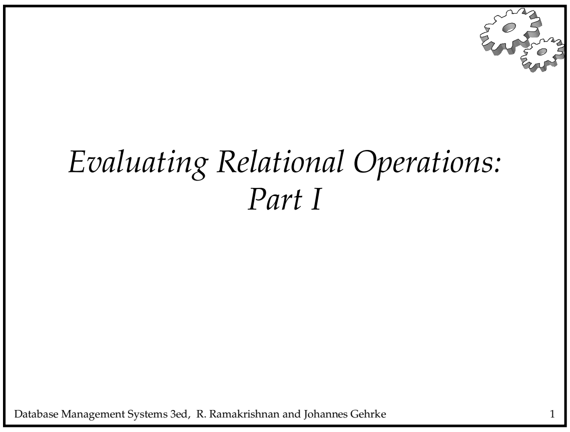
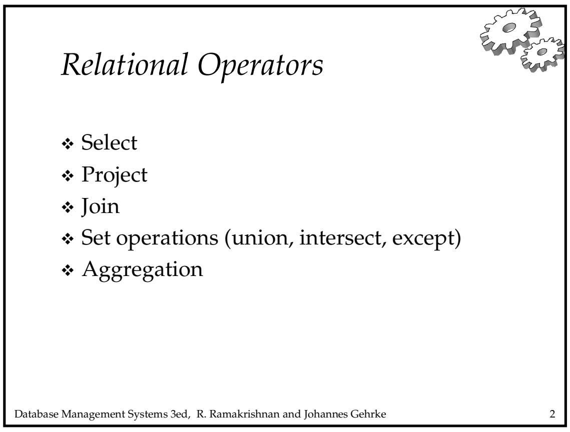
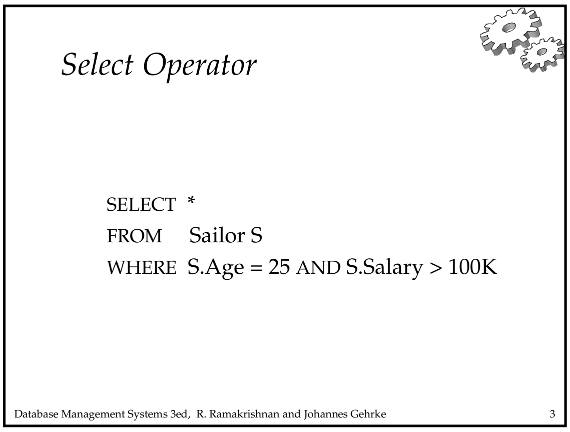


Evaluating Relational Operations: Part I



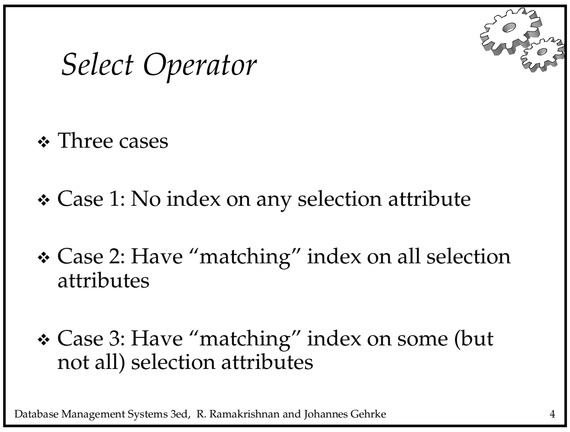
Relational Operators

- Select
- Project
- Join
- Set operations (union, intersect, except)
- Aggregation



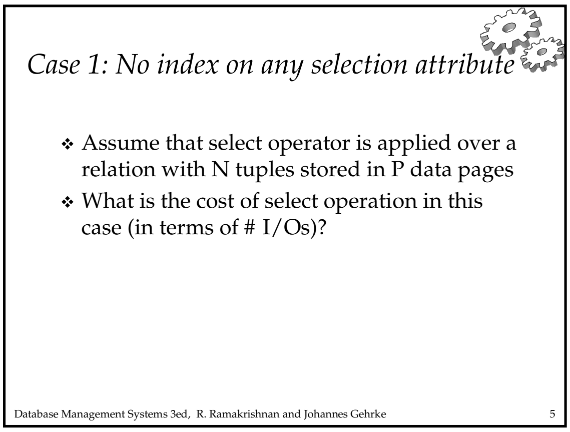
Select Operator

```
SELECT  *
FROM    Sailor S
WHERE   S.Age = 25 AND S.Salary > 100K
```



