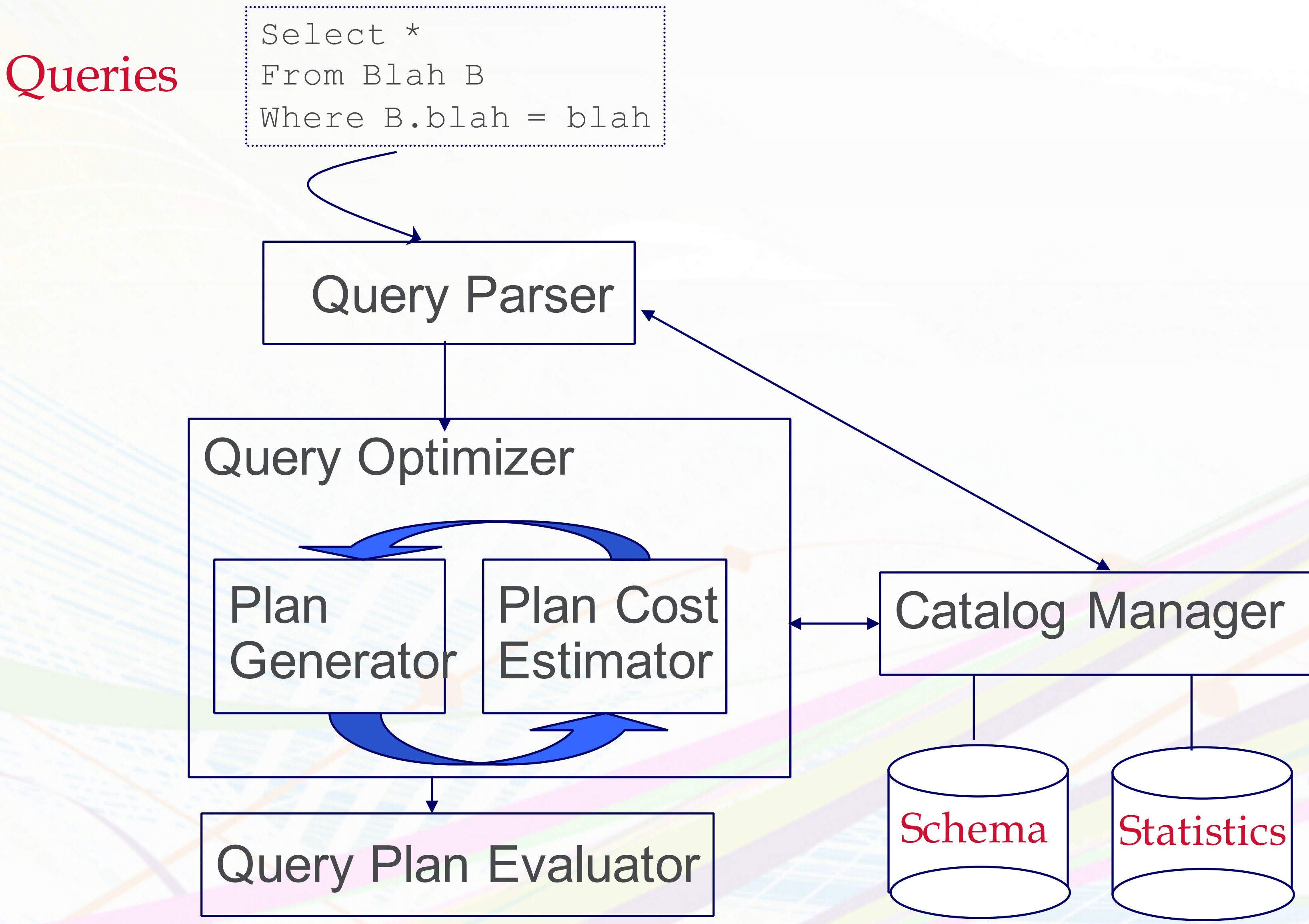
# Introduction to Query Evaluation and Optimization

