Introduction to Database Systems

CSE 444

Lecture #15
Feb 28 2001

Announcement

- ⌘Project Report due today
- ⌘HW#4 available on the web
  - Optional, but you can only benefit from it!
- ⌘Lecture on March 5
  - Given by Vivek Narasayya (my colleague)
  - Material included in Finals
  - Discussion on Finals postponed to beginning of lecture on March 7
- ⌘Watch posting on mailing list
  - Limited exclusion of material

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Review of Selected Material

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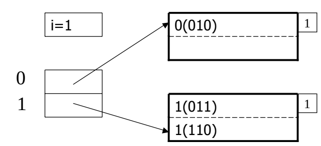
Insertion in Extensible Hash Table

⌘Insert 1110



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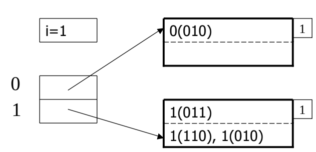
Insertion in Extensible Hash Table

⌘Now insert 1010



⌘Need to extend table, split blocks

⌘i becomes 2

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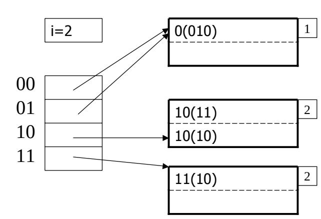
Insertion in Extensible Hash Table

⌘Now insert 1110



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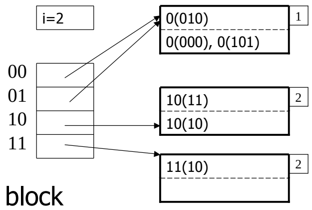
Insertion in Extensible Hash Table

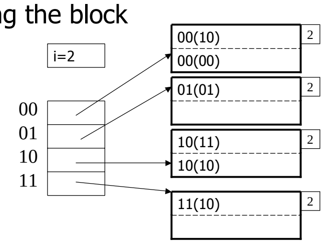
- Now insert 0000, then 0101



- Need to split block

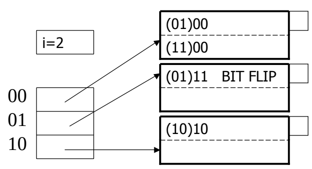
Insertion in Extensible Hash Table

- After splitting the block



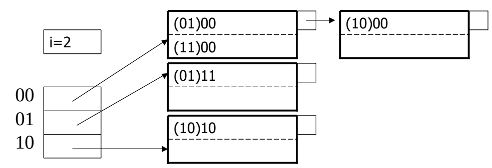
Linear Hash Table Example

- N=3



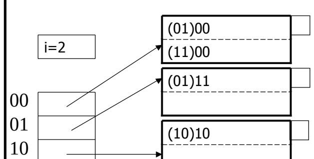
Linear Hash Table Example

- Insert 1000: overflow blocks…

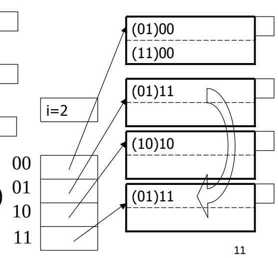


Linear Hash Table Extension

- From n=3 to n=4



- Only need to touch one block (which one ?)



Compressed BitMaps: Run Length Encoding

- Represent sequence of I 0-s followed by 1 as a binary encoding of I
- Concatenate codes for each run together
  - But, must be able to recover runs
- Scheme
  - B_I = #of bits in binary encoding of I
  - Represent as B_I – 1 1-s followed by 0 and then binary encoding of I

Indexes: Compressed BitMap

- ⌘Decode: (11101101001011)
- ⌘Run-Length: (13,0,3): Why?
- ⌘00000000000000110001
- ⌘Note: Trailing 0-s not recovered

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Indexes: Multi-column or Multiple Indexes

- ⌘Multi-column index
  - On concatenation of field1 and field2
  - Asymmetric for B+ Trees
- ⌘Index AND-ing and OR-ing
  - For Selection
  - For Join

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Indexing: When are indexes useful?