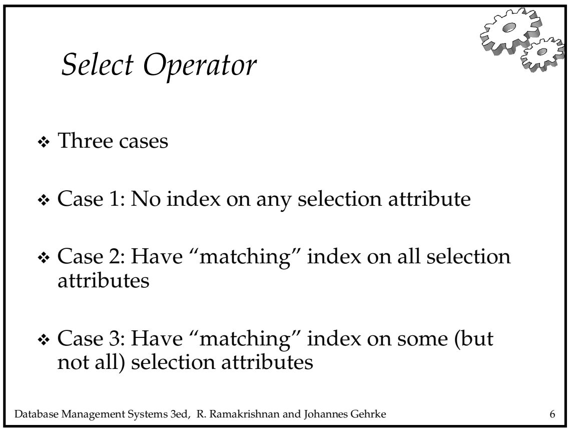
Select Operator

- Three cases
- Case 1: No index on any selection attribute
- Case 2: Have “matching” index on all selection attributes
- Case 3: Have “matching” index on some (but not all) selection attributes



Case 1: No index on any selection attribute

- Assume that select operator is applied over a relation with N tuples stored in P data pages
- What is the cost of select operation in this case (in terms of # I/Os)?



Select Operator

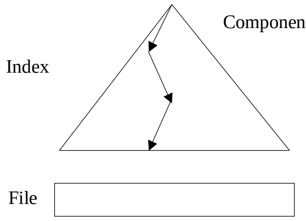
- Three cases
- Case 1: No index on any selection attribute
- Case 2: Have “matching” index on all selection attributes
- Case 3: Have “matching” index on some (but not all) selection attributes

Case 2: Example

```
SELECT  *
FROM    Sailor S
WHERE   S.Age = 25 AND S.Salary > 100K
```

- Have B+-tree index on (Age, Salary)

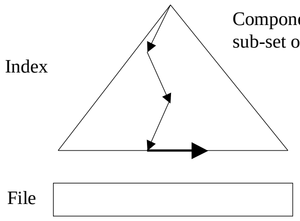
Case 2: Cost Components



Component 1: Traversing index

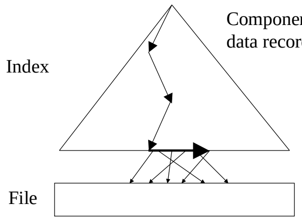
Cost for B+-trees?
For hash indices?

Case 2: Cost Components



Component 2: Traversing sub-set of data entries in index

Case 2: Cost Components



Component 3: Fetching actual data records (alternative 2 or 3)

Cost of Component 1

- D is cost of reading/writing one page to disk (using random disk I/O)
- Hash index
  - Cost = D
- B+-tree
  - Cost = D * (height of tree)

Cost of Component 2

- N data entries (= # data tuples if alternative 2)
- Hash index
  - Linear hashing
  - B hash buckets
  - Average cost = D * (N/B – 1)
- B+ tree index
  - L = average number of entries per leaf page
  - S = Selectivity (fraction of tuples satisfying selection)
  - Average cost = D * ((S * N/L) – 1)

Cost of Component 3

- S*N data entries satisfy selection condition
  - S is selectivity, N is total number of data entries
- T is number of data tuples per page
- Hash index
  - Worst-case cost = D * S * N (if unclustered index)

    D * S * N / T (if clustered index)
- B+ tree index
  - Worst-case cost = Same as hash index

Putting it all together

- Total cost of select operations using unclustered B+ tree index
  - D * (Height + (S * N/L – 1) + S * N)
- Should we always use index in this case?
  - Depends on selectivity of selection condition!
  - D * (Height + (S * N/L – 1) + S * N) < D * P
  - S < (P – Height + 1) * L / N(L + 1)
  - Simple optimization!
- What about a clustered index?