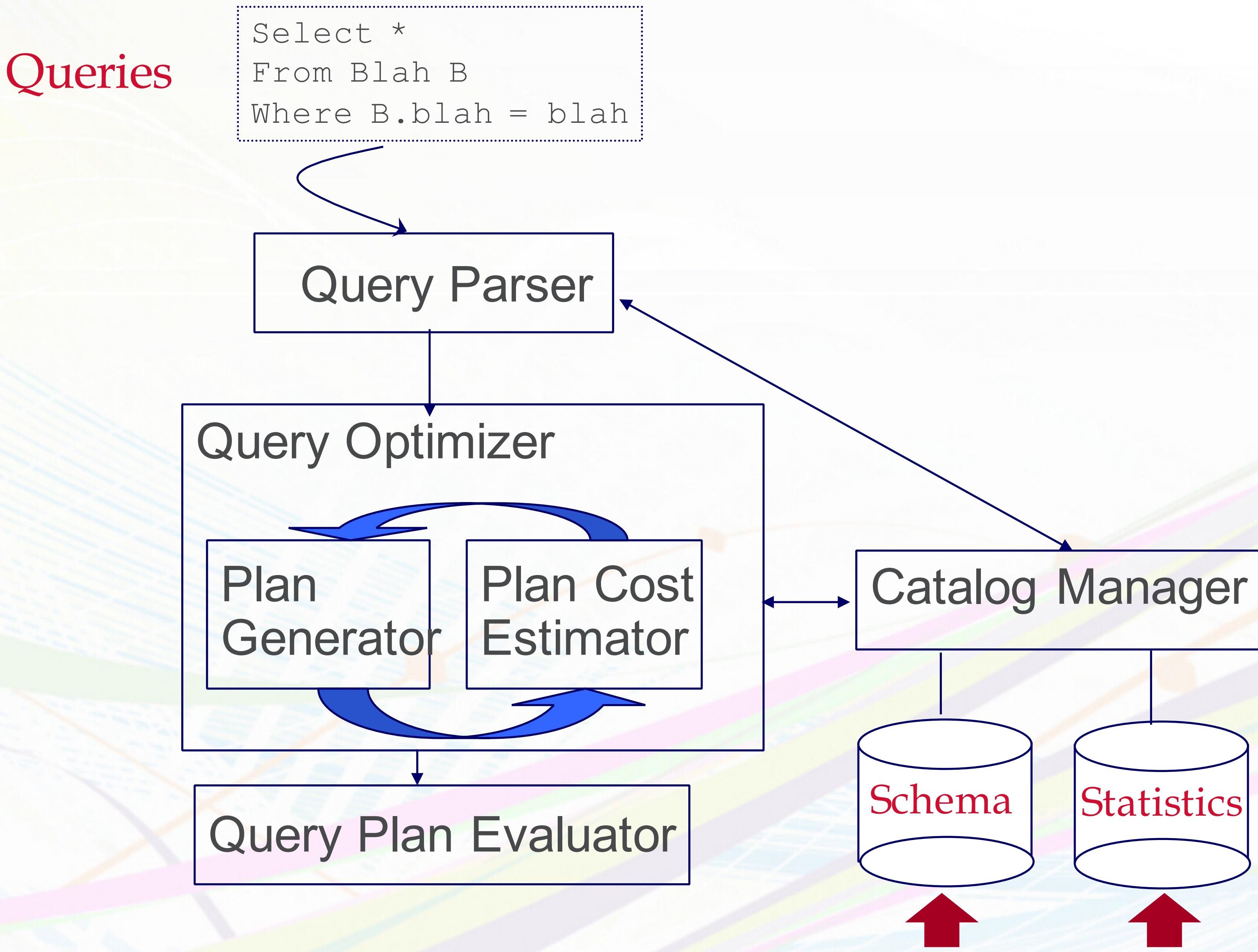
# Agenda

- Catalog (12.1)
- Intro to Operator Evaluation (12.2-3)
- Typical Query Optimizer (12.6)
- Projection: Sorting vs. Hashing (14.3.2)

# Cost-based Query Sub-System



# Cost-based Query Sub-System



# Catalog: Schema

- What would you store?
- How?

# Catalog: Schema

- What would you store?
  - *Info about tables, attributes, indexes, users*
- How?
  - *In tables!*

Attribute_Cat (attr_name: **string**, rel_name: **string**; type: **string**; position: **integer**)

*See **INFORMATION_SCHEMA** discussion from Lecture #7*

# Catalog: Statistics

- Why do we need them?
- What would you store?

# Catalog: Statistics

- Why do we need them?
  - *To estimate cost of query plans*
- What would you store?
  - **NTuples(R):** # records for table R
  - **NPages(R):** # pages for R
  - **NKeys(I):** # distinct key values for index I
  - **INPages(I):** # pages for index I
  - **IHeight(I):** # levels for I
  - **ILow(I), IHigh(I)**: range of values for I

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# Query Plan Example

```
SELECT cname, amt
  FROM customer, account
 WHERE customer.acctno =
       account.acctno
   AND account.amt > 1000
```

**Relational Algebra:**

$$\pi_{\text{cname, amt}}(\sigma_{\text{amt}>1000}\ (\text{customer} \bowtie \text{account}))$$

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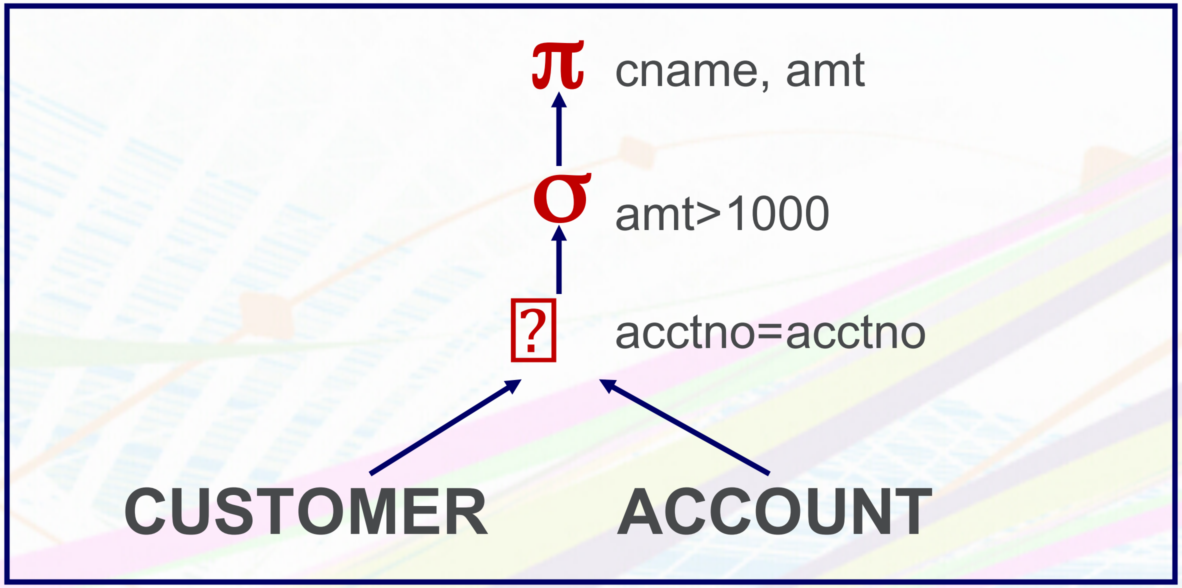

