COMP 3311
DATABASE MANAGEMENT SYSTEMS

LECTURE 14
QUERY PROCESSING: INTRODUCTION

QUERY PROCESSING: OUTLINE

Overview of Query Processing

Cost Estimates

- Selection
- Sorting
- Join
- Other Operations

Evaluation of Expressions

- Materialization
- Pipelining

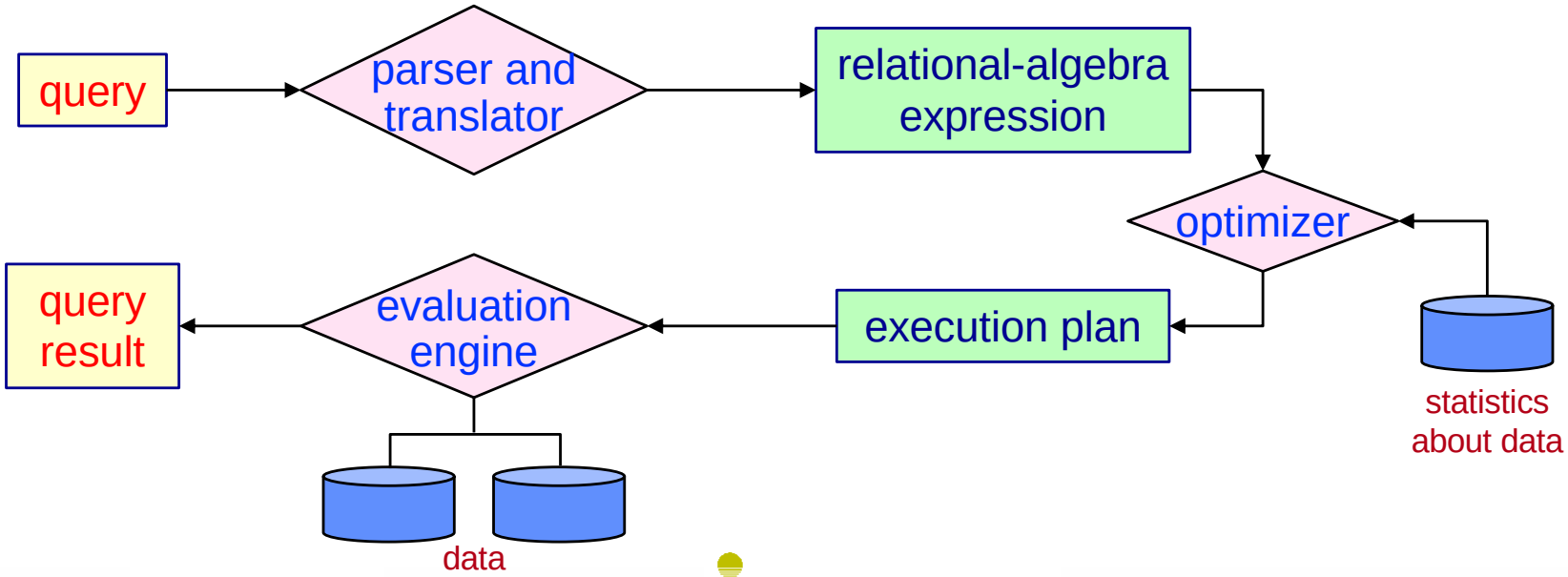
QUERY PROCESSING OVERVIEW

Parsing and Translation

– The query is checked for syntax, relations are verified against the system catalog, the query is translated into a relational-algebra expression and transformed by the optimizer into an execution plan.

Evaluation

– The evaluation engine takes an execution plan, executes that plan, and returns the query result.



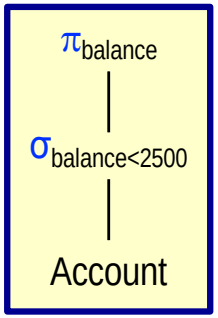
QUERY EVALUATION

- A given relational-algebra expression may have many equivalent expressions.

$$\sigma_{balance<2500}(\pi_{balance}(Account)) \equiv \pi_{balance}(\sigma_{balance<2500}(Account))$$

☞ **A relational-algebra expression can be evaluated using one of several different algorithms.**

- A query-execution plan represents a relational-algebra expression as a relational-algebra tree and annotates it with a detailed evaluation strategy for each operation.



relational-algebra tree

- To process the above query, the query-execution plan can:
  - use an index on balance to find accounts with balance<2500.
    or
  - perform a complete relation scan and discard accounts with balance≥2500.

Which option to use may depend on several factors.

QUERY COST MEASURES

Query optimization chooses, amongst all equivalent evaluation plans, the one with the (expected) lowest cost.

