Iterators and Relational Operators

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Fall 2022

Reading: R&G, Chapters 4.1 - 4.2

Announcements

- Nested loops join re-lecture
- Project 3 is out
- Exam accommodations
  - For health-related issues we will require a documentation
    - Dr’s note / covid test / DSP letter
- Anonymous feedback
  - Posting lectures on youtube
  - Gap between assignments and lectures
- We need more break videos!

Recall from Relational Algebra

SQL Query

```
SELECT S.name
FROM Reserves R, Sailors S
WHERE R.sid = S.sid
AND R.bid = 100
AND S.rating > 5
```

Query Parser & Optimizer

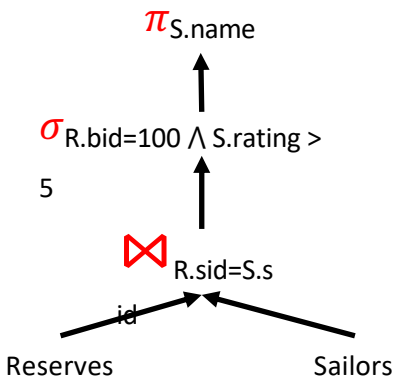
Relational Algebra

$\pi_{\text{S.name}}(\sigma_{\text{bid=100}\wedge\text{rating>5}}($ Reserves $\bowtie_{\text{R.sid=S.sid}}$ Sailors$))$

How are relational algebra operators implemented?

Equivalent to…

(Logical) Query Plan:



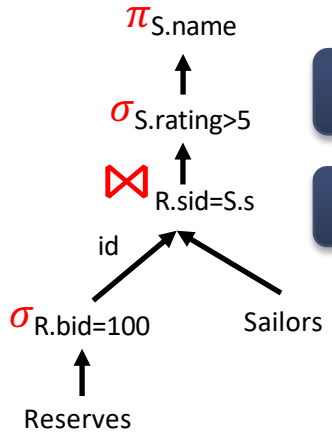
But actually will produce…

Operator Code

B+-Tree
Indexed Scan Iterator

Optimized (Physical) Query Plan:

On-the-fly
Project Iterator



On-the-fly
Select Iterator

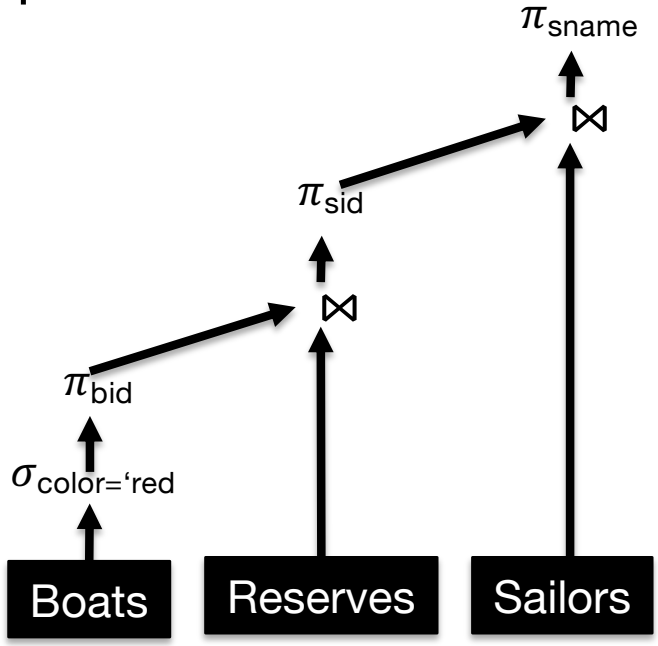
Indexed Nested Loop Join Iterator

Heap Scan Iterator

Relational Operators and Query Plans

$\pi_{\text{sname}}(\pi_{\text{sid}}(\pi_{\text{bid}}(\sigma_{\text{color='red'}}(\text{Boats})) \bowtie \text{Reserves}) \bowtie \text{Sailors})$