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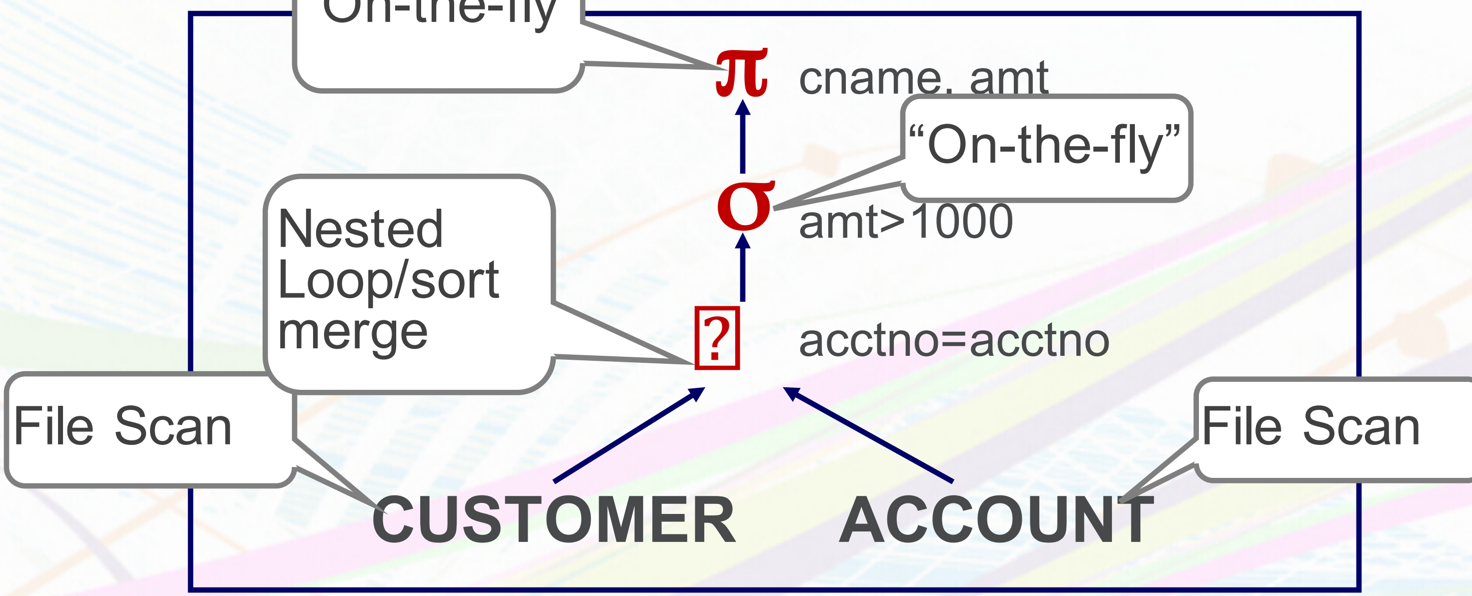