- ⌘Select Name, Age
- ⌘From Person
- ⌘Where Person.salary > 100 K and Person.state IN [NY, CA, WA]
- ⌘Group By City

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Query Execution (Contd.)

Required Reading: 2.3.3-2.3.5, 6.1- 6.7

Suggested Reading: 6.8, 6.9

Review of Last Lecture

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2-Way Merge Sort

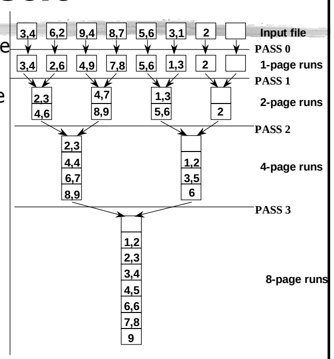
- ⌘ Each pass we read + write each page in file.
- ⌘ N pages in the file => the number of passes

$$=\lceil \log_2 N \rceil + 1$$

- ⌘ So total cost is:

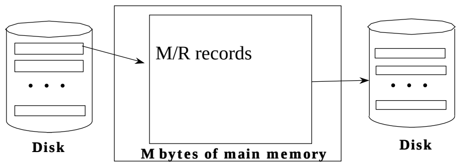
$$2N\left(\lceil \log_2 N \rceil + 1\right)$$

- ⌘ Improvement: start with larger runs
- ⌘ Sort 1GB with 1MB memory in 10 passes



Multiway Merge-Sort

- Phase one: load M bytes in memory, sort
  - Result: runs of length M/R records



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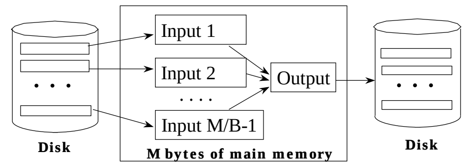
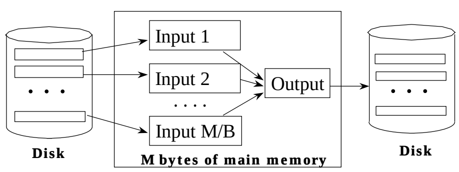
Phase Two

- Merge M/B – 1 runs into a new run
- Result: runs have now M/R (M/B – 1) records



Phase Three

- Merge M/B – 1 runs into a new run
- Result: runs have now M/R $(M/B – 1)^2$ records

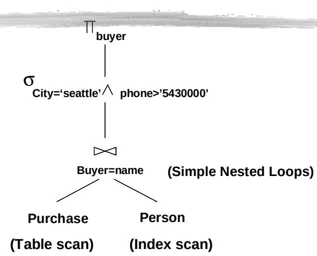


Cost of External Merge Sort

- Number of passes: $1+\lceil \log_{M/B-1} \lceil NR/M \rceil \rceil$
- Think differently
  - Given B = 4KB, M = 64MB, R = 0.1KB
  - Pass 1: runs of length M/R = 640000
    - Have now sorted runs of 640000 records
  - Pass 2: runs increase by a factor of M/B – 1 = 16000
    - Have now sorted runs of 10,240,000,000 = 10^{10} records
  - Pass 3: runs increase by a factor of M/B – 1 = 16000
    - Have now sorted runs of 10^{14} records
    - Nobody has so much data !
- Can sort everything in 2 or 3 passes !

Logical and Physical Operators

```
SELECT S.buyer
FROM Purchase P, Person Q
WHERE P.buyer=Q.name AND
      Q.city='seattle' AND
      Q.phone > '5430000'
```



Query Plan:
- logical tree
- implementation choice at every node
- scheduling of operations

Some operators are from relational algebra, and others (e.g., scan, group) are not.

