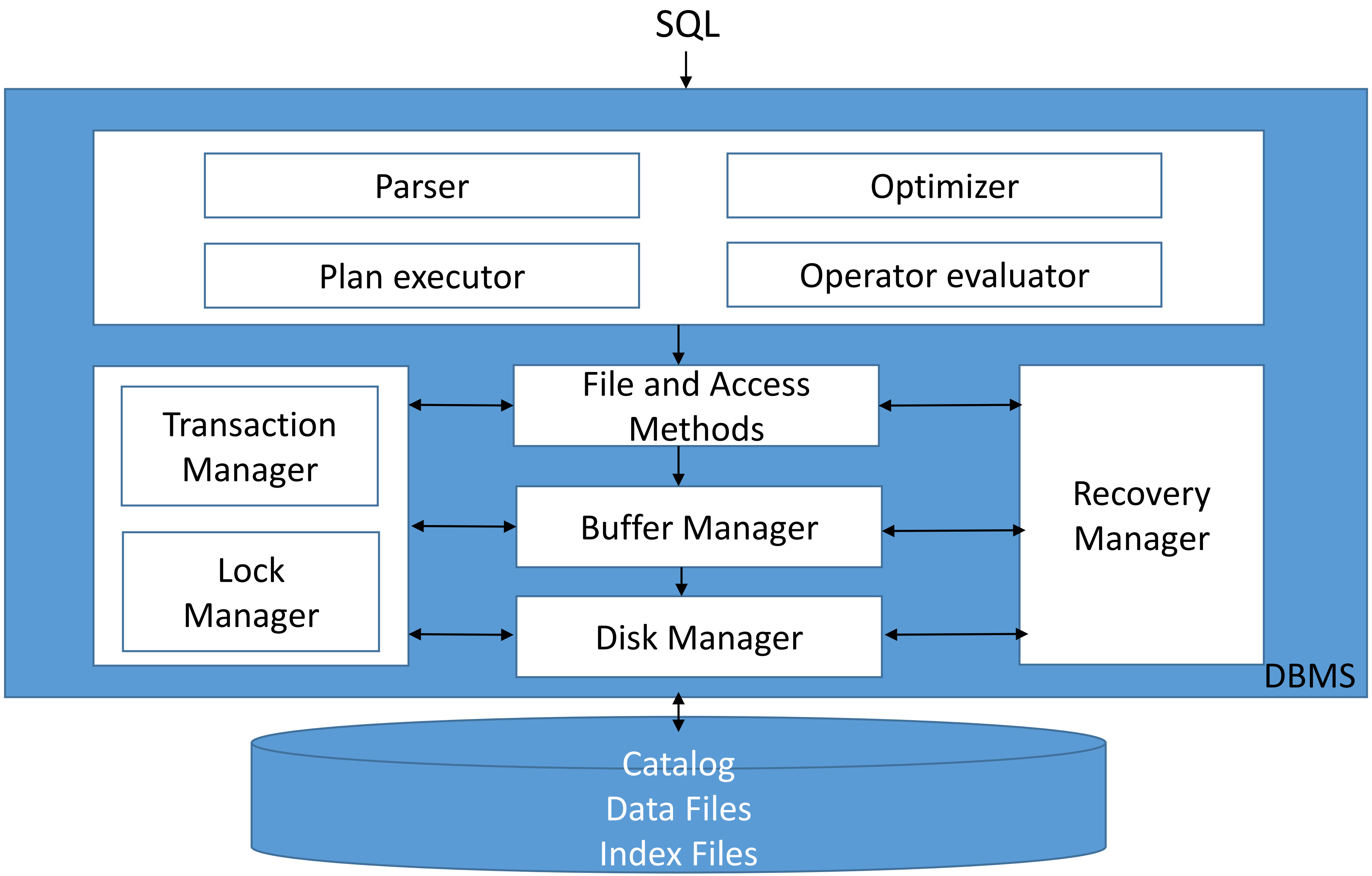
$$C \coloneqq \Pi_{\{name,day\}}(B)$$

$$D \coloneqq C \div A$$

* is there a problem if 2 different students have the same name?

The Physical Structure of Databases

DBMS Architecture



The Memory Hierarchy

- primary storage
  - cache, main memory
  - very fast access to data
  - volatile
  - currently used data
- secondary storage
  - slower devices, e.g., magnetic disks
  - nonvolatile
  - disks - sequential, direct access
  - main database

The Memory Hierarchy

- tertiary storage
  - slowest storage devices, e.g., optical disks, tapes
  - nonvolatile
  - tapes
    - only sequential access
    - good for archives, backups
    - unsuitable for data that is frequently accessed

The Memory Hierarchy

- secondary / tertiary storage
  - significantly cheaper than main memory
- large amounts of data that shouldn't be discarded when the system is restarted