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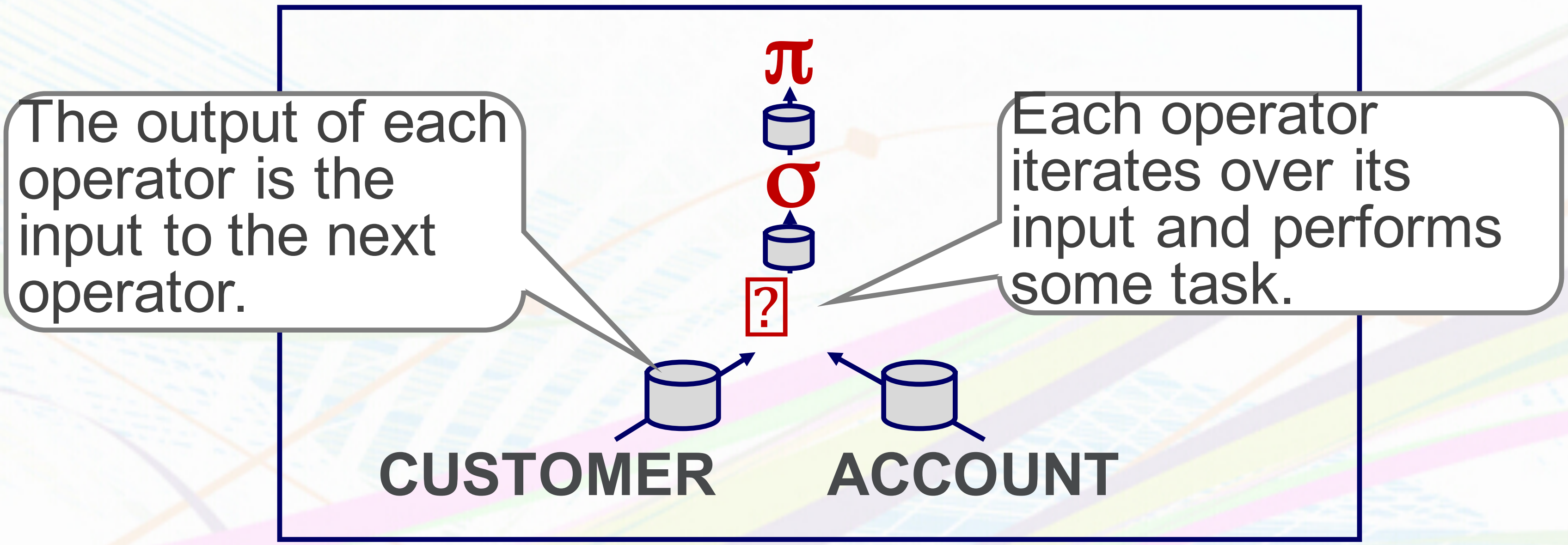

# Operator Evaluation

- Several algorithms are available for different relational operators.
- Each has its own performance trade-offs.
- The goal of the query optimizer is to choose the one that has the lowest "cost".

# Operator Execution Strategies

- Indexing
- Iteration (= seq. scanning)
- Partitioning (sorting and hashing)

# Access Paths

- How the DBMS retrieves tuples from a table for a query plan.
  - **File Scan** (Sequential Scan)
  - **Index Scan** (Tree, Hash, List, …)
- Selectivity of an access path:
  - % of pages we retrieve
  - e.g., Selectivity of a hash index, on range query: 100% (no reduction!)

# Operator Algorithms

- **Selection:**
- **Projection:**
- **Join:**
- **Group By:**
- **Order By:**

# Operator Algorithms

- **Selection:** file scan; index scan
- **Projection:** hashing; sorting
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# Query Optimization

- Bring query in internal form (eg., parse tree)

  … into “canonical form” (syntactic q-opt)
- Generate alternative plans.
- Estimate cost for each plan.
- Pick the best one.

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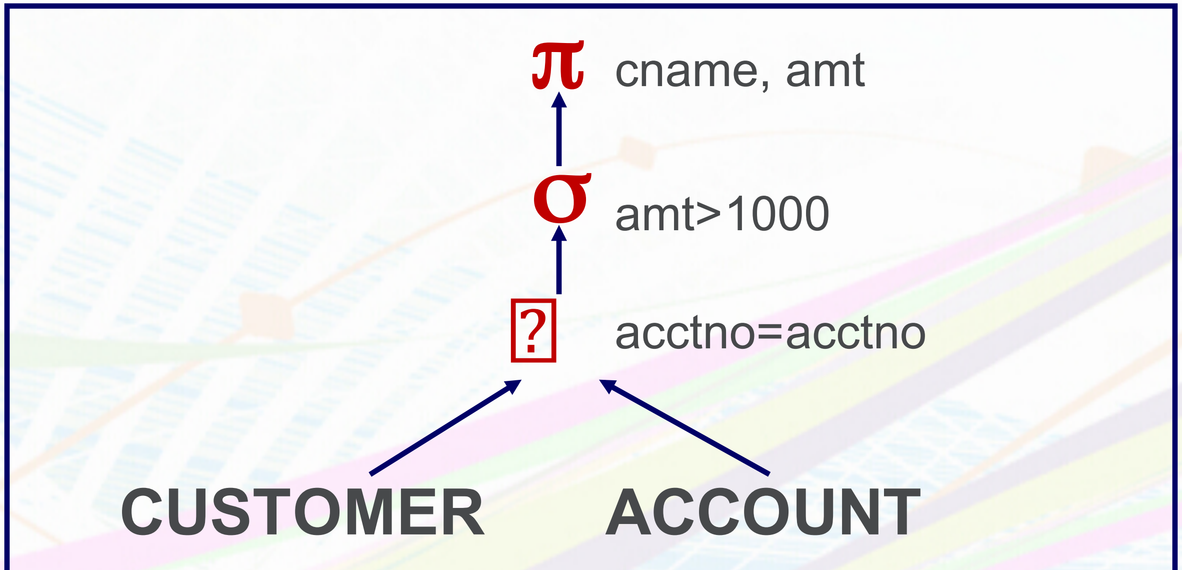