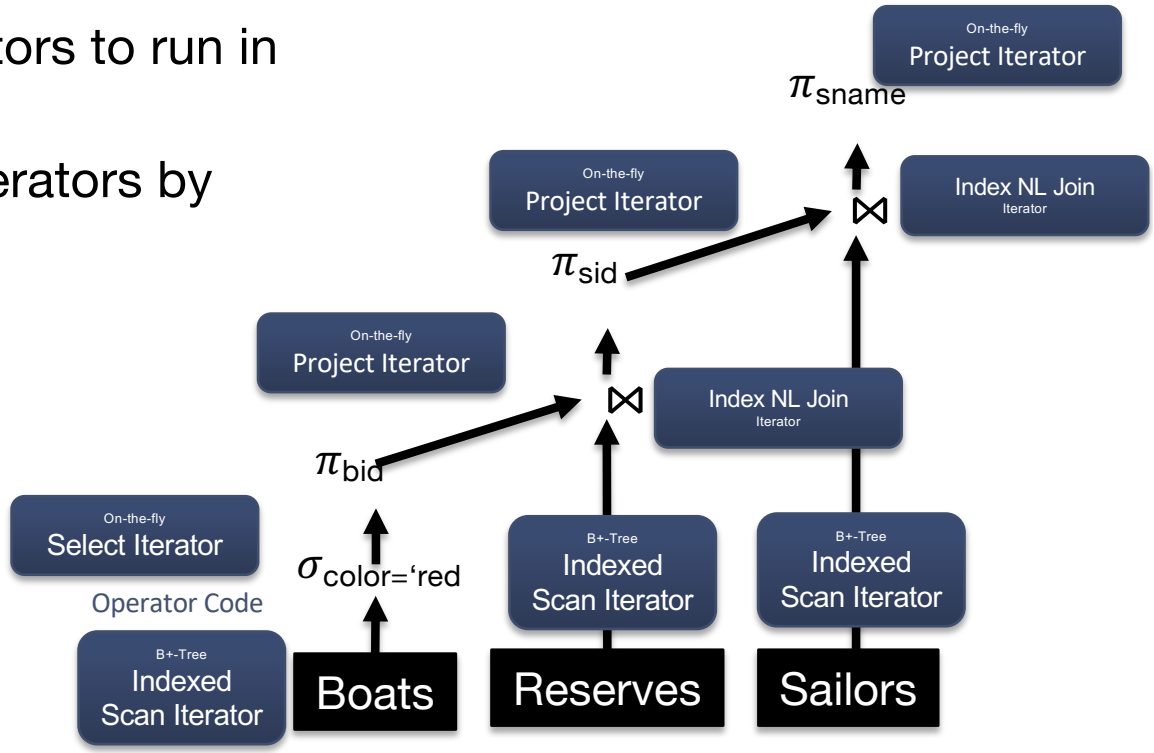
- Expression Tree Representation = Query plan
  - Edges encode "flow" of tuples
  - Vertices = Relational Alg Operators
  - Source vertices = table access operators
- Also called dataflow graph
  - Here, "flow of tuples"
  - Not specific to DBMSs
    - E.g., "big data systems", ML systems



Query Executor Instantiates Operators

$$\pi_{\text{sname}}(\pi_{\text{sid}}(\pi_{\text{bid}}(\sigma_{\text{color='red'}}(\text{Boats})) \bowtie \text{Res}) \bowtie \text{Sailors})$$

- Query optimizer selects operators to run in sequence (i.e., the query plan)
- Query executor runs these operators by creating instances thereof
- Each operator instance:
  - Implements **iterator interface**
  - Efficiently executes operator logic forwarding tuples to next operator



Iterator Interface

The relational operators implemented as subclasses of the class Iterator:

```
abstract class iterator {
        void setup(List<Iterator> inputs); // Configure the input (children) args
        void init(args);                   // Invoked before calling next: sets up state
        tuple next();                      // Invoked repeatedly: return another tuple
        void close();                      // Invoked when finished
 }
```

- **Pull-**based computation model
  - e.g., Console calls **init** on root operator of query plan, and then **next**
    - If tuple is not ready, this **next** request propagates down the query plan recursively
  - init/next can result in either *streaming ("on-the-fly")* or *blocking ("batch")* algorithm for that operator**:**
    - streaming: small, constant amount of work per call
    - blocking: does not produce output until it consumes its entire input, i.e., all rows from children!
    - Q: examples?
- Any iterator can be input to any other, since they all implement the same interface (composability)
- **State:** iterators may maintain substantial private "internal" state
  - e.g., hash tables, running counts, large sorted files …

Example: Select (on-the-fly)

- A streaming operator: small amount of work per tuple produced
- `init(predicate):`

```
child.init()
pred = predicate; // local variable storing state
current = NULL;   // local cursor
```

- `next():`

```
while (current != EOF && !pred(current))
    current = child.next(); // give us another tuple
} // exit if pred is satisfied or EOF
return current;   // return current tuple or EOF
```

- `close():`

```
child.close()
```

Example: Heap Scan

- Leaf of the query plan

- `init(relation):`

```
heap = open heap file for this relation;        // file handle
cur_page = heap.first_page();                   // first page
cur_slot = cur_page.first_slot();               // first slot on that page
```

- `next():`

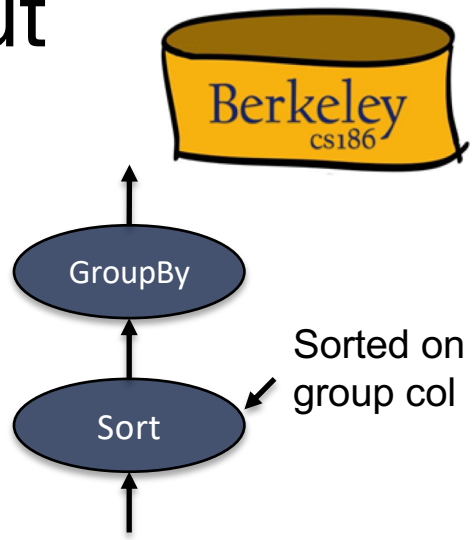
```
if (cur_page == NULL) return EOF;
current = [cur_page, cur_slot];                 // we will return this recordId
cur_slot = cur_slot.advance();                  // advance the slot for subseq. calls
if (cur_slot == NULL) {                         // advance to next page, first slot
      cur_page = cur_page.advance();
      if (cur_page != NULL)
          cur_slot = cur_page.first_slot();
}
return current;
```

- `close():`

```
heap.close()                                    // close file
```

Example: Group By on Sorted input

agg_type	state	init	merge(x)	final
COUNT	count	0	count ++	count
SUM	sum	0	sum += x	sum
AVG	?	?	?	?
MIN	?	?	?	?



