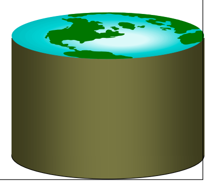
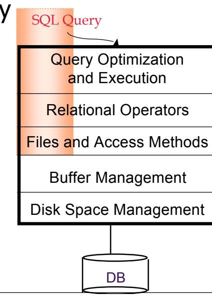
Unary Query Processing Operators

Not in the Textbook!



A "Slice" Thru 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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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>]
```

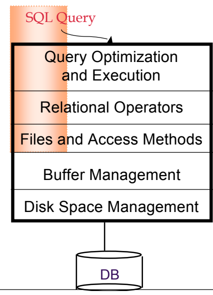
- The HAVING predicate is applied *after* grouping and aggregation
  - Hence can contain anything that could go in the SELECT list
  - I.e. aggs or GROUP BY columns
- HAVING can only be used in aggregate queries
- It's an optional clause

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

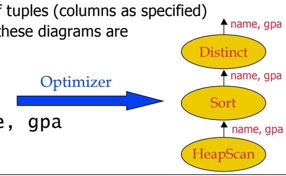
- We looked at SQL
- Now shift gears and look at Query Processing



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

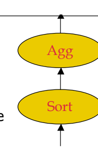
```
class Sort extends iterator {
    void init();
    tuple next();
    void close();
    iterator &inputs[1];
    int numberOfRuns;
    DiskBlock runs[];
    RID nextRID[];
}
```

- `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

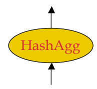
- src/backend/executor/nodeSort.c
  - ExecInitSort (init)
  - ExecSort (next)
  - ExecEndSort (close)
- The encapsulation/inheritence stuff is hardwired into the Postgres C code
  - Postgres predates even C++!
  - See src/backend/execProcNode.c for the code that "dispatches the methods" explicitly!

GROUP BY: One Solution



- The Sort iterator permutes its input so that all tuples are output in order of their grouping columns
- The Agg iterator maintains 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`
- When the Aggregate iterator sees a tuple from a new group:
  - 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`)
  - It resets its running info.
  - And updates the running info with the new tuple's info

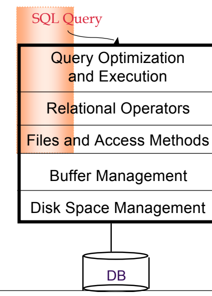
We Can Do Better!



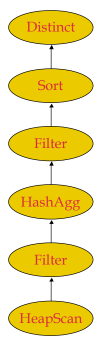
- Can use a hash-based approach
  - Build a hashtable of groups storing pairs of the form <GroupVals, TransVals>
  - When we want to insert a new tuple into the hash table
    - If we find a matching GroupVals, just update the TransVals appropriately
    - Else insert a new <GroupVals,TransVals> pair
- 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?
- What happens when hashtable runs out of memory
  - Wait for the discussion of Hash Joins, later.
- Note: This HashAgg idea was HW2 in previous years!

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