- Cost is estimated using information from the database catalog.
  - ☞ The number of records in each relation, the size of the records, whether an index is available, etc.
- The cost to execute a query depends on the size of the database buffer in main memory.
  - ☞ We often use worst case estimates, assuming only the minimum amount of memory needed for the operation is available.
- For simplicity we use *number of page I/Os* as the cost measure.
  - ☞ **We ignore the difference in cost between sequential and random I/O as well as CPU cost.**
    (Real query processors take these factors into consideration.)
  - ☞ **We normally do not include the cost of writing the final output to disk. Why?**

COST ESTIMATES: SELECTION — FILE SCAN

Algorithm A1: *linear search*

$B_r \Rightarrow$ # pages relation r occupies

Linear search is always applicable.

Cost estimate (page I/Os)

- B_r the number of pages that contain records of relation r

or

- $B_r/2$ if equality selection on a candidate key attribute, since we stop when we find the record (as there is at most only one with the specified value).

Algorithm A2: *binary search*

$B_r \Rightarrow$ # pages relation r occupies

Applicable if the selection is an equality comparison on the attribute on which the file is ordered *and* the pages are stored contiguously.

Cost estimate (page I/Os)

- $\lceil \log_2(B_r) \rceil$ if equality selection is on a candidate key attribute
- $\lceil \log_2(B_r) \rceil$ for locating the first record satisfying the selection condition
  + # pages containing records satisfying the selection condition

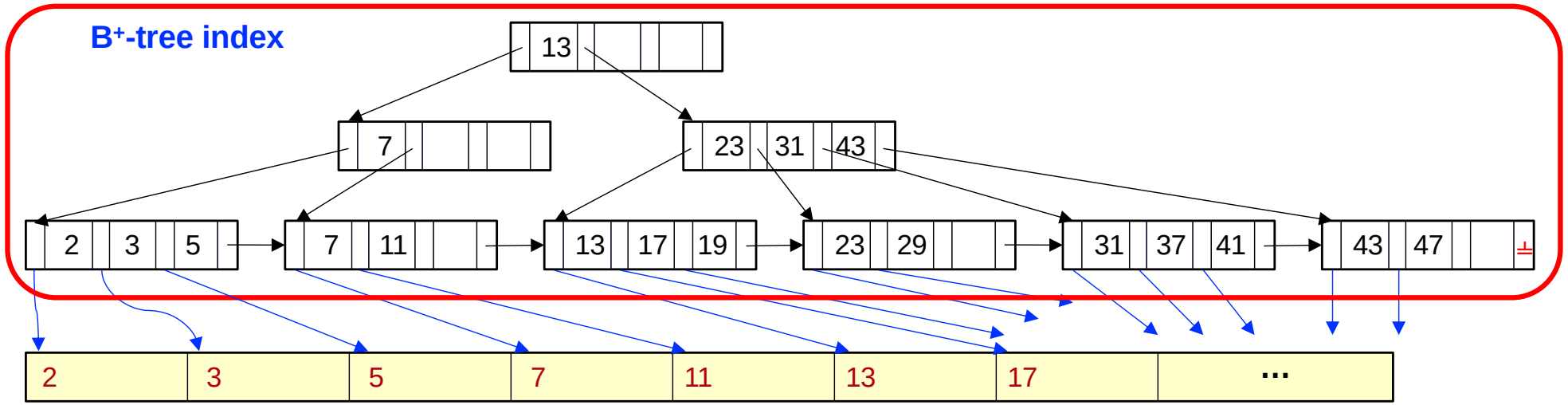
COST ESTIMATES: SELECTION — EQUALITY SEARCH

Algorithm A3: Using A Clustering Index

On candidate key ⟹ retrieves a single record.

Cost estimate (page I/Os)