Component 3: Optimization

- Alternative 2 or 3, unclustered index
- Find qualifying data entries from index
- Sort the rids of the data entries to be retrieved
  - Remember rid = (page ID, slot #)
- Fetch rids in order
  - Ensures each data page is read from disk just once!
  - Although number of data pages retrieved still likely to be more than with clustering

Select Operator

- Three cases
- Case 1: No index on any selection attribute
- Case 2: Have “matching” index on all selection attributes
- Case 3: Have “matching” index on some (but not all) selection attributes

Case 3: Example

```
SELECT  *
FROM    Sailor S
WHERE   S.Age = 25 AND S.Salary > 100K
```

- Have Hash index on Age

Evaluation Alternatives

- Alternative 1
  - Use available index (on Age) to get superset of relevant data entries
  - Retrieve the tuples corresponding to the set of data entries
  - Apply remaining predicates on retrieved tuples
  - Return those tuples that satisfy all predicates
- Alternative 2
  - Sequential scan! (always available)
  - May be better depending on selectivity

Case 3: Example

SELECT *
FROM Sailor S
WHERE S.Age = 25 AND S.Salary > 100K

- Have Hash index on Age
- Have B+ tree index on Salary

Evaluation Alternatives

- Alternative 1
  - Choose most selective access path (index)
    - Could be index on Age or Salary, depending on selectivity of the corresponding predicates
  - Use this index to get superset of relevant data entries
  - Retrieve the tuples corresponding to the set of data entries
  - Apply remaining predicates on retrieved tuples
  - Return those tuples that satisfy all predicates

Evaluation Alternatives

- Alternative 2
  - Get rids of data records using each index
    - Use index on Age and index on Salary
  - Intersect the rids
    - We'll discuss intersection soon
  - Retrieve the tuples corresponding to the rids
  - Apply remaining predicates on retrieved tuples
  - Return those tuples that satisfy all predicates
- Alternative 3
  - Sequential scan!

Relational Operators

- Select
- Project
- Join
- Set operations (union, intersect, except)
- Aggregation

Example

SELECT DISTINCT S.Name, S. Age
FROM Sailor S

Evaluation Alternatives

- Alternative 1
  - Using Indices
- Alternative 2
  - Based on sorting
- Alternative 3
  - Based on hashing

Example

SELECT DISTINCT S.Name, S. Age
FROM Sailor S

- Have B+ tree index on (Name, Age)

Evaluation Using "Covering" Index

- Simply scan leaf levels of index structure
  - No need to retrieve actual data records
  - Index-only scan
- Works so long as the index search key includes all the projection attributes
  - Extra attributes in search key are okay
  - Best if projection attributes are prefix of search key
    - Can eliminate duplicates in single pass of index-only scan
- Other examples
  - Hash index on (SSN, Name, Age)
  - B+ tree index on (Age, # Dependents, Name)

Example

SELECT DISTINCT S.Name, S. Age
FROM Sailor S

- Have Hash index on Name
- Have B+ tree index on Age
- Sailor relation has 100 other attributes!

Evaluation Using RID Joins

- Retrieve (SearchKey1, RID) pairs from first index
- Retrieve (SearchKey2, RID) pairs from second index
- Join these based on RID to get (SearchKey1, SearchKey2, RID) triples
  - We will discuss joins soon!
- Project out the third column to get the desired result

Evaluation Alternatives

- Alternative 1
  - Using Indices
- Alternative 2
  - Based on sorting
- Alternative 3
  - Based on hashing

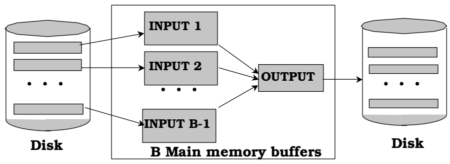
Example

SELECT DISTINCT S.Name, S. Age
FROM Sailor S

- No indices

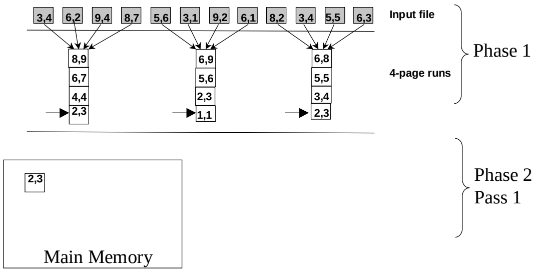
General External Merge Sort

- Phase 2: Make multiple passes to merge runs
  - Pass 1: Produce runs of length B(B-1) pages
  - Pass 2: Produce runs of length $B(B-1)^2$ pages
  - …
  - Pass P: Produce runs of length $B(B-1)^P$ pages