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Estimating the Cost of Operators

- Very important for the optimizer (next week)
- Parameters for a relation R
  - B(R) = number of blocks holding R
    - Meaningful if R is clustered
  - T(R) = number of tuples in R
    - E.g. may need when R is unclustered
  - V(R,a) = number of distinct values of the attribute a

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Scanning Tables

- The table is *clustered*
  - Table-scan: if we know where the blocks are
- The table is unclustered (e.g. its records are placed on blocks with other tables)
  - May need one read for each record
- Also, index scan (discussed later)

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Sorting While Scanning

- Sometimes it is useful to have the output sorted
- Three ways to scan it sorted:
  - If it fits in memory, sort there
  - If not, use multiway merging

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Cost of the Scan Operator

- Clustered relation:
  - B(R); to sort: 3B(R)
- Unclustered relation
  - T(R); to sort: T(R) + 2B(R)

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One-pass Algorithms

Grouping: $\gamma_{\text{city, sum(price)}}$ (R)

- Need to store all cities in memory
- Also store the sum(price) for each city
- Balanced search tree or hash table
- Cost: B(R)
- Assumption: number of cities fits in memory

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Nested Loop Joins

- Block-based Nested Loop Join

```
For each (M-1) blocks bs of S do
   for each block br of R do
         for each tuple s in bs
              for each tuple r in br do
                   if r and s join then output(r,s)
```

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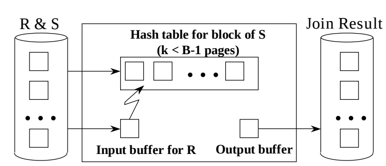
Nested Loop Joins



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Nested Loop Joins

- Block-based Nested Loop Join
- Cost:
  - Read S once: cost B(S)
  - Outer loop runs B(S)/(M-1) times, and each time need to read R: costs B(S)B(R)/(M-1)
  - Total cost: B(S) + B(S)B(R)/(M-1)
- Notice: it is better to iterate over the smaller relation first
- R $\bowtie$ S: R=outer relation, S=inner relation

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Two-Pass Algorithms Based on Sorting

- Recall: multi-way merge sort needs only two passes !
- Assumption: B(R) <= M^2
- Cost for sorting: 3B(R)

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Two-Pass Algorithms Based on Sorting

Grouping: $\gamma_{city,\ sum(price)}$ (R)

- Same as before: sort, then compute the sum(price) for each group
- As before: compute sum(price) during the merge phase.
- Total cost: 3B(R)
- Assumption: B(R) <= M^2

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Two-Pass Join Algorithms Based on Sorting

- Start by sorting both R and S on the join attribute:
  - Cost: 4B(R)+4B(S) (because need to write to disk)
- Read both relations in sorted order, match tuples
  - Cost: B(R)+B(S)
- Difficulty: many tuples in R may match many in S
  - If at least one set of tuples fits in M, we are OK
  - Otherwise need nested loop
  - Total cost: 5B(R)+5B(S)
  - Assumption: B(R) <= M^2, B(S) <= M^2

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Two-Pass Algorithms Based on Sorting

Join R $\bowtie$ S

- If the number of tuples in R matching those in S is small (or vice versa) we can compute the join during the merge phase
- Total cost: 3B(R)+3B(S)
- Assumption: B(R) + B(S) <= M^2

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Query Execution (contd.) [New Material]

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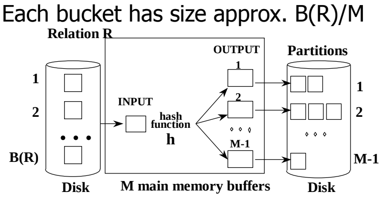
Two Pass Algorithms Based on Hashing

- Idea: partition a relation R into buckets, on disk
- Each bucket has size approx. B(R)/M



- Does each bucket fit in main memory ?
  - Yes if B(R)/M <= M, i.e. B(R) <= M^2

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Hash Based Algorithms for δ

- Recall: $\delta(R)$ = duplicate elimination
- Step 1. Partition R into buckets
- Step 2. Apply δ to each bucket (may read in main memory)
- Cost: 3B(R)
- Assumption:B(R) <= M^2