- For a tree index: $HT_i + 1$ where HT_i is the height of the tree index



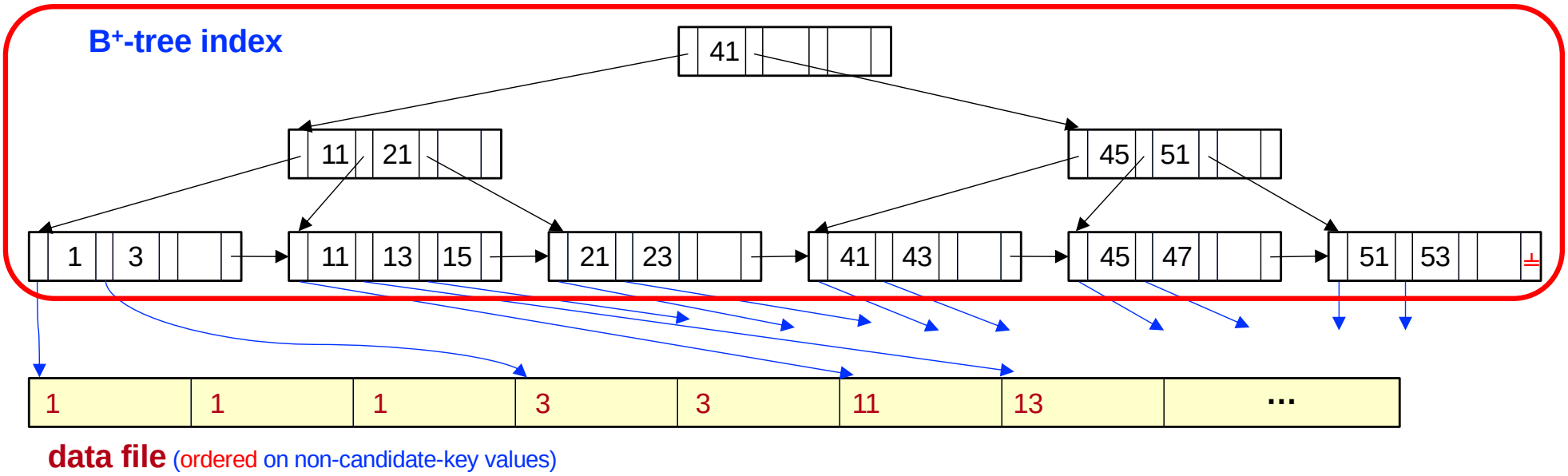
COST ESTIMATES: SELECTION — EQUALITY SEARCH

Algorithm A4: Using A Clustering Index

On non-candidate key ⟹ retrieves multiple records.

Cost estimate (page I/Os)

- For a tree index: HT_i + # pages with records that satisfy the selection condition



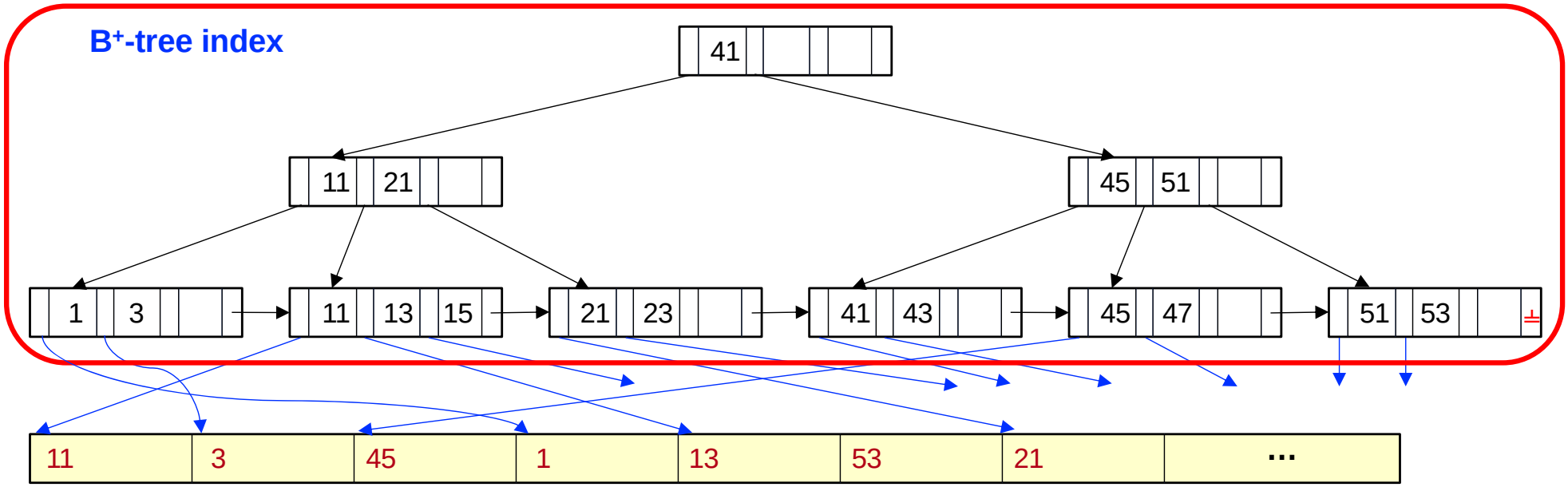
COST ESTIMATES: SELECTION — EQUALITY SEARCH

Algorithm A5: Using A Non-clustering (Secondary) Index

On candidate key ⟹ retrieves a single record.

