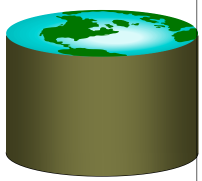
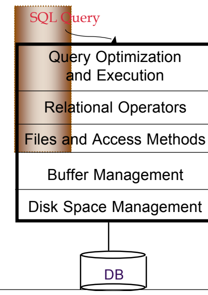
Unary Query Processing Operators

Not in the Textbook!



A "Slice" Through Query Processing

- **We'll study single-table queries today**
  - SQL details
  - Query Executor Architecture
  - Simple Query "Optimization"



Basic Single-Table Queries

```
SELECT [DISTINCT] <column expression list>
  FROM <single table>
 [WHERE <predicate>]
 [GROUP BY <column list>
  [HAVING <predicate>] ]
 [ORDER BY <column list>]
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- **Simplest version is straightforward**
  - Produce all tuples in the table that satisfy the predicate
  - Output the expressions in the SELECT list
    - Expression can be a column reference, or an arithmetic expression over column refs

Basic Single-Table Queries

```
SELECT            S.name, S.gpa
  FROM Students S
 WHERE S.dept = 'CS'
 [GROUP BY <column list>
  [HAVING <predicate>] ]
 [ORDER BY <column list>]
```

- **Simplest version is straightforward**
  - Produce all tuples in the table that satisfy the predicate
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    - Expression can be a column reference, or an arithmetic expression over column refs

SELECT DISTINCT

```
SELECT  DISTINCT  S.name, S.gpa
  FROM Students S
 WHERE S.dept = 'CS'
 [GROUP BY <column list>
  [HAVING <predicate>] ]
 [ORDER BY <column list>]
```

- **DISTINCT flag specifies removal of duplicates before output**

ORDER BY

```
SELECT  DISTINCT  S.name, S.gpa, S.age*2 AS a2
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
 ORDER BY S.gpa, S.name, a2;
```

- **ORDER BY clause specifies that output should be sorted**
  - Lexicographic ordering again!
- **Obviously must refer to columns in the output**
  - Note the AS clause for naming output columns!

ORDER BY

```
SELECT  DISTINCT  S.name, S.gpa
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
 ORDER BY S.gpa DESC, S.name ASC;
```

- **Ascending order by default, but can be overriden**
  - DESC flag for descending, ASC for ascending
  - Can mix and match, lexicographically

Aggregates

```
SELECT [DISTINCT] AVERAGE(S.gpa)
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
[ORDER BY <column list>]
```

- **Before producing output, compute a summary (a.k.a. an *aggregate*) of some arithmetic expression**
- **Produces 1 row of output**
  - with one column in this case
- **Other aggregates: SUM, COUNT, MAX, MIN**
- **Note: can use DISTINCT *inside* the agg function**
  - SELECT COUNT(DISTINCT S.name) FROM Students S
  - vs. SELECT DISTINCT COUNT (S.name) FROM Students S;

GROUP BY

```
SELECT [DISTINCT] AVERAGE(S.gpa), S.dept
  FROM Students S
[WHERE <predicate>]
 GROUP BY S.dept
 [HAVING <predicate>]
[ORDER BY <column list>]
```

- **Partition the table into groups that have the same value on GROUP BY columns**
  - Can group by a list of columns
- **Produce an aggregate result per group**
  - Cardinality of output = # of distinct group values
- **Note: can put grouping columns in SELECT list**
  - For aggregate queries, SELECT list can contain aggs and GROUP BY columns only!
  - What would it mean if we said SELECT S.name, AVERAGE(S.gpa) above??

HAVING

```
SELECT [DISTINCT] AVERAGE(S.gpa), S.dept
  FROM Students S
[WHERE <predicate>]
 GROUP BY S.dept
  HAVING COUNT(*) > 5
[ORDER BY <column list>]
```

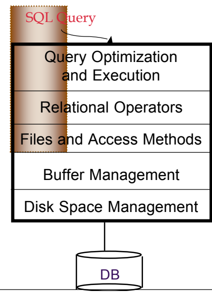
- **The HAVING predicate is applied *after* grouping and aggregation**
  - Hence can contain anything that could go in the SELECT list
  - I.e. aggs or GROUP BY columns
- **HAVING can only be used in aggregate queries**
- **It's an optional clause**

Putting it all together