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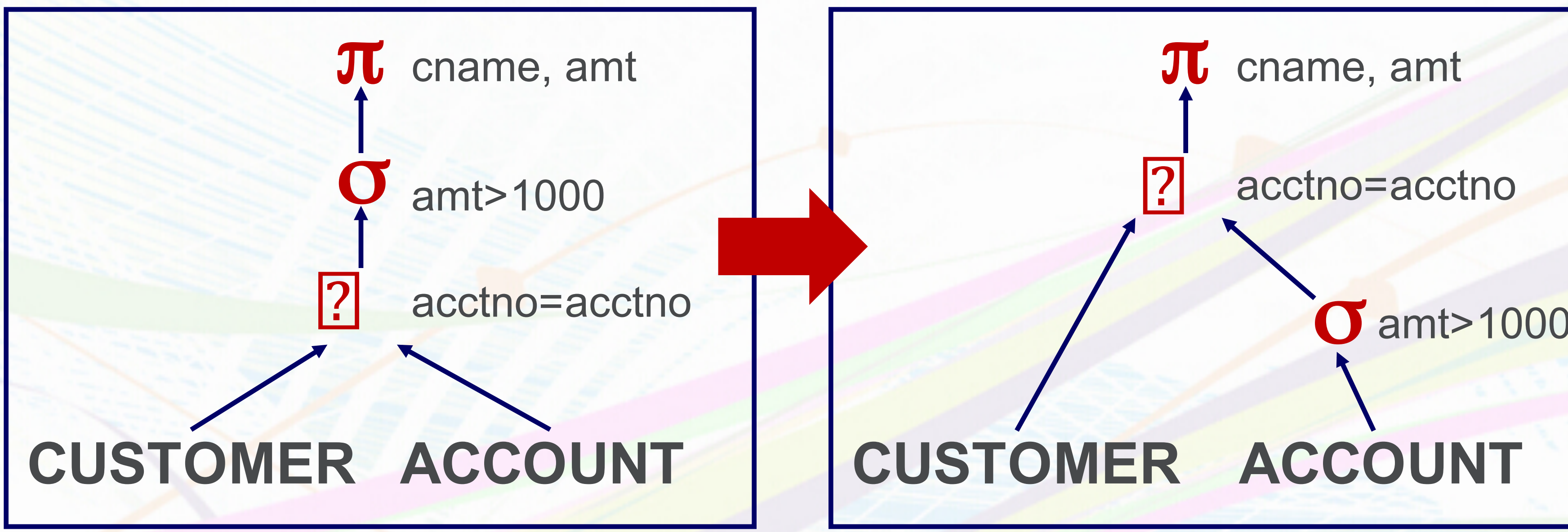


Pushing selection

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# Duplicate Elimination

```
SELECT DISTINCT bname
  FROM account
 WHERE amt > 1000
```

- What does it do, in English?
- How to execute it?

$$\pi_{\textbf{DISTINCT}\ \text{bname}}\ (\sigma_{\text{amt}>1000}\ (\text{account}))$$

Not technically correct because relational algebra doesn't have "DISTINCT"