Cost estimate (page I/Os)

- For a tree index: $HT_i + 1$ where HT_i is the height of the tree index
- For a hash index: 1 + 1 *or* 1.2 + 1 if there exist overflow buckets

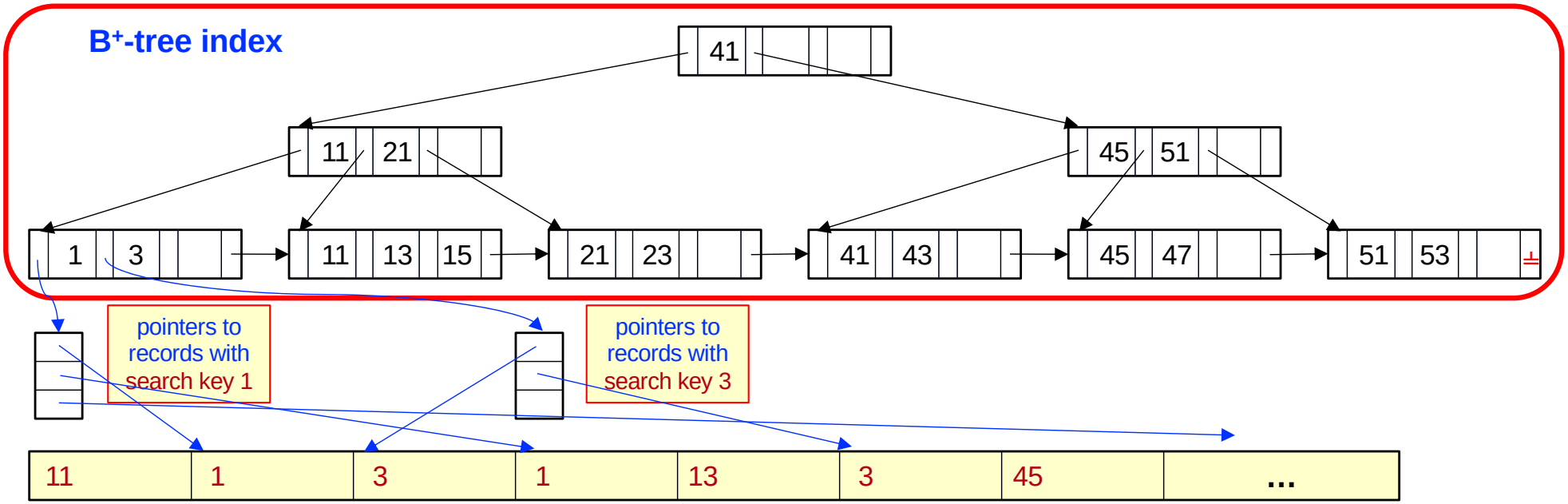


COST ESTIMATES: SELECTION — EQUALITY SEARCH

On non-candidate key ⟹ retrieves multiple records.

- For a tree index: HT_i + cost to retrieve indirection pointers + # records retrieved (assumes each record requires a page access)
- For a hash index: 1 + cost to retrieve indirection pointers + # records retrieved
  or
  1.2 + cost to retrieve indirection pointers + # records retrieved if there exist overflow buckets

☞ **Can be very expensive!**



COST ESTIMATES: SELECTION — COMPARISONS

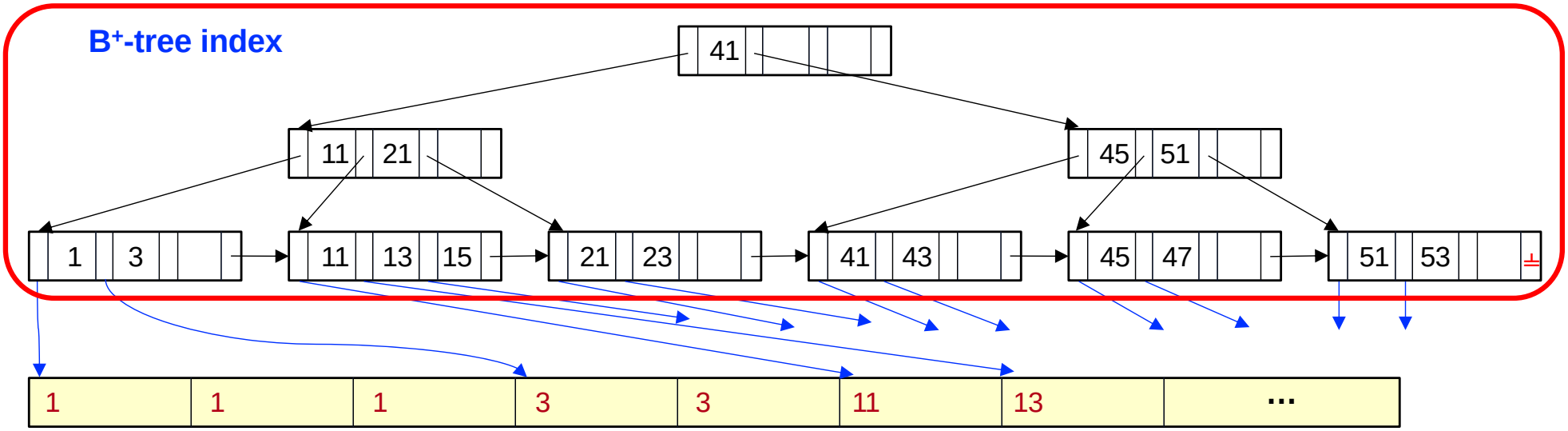
$\sigma_{A \geq v}(r)$ *or* $\sigma_{A \leq v}(r)$