=> the need for DBMSs that bring data from disks into main memory for processing

Secondary Storage – Magnetic Disks

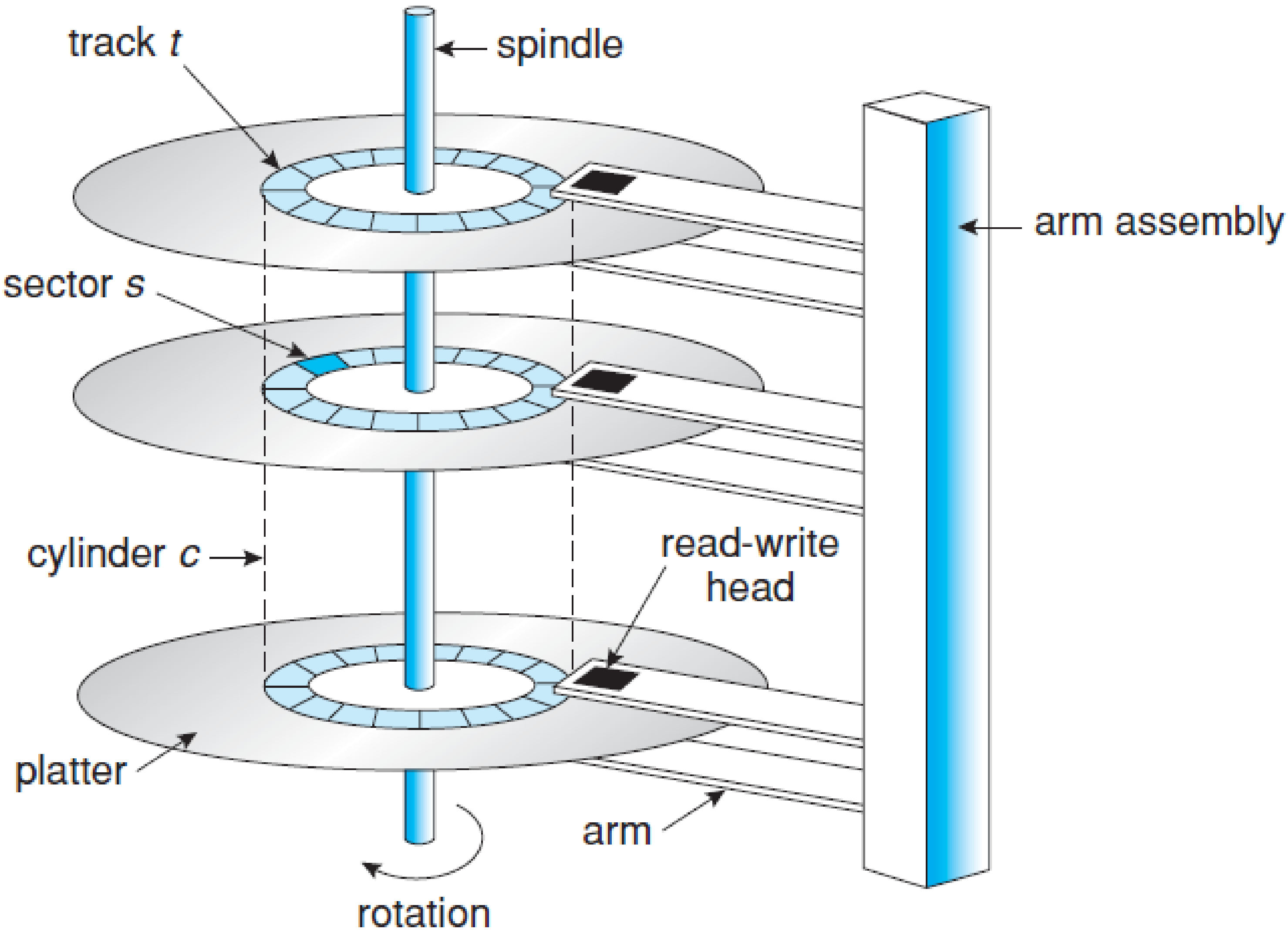
- direct access
- extremely used in database applications
- applications don't need to know whether the data is on disk or in main memory
- disk block
  - sequence of contiguous bytes
  - unit for data storage
  - unit for data transfer (reading / writing)
  - reading / writing a block - an input / output (I/O) operation
- tracks
  - concentric rings containing blocks, recorded on one or more platters

Secondary Storage – Magnetic Disks

- sectors
  - arcs on tracks
- platters
  - single-sided, double-sided (data recorded on one / both surfaces)
- cylinder
  - all tracks with the same diameter
- disk heads
  - one per recorded surface
  - to read / write a block, a head must be on top of the block
  - smaller platter size => decreased seek time
  - all the heads are moved as a unit
  - systems with one active head

Secondary Storage – Magnetic Disks

- sector size
  - characteristic of the disk, cannot be modified
- block size
  - multiple of the sector size



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References

- [Ta13] ȚÂMBULEA, L., Curs Baze de date, Facultatea de Matematică și Informatică, UBB, 2013-2014
- [Ra00] RAMAKRISHNAN, R., GEHRKE, J., Database Management Systems (2nd Edition), McGraw-Hill, 2000
- [Da03] DATE, C.J., An Introduction to Database Systems (8th Edition), Addison-Wesley, 2003
- [Ga08] GARCIA-MOLINA, H., ULLMAN, J., WIDOM, J., Database Systems: The Complete Book, Prentice Hall Press, 2008
- [Ra07] RAMAKRISHNAN, R., GEHRKE, J., Database Management Systems, McGraw-Hill, 2007, http://pages.cs.wisc.edu/~dbbook/openAccess/thirdEdition/slides/slides3ed.html
- [Si08] SILBERSCHATZ, A., GALVIN, P.B., GAGNE, G., Operating System Concepts (8th Edition), Wiley Publishing, 2008
- [Ul11] ULLMAN, J., WIDOM, J., A First Course in Database Systems, http://infolab.stanford.edu/~ullman/fcdb.html