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Hash Based Algorithms for γ

- Recall: $\gamma(R)$ = grouping and aggregation
- Step 1. Partition R into buckets
- Step 2. Apply γ to each bucket (may read in main memory)

- Cost: 3B(R)
- Assumption:B(R) <= M^2

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Hash-based Join

- R $\bowtie$ S
- Recall the *main memory hash-based join*:
  - Scan S, build buckets in main memory
  - Then scan R and join

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Partitioned Hash Join

R $\bowtie$ S
- Step 1:
  - Hash S into M buckets
  - send all buckets to disk
- Step 2
  - Hash R into M buckets
  - Send all buckets to disk
- Step 3
  - Join every pair of buckets

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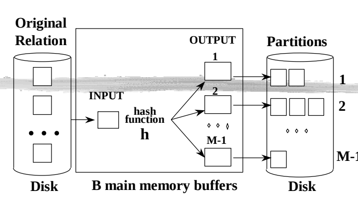
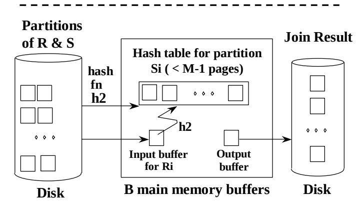
Hash-Join

- Partition both relations using hash fn **h**: R tuples in partition i will only match S tuples in partition i.



- Read in a partition of R, hash it using **h2 (<> h!)**. Scan matching partition of S, search for matches.



Partitioned Hash Join

- Cost: 3B(R) + 3B(S)
- Assumption: min(B(R), B(S)) <= M^2

Hybrid Hash Join Algorithm

- Partition S into k buckets
- But keep first bucket S_1 in memory, k-1 buckets to disk
- Partition R into k buckets
  - First bucket R_1 is joined immediately with S_1
  - Other k-1 buckets go to disk
- Finally, join k-1 pairs of buckets:
  - (R_2,S_2), (R_3,S_3), …, (R_k,S_k)

Hybrid Join Algorithm

- How big should we choose k ?
- Average bucket size for S is B(S)/k
- Need to fit B(S)/k + (k-1) blocks in memory
  - B(S)/k + (k-1) <= M
  - k slightly smaller than B(S)/M

Hybrid Join Algorithm

- How many I/Os ?
- Recall: cost of partitioned hash join:
  - 3B(R) + 3B(S)
- Now we save 2 disk operations for one bucket
- Recall there are k buckets
- Hence we save 2/k(B(R) + B(S))
- Cost: (3-2/k)(B(R) + B(S)) =
  (3-2M/B(S))(B(R) + B(S))

Indexed Based Algorithms

- Recall that in a clustered index all tuples with the same value of the key are clustered on as few blocks as possible

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- Note: book uses another term: "clustering index". Difference is minor…

Index Based Selection

- Selection on equality: $\sigma_{a=v}(R)$
- Clustered index on a: cost B(R)/V(R,a)
- Unclustered index on a: cost T(R)/V(R,a)

Index Based Selection

- Example: B(R) = 2000, T(R) = 100,000, V(R, a) = 20, compute the cost of $\sigma_{a=v}(R)$
- Cost of table scan:
  - If R is clustered: B(R) = 2000 I/Os
  - If R is unclustered: T(R) = 100,000 I/Os
- Cost of index based selection:
  - If index is clustered: B(R)/V(R,a) = 100
  - If index is unclustered: T(R)/V(R,a) = 5000
- Notice: when V(R,a) is small, then unclustered index is useless

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Index Based Join

- $R \bowtie S$
- Assume S has an index on the join attribute
- Iterate over R, for each tuple fetch corresponding tuple(s) from S
- Assume R is clustered. Cost:
  - If index is clustered: B(R) + T(R)B(S)/V(S,a)
  - If index is unclustered: B(R) + T(R)T(S)/V(S,a)