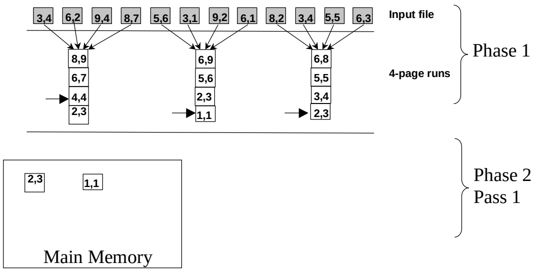
General External Merge Sort: Phase 2

- # buffer pages B = 4



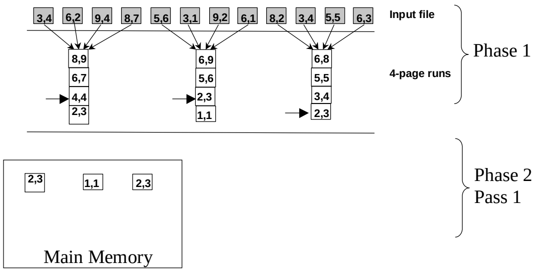
General External Merge Sort: Phase 2

- # buffer pages B = 4



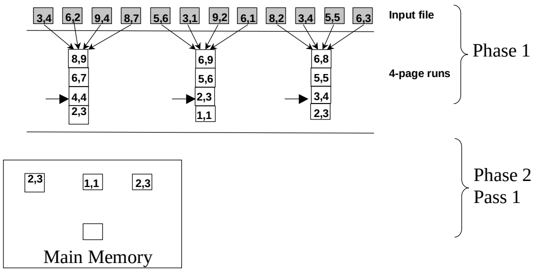
General External Merge Sort: Phase 2

- # buffer pages B = 4



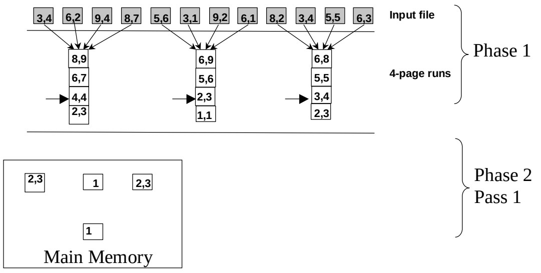
General External Merge Sort: Phase 2

- # buffer pages B = 4



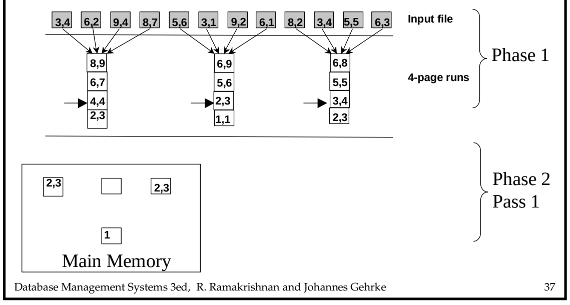
General External Merge Sort: Phase 2

- # buffer pages B = 4



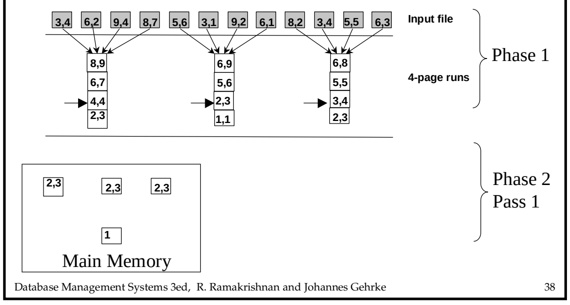
General External Merge Sort: Phase 2

- # buffer pages B = 4



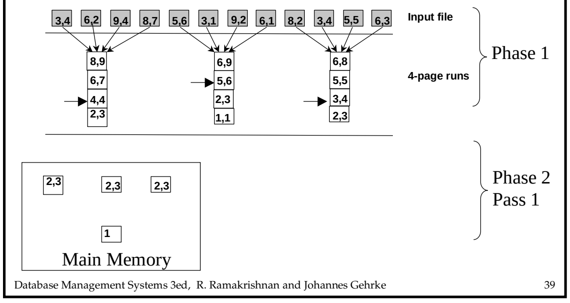
General External Merge Sort: Phase 2

- # buffer pages B = 4



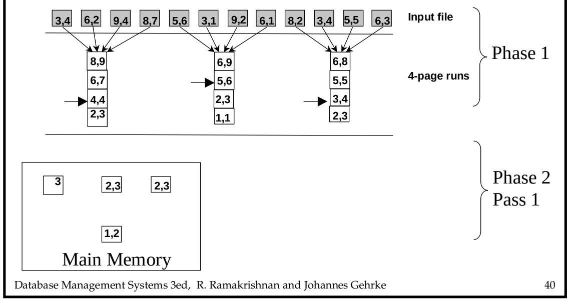
General External Merge Sort: Phase 2

- # buffer pages B = 4



General External Merge Sort: Phase 2

- # buffer pages B = 4



General External Merge Sort: Phase 2

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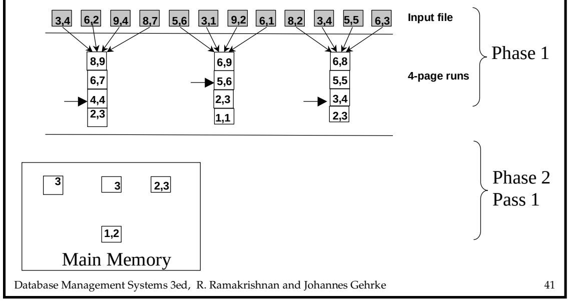
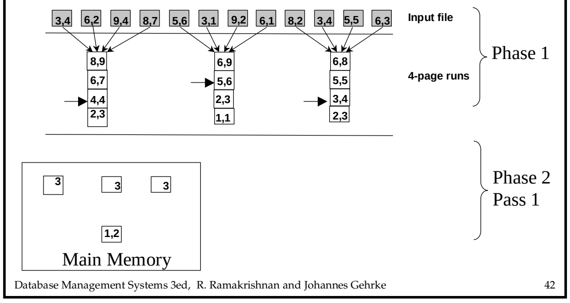


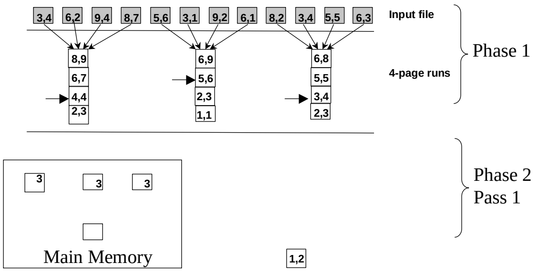
General External Merge Sort: Phase 2

- # buffer pages B = 4



General External Merge Sort: Phase 2

- # buffer pages B = 4



Modifications to External Sorting

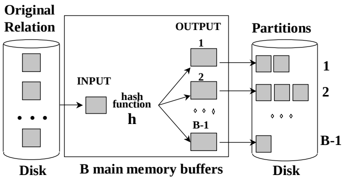
- Phase 1
  - Project out unwanted columns
  - Still produce runs of length B (or 2B) pages
  - But tuples in runs are smaller than input tuples (so smaller runs)
- Phase 2