# Duplicate Elimination

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  FROM account
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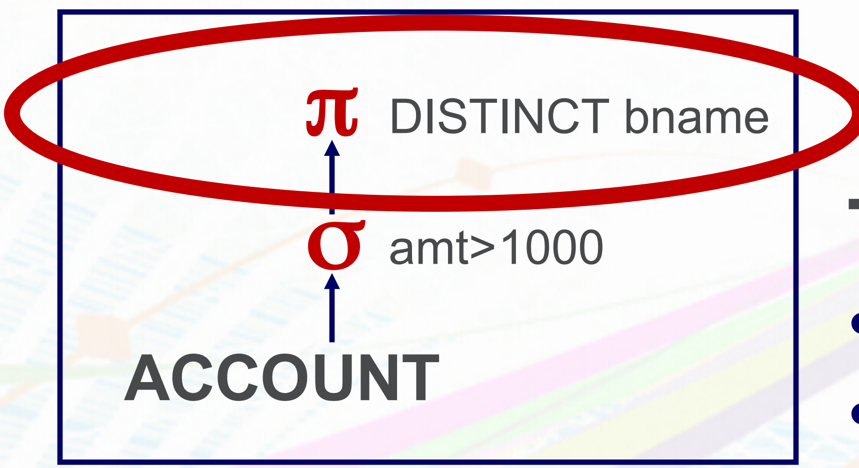
```




**Two Choices:**

- Sorting
- Hashing

# Sorting Projection

$\pi$ DISTINCT bname

$\sigma$ amt>1000

ACCOUNT

| acctno | bname | amt |
|---|---|---|
| A-123 | Redwood | 1800 |
| A-789 | Downtown | 2000 |
| A-123 | Perry | 1500 |
| A-456 | Downtown | 1300 |

**Filter**

| acctno | bname | amt |
|---|---|---|
| A-123 | Redwood | 1800 |
| A-789 | Downtown | 2000 |
| A-123 | Perry | 1500 |
| A-456 | Downtown | 1300 |

**Remove Columns**

| bname |
|---|
| Redwood |
| Downtown |
| Perry |
| Downtown |

**Sort**

| bname |
|---|
| Downtown |
| ~~Downtown~~ |
| Perry |
| Redwood |

**Eliminate Dupes**

# Alternative to Sorting: Hashing!

- What if we don't need the *order* of the sorted data?
  - Forming groups in **GROUP BY**
  - Removing duplicates in **DISTINCT**
- Hashing does this!
  - And may be cheaper than sorting! (why?)

# Hashing Projection

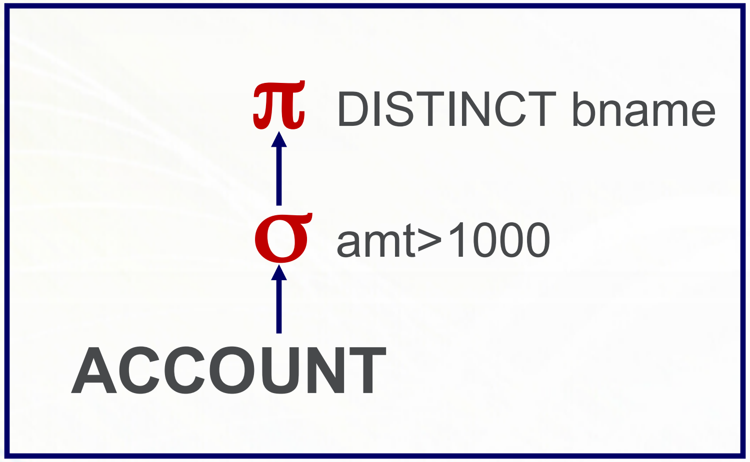
- Populate an ephemeral hash table as we iterate over a table.
- For each record, check whether there is already an entry in the hash table:
  - **DISTINCT**: Discard duplicate.
  - **GROUP BY**: Perform aggregate computation.
- Two phase approach.

# Phase 1: Partition

- Use a hash function ***$h_1$*** 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.

- Assume that we have ***B*** buffers.

# Phase 1: Partition

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| Redwood |
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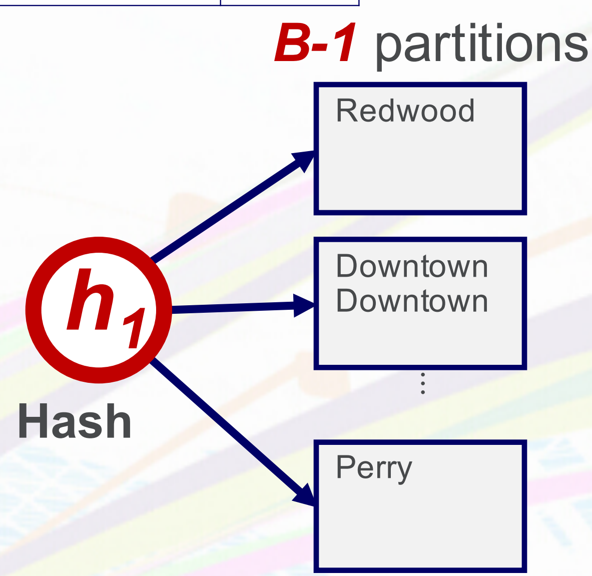
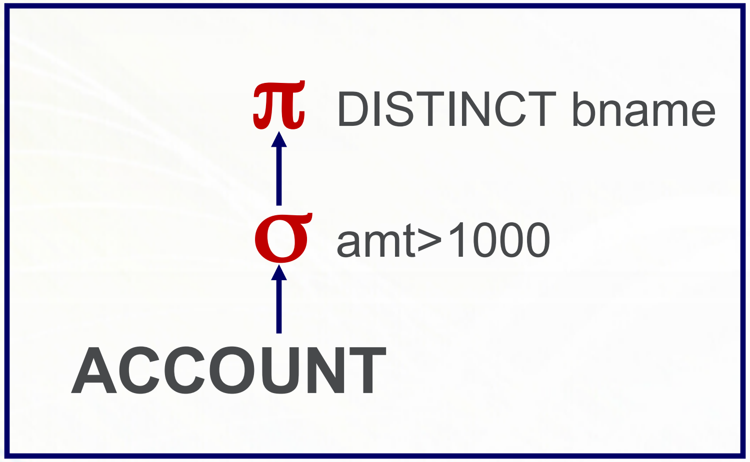


# Phase 2: ReHash

- For each partition on disk:
  - Read it into memory and build an in-memory hash table based on a hash function $h_2$
  - Then go through each bucket of this hash table to bring together matching tuples
- This assumes that each partition fits in memory.

# Phase 2: ReHash




| acctno | bname | amt |
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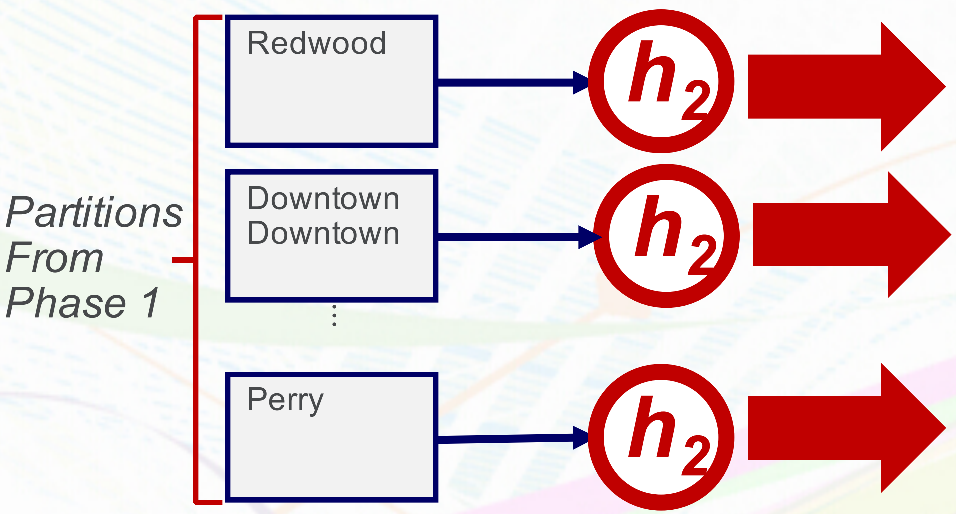