Use linear search, binary search or indexes as follows:

Algorithm A6: *clustering index, relation sorted on A*

$\sigma_{A \geq v}(r)$ use the index to find the first record where $A \geq v$ and scan the relation sequentially from there.

$\sigma_{A \leq v}(r)$ do not use the index; instead, scan the relation sequentially until you find the first record where $A > v$.



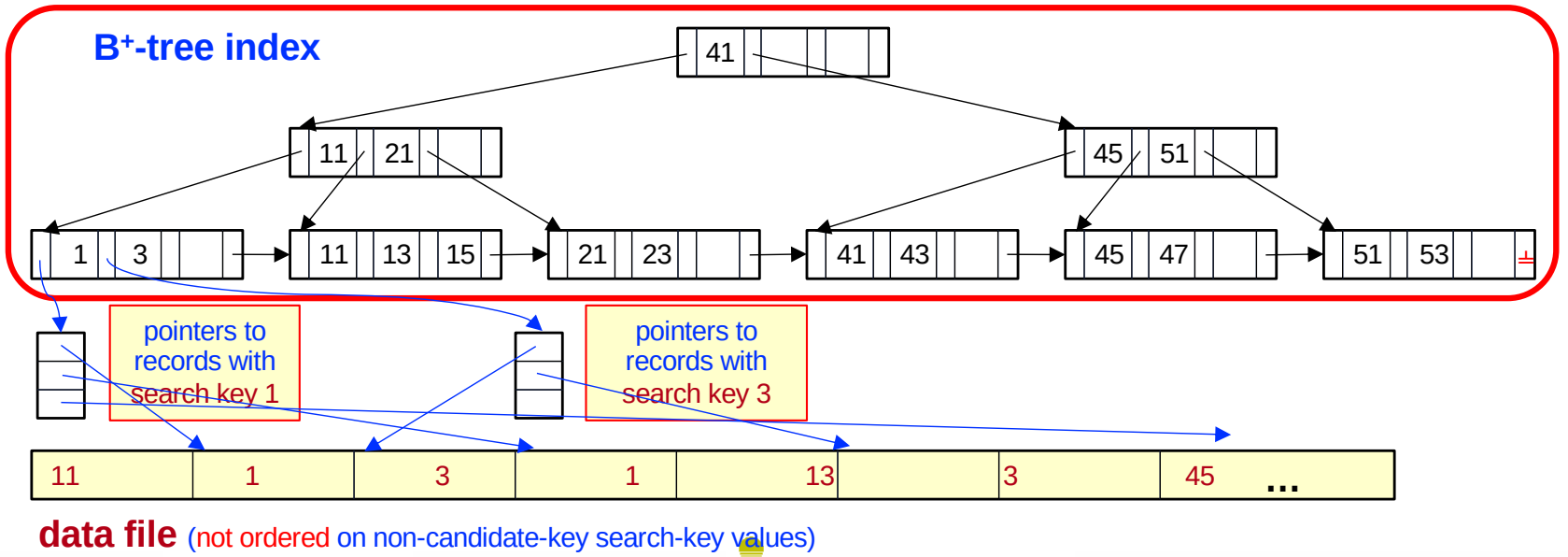
COST ESTIMATES: SELECTION — COMPARISONS

$\sigma_{A \geq v}(r)$ *or* $\sigma_{A \leq v}(r)$

Algorithm A7: *non-clustering (secondary index)*

$\sigma_{A \geq v}(r)$ use the index to find first index entry where $A \geq v$ and scan the leaf pages of the index sequentially from there to find pointers to the records.