```
SELECT S.dept, AVERAGE(S.gpa), COUNT(*)
  FROM Students S
 WHERE S.gender = "F"
 GROUP BY S.dept
  HAVING COUNT(*) > 5
 ORDER BY S.dept;
```

Context

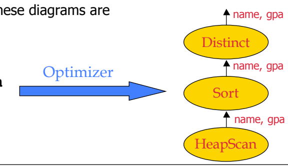
- We looked at SQL
- Now shift gears and look at Query Processing



Query Processing Overview

- **The *query optimizer* translates SQL to a special internal "language"**
  - Query Plans
- **The *query executor* is an *interpreter* for query plans**
- **Think of query plans as "box-and-arrow" *dataflow* diagrams**
  - Each box implements a *relational operator*
  - Edges represent a flow of tuples (columns as specified)
  - For single-table queries, these diagrams are straight-line graphs

```
SELECT DISTINCT name, gpa
  FROM Students
```



Iterators

- **The relational operators are all subclasses of the class** `iterator`:

```
class iterator {
    void init();
    tuple next();
    void close();
    iterator &inputs[];
    // additional state goes here
}
```

- **Note:**
  - Edges in the graph are specified by inputs (max 2, usually)
  - Encapsulation: any iterator can be input to any other!
  - When subclassing, different iterators will keep different kinds of state information

Example: Sort

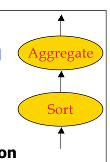
```
class Sort extends iterator {
   void init();
   tuple next();
   void close();
   iterator &inputs[1];
   int numberOfRuns;
   DiskBlock runs[];
   RID nextRID[];
}
```

- **`init()`:**
  - generate the sorted runs on disk
  - Allocate `runs[]` array and fill in with disk pointers.
  - Initialize numberOfRuns
  - Allocate nextRID array and initialize to NULLs
- **`next()`:**
  - nextRID array tells us where we're "up to" in each run
  - find the next tuple to return based on nextRID array
  - advance the corresponding nextRID entry
  - return tuple (or EOF -- "End of Fun" -- if no tuples remain)
- **`close()`:**
  - deallocate the runs and nextRID arrays

Postgres Version

- **src/backend/executor/nodeSort.c**
  - ExecInitSort (init)
  - ExecSort (next)
  - ExecEndSort (close)
- **The encapsulation stuff is hardwired into the Postgres C code**
  - Postgres predates even C++!
  - See src/backend/execProcNode.c for the code that "dispatches the methods" explicitly!

Sort GROUP BY: Naïve Solution



- **The Sort iterator (could be external sorting, as explained last week) naturally permutes its input so that all tuples are output in sequence**
- **The Aggregate iterator keeps running info ("transition values") on agg functions in the SELECT list, per group**
  - E.g., for COUNT, it keeps `count-so-far`
  - For SUM, it keeps `sum-so-far`
  - For AVERAGE it keeps `sum-so-far` *and* `count-so-far`
- **As soon as the Aggregate iterator sees a tuple from a new group:**
  1. It produces an output for the old group based on the agg function
     E.g. for AVERAGE it returns (`sum-so-far/count-so-far`)
  2. It resets its running info.
  3. It updates the running info with the new tuple's info

An Alternative to Sorting: Hashing!

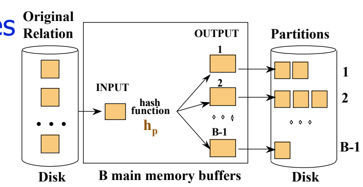
- **Idea:**
  - Many of the things we use sort for don't exploit the *order* of the sorted data
  - E.g.: forming groups in GROUP BY
  - E.g.: removing duplicates in DISTINCT
- **Often good enough to match all tuples with equal field-values**
- **Hashing does this!**
  - And may be cheaper than sorting! (Hmmm…!)
  - But how to do it for data sets bigger than memory??

General Idea

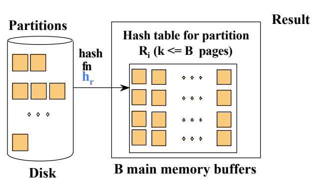
- **Two phases:**
  - Partition: use a hash function h_p to split tuples into partitions on disk.
    - We know that all matches live in the same partition.
    - Partitions are "spilled" to disk via output buffers