| key | value |
|---|---|
| XXX | Downtown |
| YYY | Redwood |
| ZZZ | Perry |

**Hash Table**

| bname |
|---|
| Downtown |
| Perry |
| Redwood |

**Eliminate Dupes**

# Analysis

- How big of a table can we hash using this approach?
  - ***B-1*** "spill partitions" in Phase 1
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    - A table of ***N*** blocks needs about ***sqrt(N)*** buffers
  - What assumption do we make?

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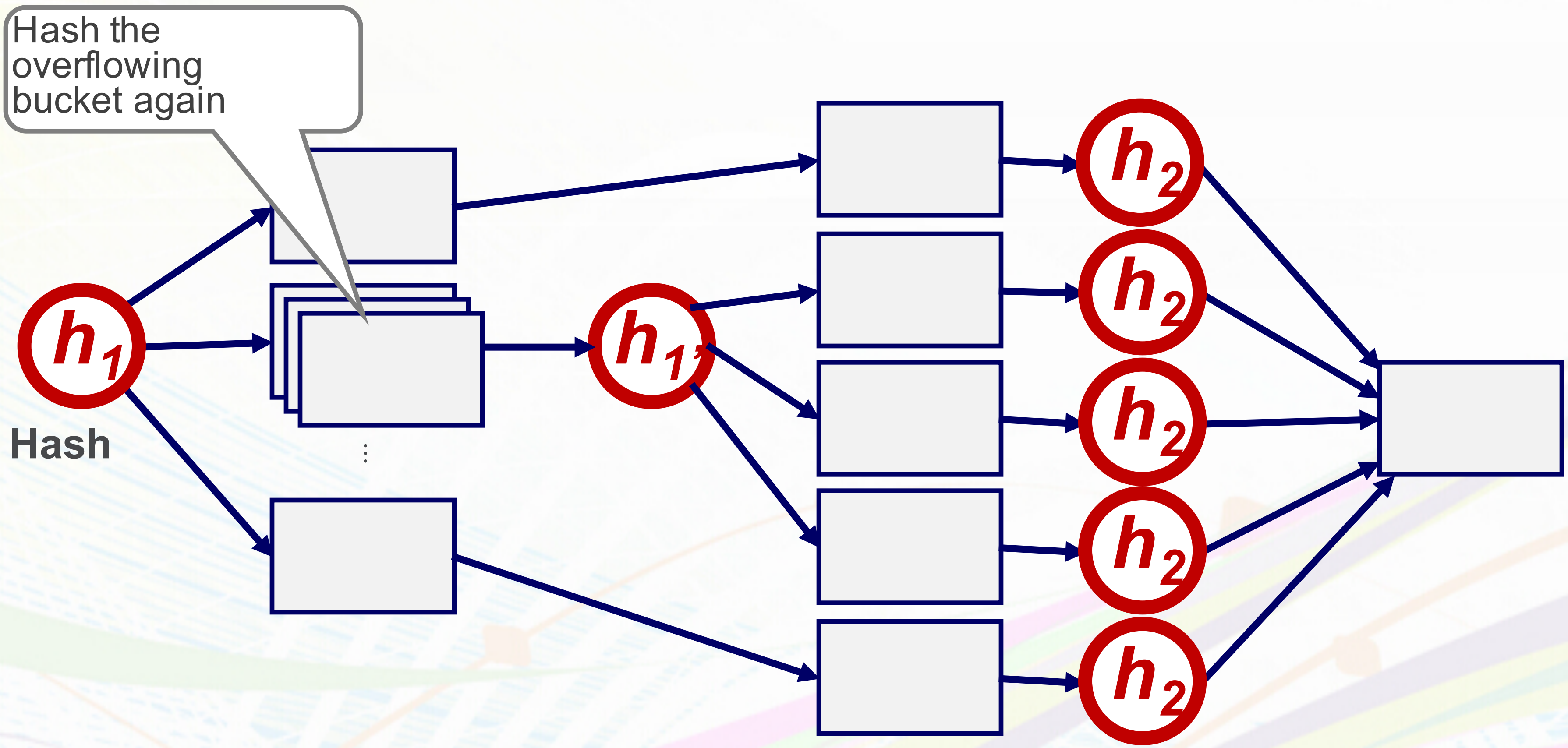
- How big of a table can we hash using this approach?
  - ***B-1*** "spill partitions" in Phase 1
  - Each should be no more than ***B*** blocks big
  - Answer: ***B·(B-1)***.
    - A table of ***N*** blocks needs about ***sqrt(N)*** buffers
  - Assumes hash distributes records evenly!
    - Use a "fudge factor" ***f >1*** for that: we need
    - ***B ~ sqrt( f ·N)***

# Analysis

- Have a bigger table? Recursive partitioning!
  - In the ReHash phase, if a partition ***i*** is bigger than ***B***, then recurse.
  - Pretend that ***i*** is a table we need to hash, run the Partitioning phase on ***i***, and then the ReHash phase on each of its (sub)partitions

# Recursive Partitioning



# Real Story

- Partition + Rehash
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- Partition + Rehash
- Performance is very slow!
- What could have gone wrong?
- Hint: some buckets are empty; some others are way over-full.

# Hashing vs. Sorting

- Which one needs more buffers?

# Hashing vs. Sorting

- **Recall: We can hash a table of size *N* blocks in *sqrt(N)* space**
- How big of a table can we sort in 2 passes?
  - Get ***N/B*** sorted runs after Pass 0
  - Can merge all runs in Pass 1 if ***N/B ≤ B-1***
    - Thus, we (roughly) require: $N \leq B^2$
    - We can sort a table of size ***N*** blocks in about space ***sqrt(N)***
  - **Same as hashing!**

# Hashing vs. Sorting

- Choice of sorting vs. hashing is subtle and depends on optimizations done in each case
- optimizations for sorting:
  - Heapsort in Pass 0 for longer runs
  - Chunk I/O into large blocks to amortize seek+RD costs
  - Double-buffering to overlap CPU and I/O

# Hashing vs. Sorting

- Choice of sorting vs. hashing is subtle and depends on optimizations done in each case
- Another optimization when using sorting for aggregation:
  - “Early aggregation” of records in sorted runs
- Let’s look at some optimizations for hashing next…

# Hashing: We Can Do Better!

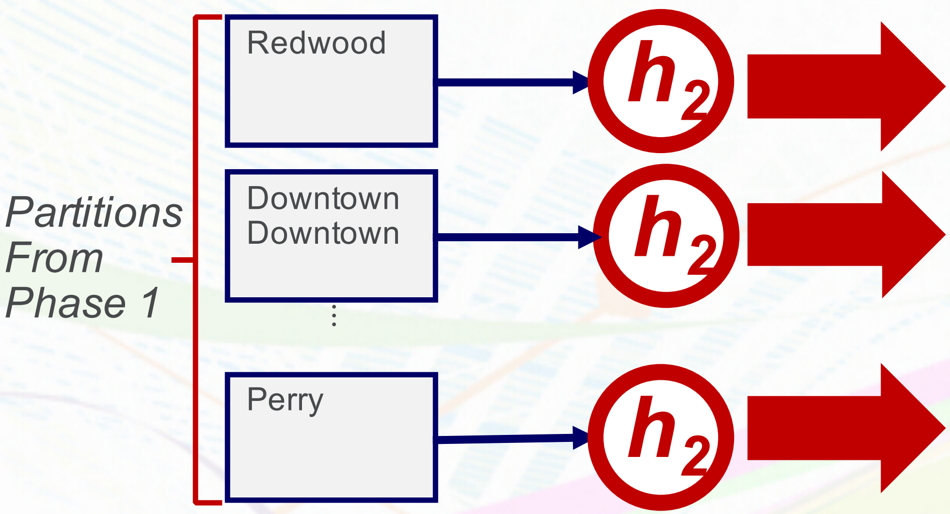
- Combine the summarization into the hashing process - How?

# Hashing: We Can Do Better!

- During the ReHash phase, store pairs of the form **<GroupKey, RunningVal>**
- When we want to insert a new tuple into the hash table:
  - If we find a matching **GroupKey**, just update the **RunningVal** appropriately
  - Else insert a new **<GroupKey, RunningVal>**

# Hashing Aggregation

**SELECT** acctno, SUM(amt)
**FROM** account
**GROUP BY** acctno




Running Totals

| key | value |
|---|---|
| XXX | <A-123, 1200> |
| YYY | <A-789,1000> |
| ZZZ | <A-456,1500> |

**Hash Table**

| acctno | SUM(amt) |
|---|---|
| A-123 | 4355 |
| A-789 | 6895 |
| A-456 | 7901 |

**Final Result**

# Hashing Aggregation

- What’s the benefit?
- How many entries will we have to handle?
  - Number of distinct values of GroupKeys columns
  - Not the number of tuples!!
  - Also probably “narrower” than the tuples

# So, hashing is better…right?

- Any caveats?

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- Any caveats?
- A1: Sorting is better on non-uniform data
- A2: ... and when sorted output is required later.

- Hashing vs. sorting:
  – Commercial systems use either or both

# Summary

- Query processing architecture:
  - Query parser
  - Query optimizer translates SQL to a query plan = graph of iterators
  - Query executor "interprets" the plan
- Hashing is a useful alternative to sorting for duplicate elimination / group-by
  - Both are valuable techniques for a DBMS

- Read chapters 12, 14, 15
- Exercises: 12.1-12.5 on pages 418-420

Additional reading if interested

http://dl.acm.org/citation.cfm?id=627627