$\sigma_{A \leq v}(r)$ use the index to scan the leaf pages of sequentially finding pointers to records, until the first entry where $A > v$.



COST ESTIMATES: SELECTION — COMPARISONS (cont'd)

Conjunction (AND): $\sigma_{\theta 1 \wedge \theta 2 \wedge \ldots \wedge \theta n}(r)$

Algorithm A8: *using one index*

- Select a θ_i and algorithms A1 through A7 that results in the least cost for $\sigma_{\theta i}(r)$.
- *Check the remaining conditions in the record after retrieving it into memory.*

Algorithm A9: *using a composite index*

- If available, use a composite (multi-attribute) index (i.e., a combination of θ_i).
- The type of index determines which of the algorithms A2, A3 or A4 will be used.

COST ESTIMATES: SELECTION — COMPARISONS (cont'd)

Conjunction (AND): $\sigma_{\theta 1 \wedge \theta 2 \wedge \ldots \wedge \theta n}(r)$ *or* **Disjunction (OR):** $\sigma_{\theta 1 \vee \theta 2 \vee \ldots \vee \theta n}(r)$

Algorithm A10: *conjunction by intersection of record pointers*

If *any attributes* of the individual conditions have indexes with record pointers, then use corresponding index and intersect record pointers. **Else** use linear search.

- For conditions that do not have appropriate indexes, *check the conditions in the records in memory*.

Algorithm A11: *disjunction by union of record pointers*

If *all attributes* of the individual conditions have indexes with record pointers, then use corresponding index and union record pointers. **Else** use linear search.

- For both cases, use the record pointers to retrieve the records from the file.

  Note: In some cases only an index scan is required (e.g., count).

Cost estimate

- Using indexes: sum of the costs of the individual index scans
  + the cost of retrieving the records

COST ESTIMATES: SELECTION — COMPARISONS (cont'd)

Negation (NOT): $\sigma_{\neg\theta}(r)$

- Use linear search.
- If very few records satisfy $\neg\theta$ *and* an index is applicable for θ then
  - Use the index to find records satisfying the negation and retrieve the records from the file.

Example

Suppose that a B^+-tree index on branchCity is available on relation Branch, and that no other index is available.

$$\sigma_{\neg(\text{branchCity}<\text{'Brooklyn'})}(\text{Branch})$$

Use the index to locate the first record whose branchCity field has value "Brooklyn". From this record, follow the pointer chains in the index until the end, retrieving all the records.