- Say input is sorted, and we want to do a group by
  - Sort not necessary, can also do group by with hashing
- Keep "group" in iterator state, add `merge(tuple)` function
  - Initialize group state
  - Operate one tuple at a time in `next`, and `merge` tuple with existing group state
    - Create new group if needed
  - Return result tuple when done with group

Example: Group By on Sorted input

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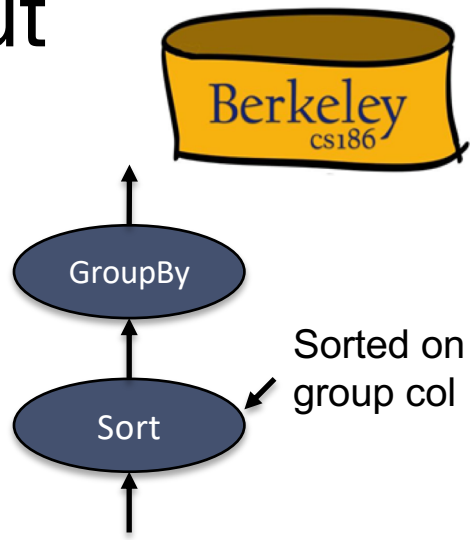
COUNT	count	0	count ++	count
SUM	sum	0	sum += x	sum
AVG	[count, sum]	[0, 0]	[count++, sum+=x]	sum / count
MIN	min	+infinity	min > x ? x : min	min



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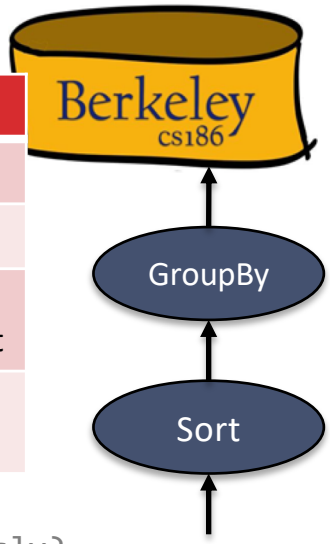


- `init(group_keys, aggs):`

```
  child.init();
  cur_group = NULL; // no group so far
```

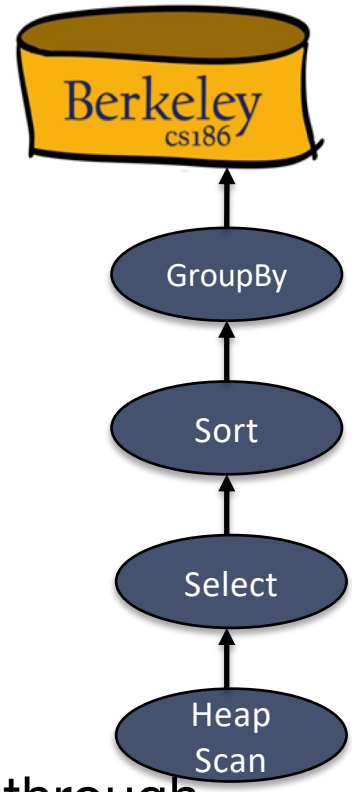
```
next():
  result = NULL;
  do {
    tup = child.next();
    if (group(tup) != cur_group) {                    // New group!
      if (cur_group != NULL)                          // Have we seen a group previously?
        result = [cur_group, final() of all aggs]     // Form result for that current group
        cur_group = group(tup);                       // Initialize new group state
        call init() on group state
    }
    call merge(tup) to merge tup into state
  } while (!result);                                  // Exit if current group result is formed
  return result;
```

- `close():`

```
  child.close()
```

Neat: only maintains one tuple of partial results in memory at any time!

A Full (Single Table) Query Plan



- A Query Plan is Single-threaded!
- Exercise: trace the calls that lead to flow of tuples:
  - Call init() on the root GroupBy
    - How does init() recurse down the chain and return?
  - Call next() on root
    - How does next() recurse down the chain and return a tuple?
  - Note how the blocking operator (sort) interacts with the other, streaming operators
    - Select and GroupBy are essentially streaming operators
- We don't store each operator output on disk; tuples stream through the plan's call stack
  - Some operators like Sort use disk internally – but not exposed outside the operator

Summary

- We just finished our tour of the upper layer of the DBMS
- We have now seen how SQL queries can be represented using relational algebra trees
- We have also seen how relational algebra operators are implemented
  - init / next / close
  - Streaming vs blocking
- We saw earlier the different algos for implementing various relational algebra operators
  - Sort, hash, join, etc
- We didn't cover how SQL text are translated into RA trees
  - Take CS164!