  - Eliminate duplicates during merge
  - Smaller runs
- Exercise: Calculate I/O cost assuming certain size of projection columns and certain distributionof duplicates

Evaluation Alternatives

- Alternative 1
  - Using Indices
- Alternative 2
  - Based on sorting
- Alternative 3
  - Based on hashing

Projection Based on Hashing

- Assume relation does not fit in memory
- Phase 1
  - Divide relation into partitions
  - No duplicate elimination yet!



Phase 1: Analysis

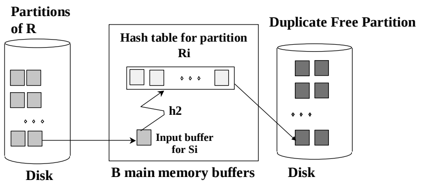
- Number of data pages = N
  - Assume all attributes are projected out
- Cost of reading/writing disk page = D
- Number of Partitions = B-1
- Length of each partition = N/(B-1)
- Cost of Phase 1 = 2 * D * N

Two Cases for Each Partition

- Case 1
  - Partitions fits in memory
- Case 2
  - Partition does not fit in memory

Case 1: Partition Fits in Memory

- Use h2 <> h1!



- R is number of pages in result
  - After eliminating duplicates
- Cost = D * (N + R)

Case 2: Partition Doesn't fit in Memory

- Recursively apply Phase 1 algorithm on the partition!
  - Use hash function h2 <> h1!
- Analysis
  - Size of each partition after P partitioning phases = $N/(B-1)^P$
  - Stop partitioning when : $N/(B-1)^P = B-1$
  - # Partitioning phases = $\log_{B-1}(N) - 1$
  - Total cost of Phase 1 = $2 * D * (\log_{B-1}(N) - 1)$

Comments on Projection

- Sort-based approach vs. hash-based approach
  - Which one would you choose?
  - Why?
- Sort-based approach!
  - Better handling of skew
  - Results in sorted order