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Index Based Join

- Assume both R and S have a sorted index (B+ tree) on the join attribute
- Then perform a merge join (called zig-zag join)
- Cost: B(R) + B(S)

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Optimization

- Algebraic laws provide alternative execution plans
- Estimate costs of alternative modes of execution
- Efficiently search the space of alternatives
  - Simplify search by applying heuristics (without costing)
    - apply laws that *seem* to result in cheaper plans

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Converting from SQL to Logical Plans

Select a1, …, an
From R1, …, Rk
Where C

$\Pi_{a1,\ldots,an}(\sigma_C(R1 \bowtie R2 \bowtie \ldots \bowtie Rk))$

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Converting from SQL to Logical Plans

Select a1, …, an
From R1, …, Rk
Where C
Group by b1, …, bl

$\Pi_{a1,\ldots,an}(\gamma_{b1, \ldots, bm, aggs}(\sigma_C(R1 \bowtie R2 \bowtie \ldots \bowtie Rk)))$

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Algebraic Laws

- Commutative and Associative Laws
  - $R \cup S = S \cup R$, $R \cup (S \cup T) = (R \cup S) \cup T$
  - $R \cap S = S \cap R$, $R \cap (S \cap T) = (R \cap S) \cap T$
  - $R \bowtie S = S \bowtie R$, $R \bowtie (S \bowtie T) = (R \bowtie S) \bowtie T$
- Distributive Laws
  - $R \bowtie (S \cup T) = (R \bowtie S) \cup (R \bowtie T)$

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Algebraic Laws

- Laws involving selection:
  - $\sigma_{C \text{ AND } C'}(R) = \sigma_C(\sigma_{C'}(R)) = \sigma_C(R) \cap \sigma_{C'}(R)$
  - $\sigma_{C \text{ OR } C'}(R) = \sigma_C(R) \cup \sigma_{C'}(R)$
  - $\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$
    - When C involves only attributes of R
  - $\sigma_C(R - S) = \sigma_C(R) - S$
  - $\sigma_C(R \cup S) = \sigma_C(R) \cup \sigma_C(S)$
  - $\sigma_C(R \cap S) = \sigma_C(R) \cap S$

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Algebraic Laws

- Example: R(A, B, C, D), S(E, F, G)
  - $\sigma_{F=3}(R \bowtie_{D=E} S) =$?
  - $\sigma_{A=5 \text{ AND } G=9}(R \bowtie_{D=E} S) =$?

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Algebraic Laws

- Laws involving projections
  - $\Pi_M(R \bowtie S) = \Pi_N(\Pi_P(R) \bowtie \Pi_Q(S))$
    - Where N, P, Q are appropriate subsets of attributes of M
  - $\Pi_M(\Pi_N(R)) = \Pi_{M,N}(R)$
- Example R(A,B,C,D), S(E, F, G)
  - $\Pi_{A,B,G}(R \bowtie_{D=E} S) = \Pi_?(\Pi_?(R) \bowtie_{D=E} \Pi_?(S))$

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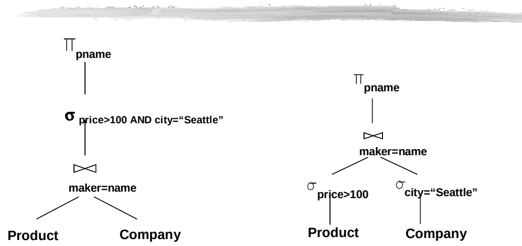
Heuristic: Predicate Pushdown



The earlier we process selections, less tuples we need to manipulate higher up in the tree (but may cause us to loose an important ordering of the tuples).

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Determining Join Order

- Select-project-join
- Push selections down, pull projections up
- Hence: we need to choose the join order
- This is the main focus of an optimizer

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