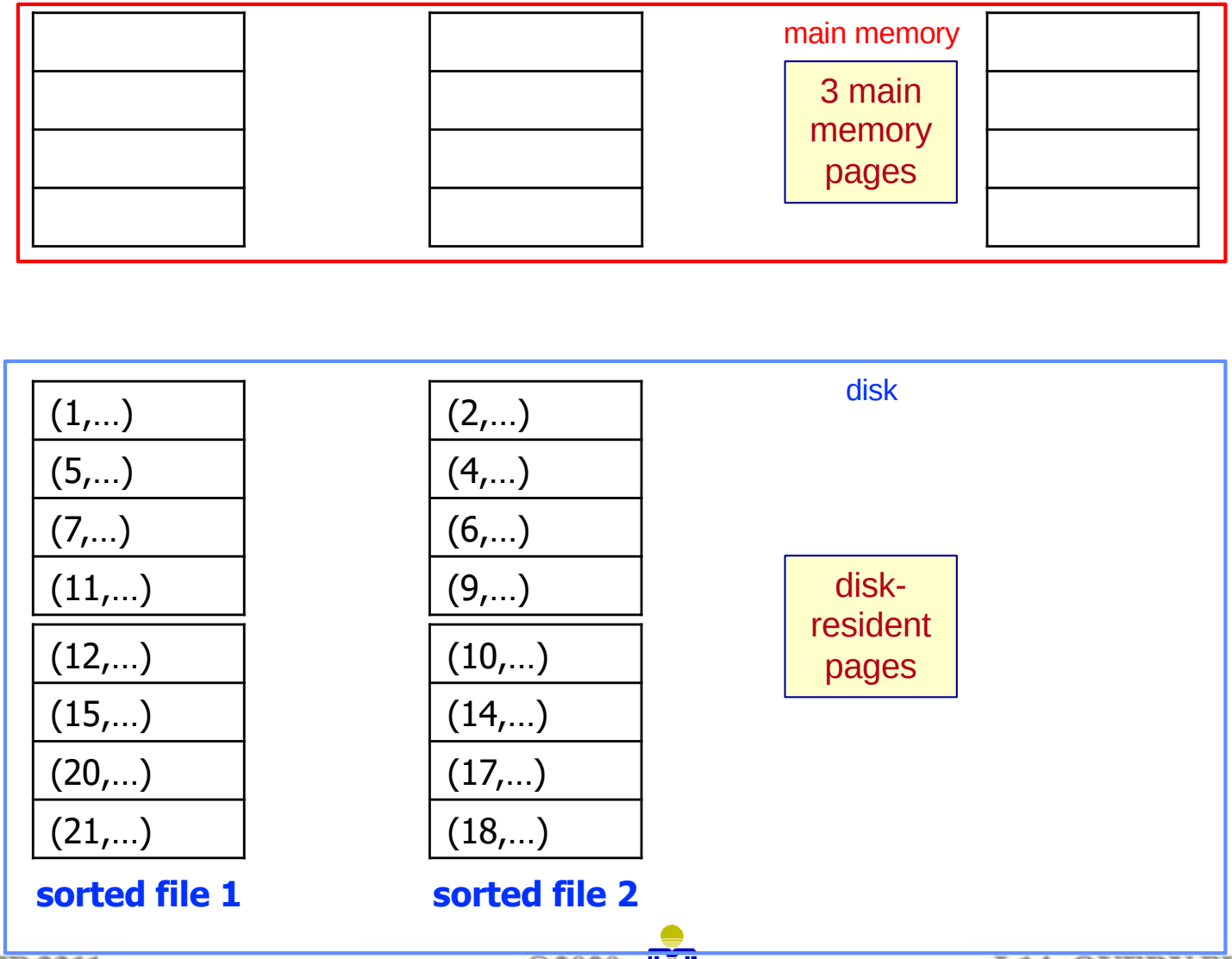
SORTING IN A DBMS

- When does a DBMS need to sort data?
  - To order query results (e.g., increasing by age).
  - To remove duplicate results.
  - For bulk loading a B^+-tree index.
  - Before performing a join operation (e.g., merge-join).
- Often database data is too large to fit into available main memory all at once.

☞ **External sorting is often required.**

EXTERNAL SORTING (DISK-RESIDENT FILES)

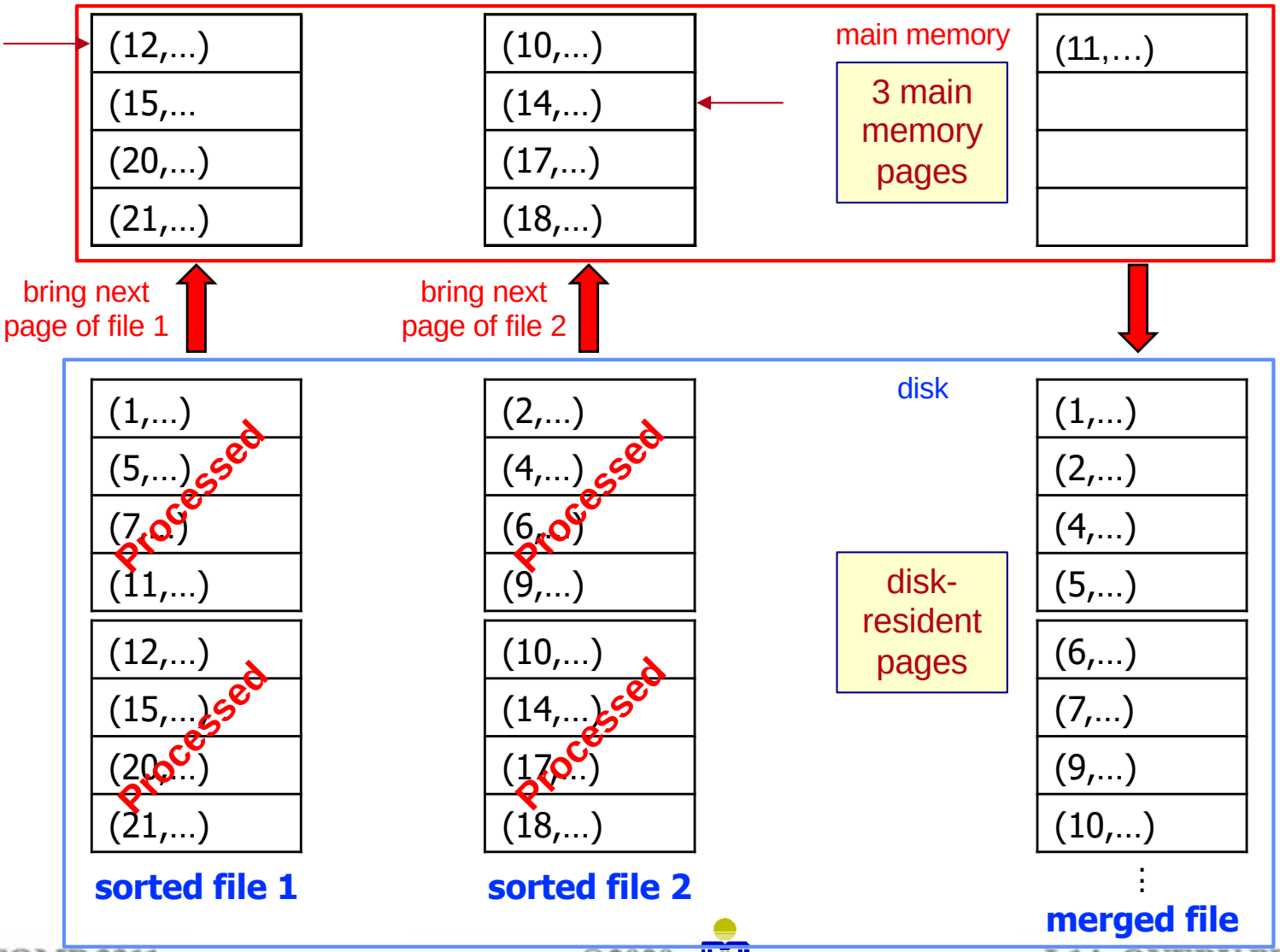
Merging 2 sorted files, 2 pages each with 3 pages of main memory