  - ReHash: for each partition on disk, read it into memory and build a main-memory hash table based on a hash function h_r
    - Then go through each bucket of this hash table to bring together matching tuples

Two Phases

- **Partition:**



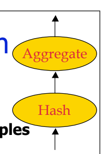
- **Rehash:**



Analysis

- **How big of a table can we hash in one pass?**
  - B-1 "spill partitions" in Phase 1
  - Each should be no more than B blocks big
  - Answer: B(B-1).
    - Said differently: We can hash a table of size N blocks in about space $\sqrt{N}$
  - Much like sorting!
- **Have a bigger table? Recursive partitioning!**
  - In the ReHash phase, if a partition *b* is bigger than B, then recurse:
    - pretend that *b* is a table we need to hash, run the Partitioning phase on *b*, and then the ReHash phase on each of its (sub)partitions

Hash GROUP BY: Naïve Solution (similar to the Sort GROUPBY)



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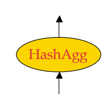
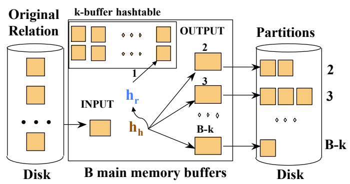
We Can Do Better!



- **Combine the summarization into the hashing process**
  - During the ReHash phase, don't store tuples, store pairs of the form <GroupVals, TransVals>
  - When we want to insert a new tuple into the hash table
    - If we find a matching GroupVals, just update the TransVals appropriately
    - Else insert a new <GroupVals,TransVals> pair
- **What's the benefit?**
  - Q: How many pairs will we have to handle?
  - A: Number of distinct values of GroupVals columns
    - Not the number of tuples!!
  - Also probably "narrower" than the tuples
- **Can we play the same trick during sorting?**

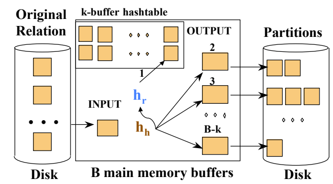
Even Better: Hybrid Hashing

- **What if the set of <GroupVals,TransVals> pairs fits in memory**
  - It would be a waste to spill it to disk and read it all back!
  - Recall this could be true even if there are *tons* of tuples!
- **Idea: keep a smaller 1st partition in memory during phase 1!**
  - Output its stuff at the end of Phase 1.
  - Q: how do we choose the number k?



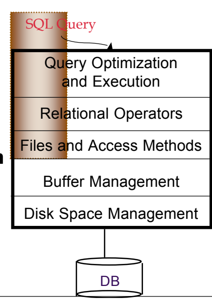
A Hash Function for Hybrid Hashing

- **Assume we like the hash-partition function h_p**
- **Define h_h operationally as follows:**
  - $h_h(x) = 1$ if in-memory hashtable is not yet full
  - $h_h(x) = 1$ if x is already in the hashtable
  - $h_h(x) = h_p(x)$ otherwise
- **This ensures that:**
  - Bucket 1 fits in k pages of memory
  - If the entire set of distinct hashtable entries is smaller than k, we do *no spilling!*



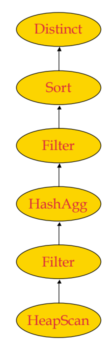
Context

- **We looked at SQL**
- **We looked at Query Execution**
  - Query plans & Iterators
  - A specific example
- **How do we map from SQL to query plans?**



Query Optimization

- **A deep subject, focuses on multi-table queries**
  - We will only need a cookbook version for now.
- **Build the dataflow bottom up:**
  - Choose an Access Method (HeapScan or IndexScan)
    - Non-trivial, we'll learn about this later!
  - Next apply any WHERE clause filters
  - Next apply GROUP BY and aggregation
    - Can choose between sorting and hashing!
  - Next apply any HAVING clause filters
  - Next Sort to help with ORDER BY and DISTINCT
    - In absence of ORDER BY, can do DISTINCT via hashing!
  - Note: Where did SELECT clause go?
    - Implicit!!



Summary

- **Single-table SQL, in detail**
- **Exposure to query processing architecture**
  - Query optimizer translates SQL to a query plan
  - Query executor "interprets" the plan
    - Query plans are graphs of iterators
- **Hashing is a useful alternative to sorting**
  - For many but not all purposes