EXTERNAL SORTING (DISK-RESIDENT FILES)

(CONT'D)

Merging 2 sorted files, 2 pages each with 3 pages of main memory



EXTERNAL SORTING (DISK-RESIDENT FILES) (CONT'D)

Continuing the previous example:

Question: We assumed that each file is already sorted. If a file is not sorted, how do we sort it (using only the 3 buffer pages)?

Question: The previous example assumes two separate files. How do we apply this idea to sort a single file?

Question: Can we do better if we have *M* > 3 main memory pages?

EXTERNAL SORT-MERGE ALGORITHM

Let *M* denote the memory size (in pages).

Create sorted runs

Let *i* be 0 initially.
Repeat the following **until** the end of the relation:
(a) Read *M* pages of the relation into memory.
(b) Sort the in-memory pages.
(c) Write sorted data to run R_i; increment *i.*
Let the final value of *i* be *N.*

Merge the runs (N-way merge) (We assume (for now) that $N < M$.)

Use *N* pages of memory to buffer input runs, and 1 page to buffer output.
Read the first page of each run into its buffer page.
repeat
Select the first record (in sort order) among all buffer pages.
Write the record to the output buffer; if the output buffer is full write it to disk.
Delete the record from its input buffer page.
If the buffer page becomes empty **then**
Read the next page (if any) of the run into the buffer.
until all input buffer pages are empty.

EXTERNAL SORT-MERGE ALGORITHM (CONT'D)

- Let M denote the memory size (in pages), i the number of runs (i.e., the number of files to be merged).
- If $i \geq M$, several merge *passes* are required.

  In each pass, contiguous groups of M - 1 runs are merged.
- A pass reduces the number of runs by a factor of M -1 and creates runs longer by the same factor.

  E.g., If M=11, and there are 90 runs, one pass reduces the number of runs to $\lceil 90/10 \rceil = 9$, each 10 times the size of the initial runs.
- Repeated passes are performed until all runs are merged into one.

Number of passes (sort & merge)

- $1 + \lceil \log_{M-1}(B_r/M) \rceil$ passes where B_r is the file size in pages

I/O cost (sort & merge)

- $2*B_r + 2*B_r*\lceil \log_{M-1}(B_r/M) \rceil = 2*B_r*(1 + \lceil \log_{M-1}(B_r/M) \rceil)$ pages

  ($2*B_r$: sort; $2*B_r*\lceil \log_{M-1}(B_r/M) \rceil$: merge)

EXTERNAL SORT-MERGE ALGORITHM (CONT'D)

- Example assuming the number of pages B_r=12 with 1 record per page and M=3 buffer pages.

- **Number of passes**

  $1+\lceil \log_{M-1}(B_r/M) \rceil = 3$

- **Number of disk I/Os** (read and write):

  Pass 0 (create sorted runs): 12 x 2 = 24

  Pass 1 (merge): 12 x 2 = 24

  Pass 2 (merge): 12 x 2 =24

  Total I/O cost = 72 pages

  ☞ $2* B_r*(1+\lceil \log_{M-1}(B_r/M) \rceil) =$
  $2*12*(1+\lceil \log_2(4) \rceil) = 72$