# Iterators, Relational Operators and Joins

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R&G Chapters 12 & 14

# Recall from Last Lecture

SQL Query

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

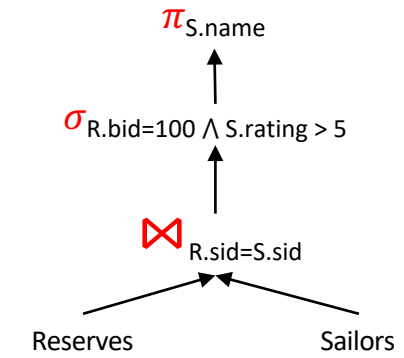
Query Parser & Optimizer

Relational Algebra

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

Equivalent to…

**(Logical) Query Plan:**

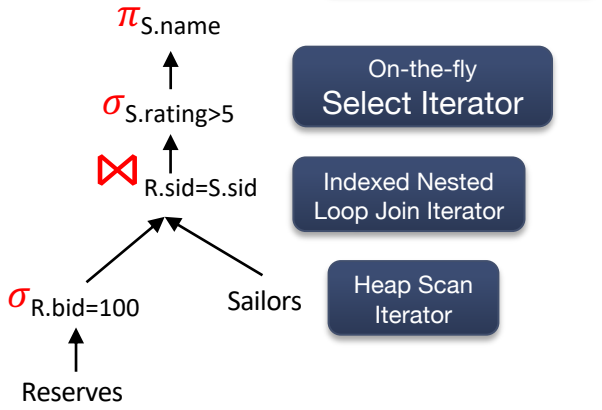



But actually will produce…

Operator Code

B+-Tree
Indexed Scan Iterator

**Optimized (Physical) Query Plan:**




On-the-fly Project Iterator

On-the-fly Select Iterator

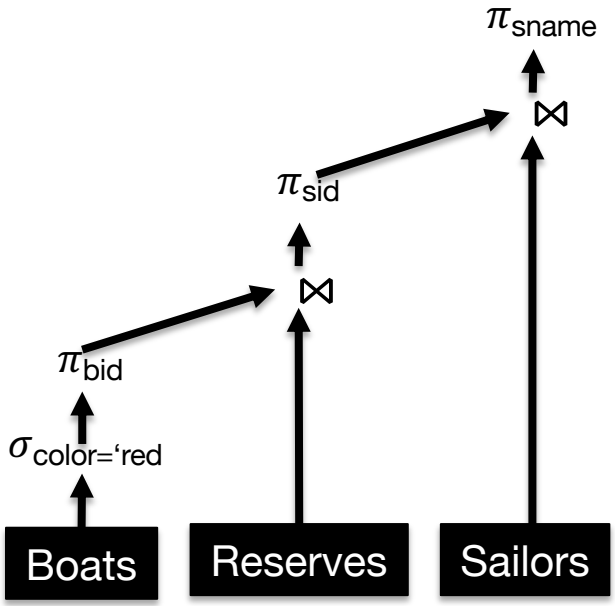
Indexed Nested Loop Join Iterator

Heap Scan Iterator

# Relational Operators and Query Plans

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

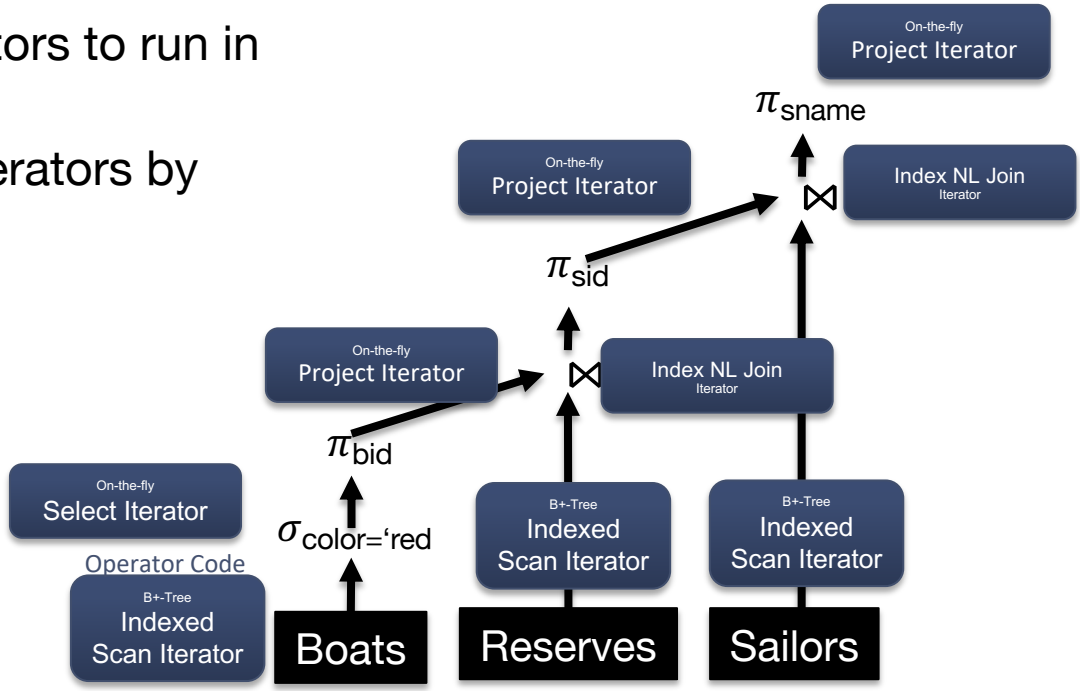
- Expression Tree Representation = Query plan
  - Edges encode “flow” of tuples
  - Vertices = Relational Alg Operators
  - Source vertices = table access operators
- Also called dataflow graph
  - Here, “flow of tuples”
  - Not specific to DBMSs
    - E.g., “big data systems”, ML systems



# 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); // configuring 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;
```

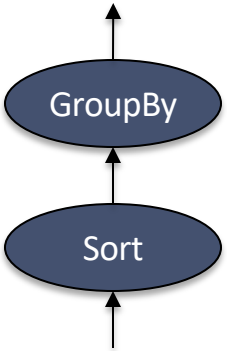
- `close():`

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

# Example: Sort (2-pass)

- ```
  init(keys):
    // input keys to sort by
    // first, all of pass 0, a blocking call
   child.init()
   repeatedly call child.next() and generate the sorted runs on disk, until child
   gives EOF
   // second, set up for pass 1, assumes enough buffers to merge
   open each sorted run file and load one page per run into input buffer for pass 1
  ```
- ```
  next():        // pass 1 merge (assumes enough buffers to merge)
   output = min tuple across all buffers
   if min tuple was last one in its buffer, fetch next page from that run into buffer
   return output  // (or EOF if no tuples remain)
  ```
- ```
  close():
   deallocate the runs files
   child.close()
  ```
  ```

# 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
  - Not necessary, can also do group by without sorting (see later)
- Similar approach for “merging” tuples per group to form a result tuple per group across aggregates
  - Initialize some state per group
  - Operate one tuple at a time, and do the ”merge” with existing state
  - Return result tuple when done with group

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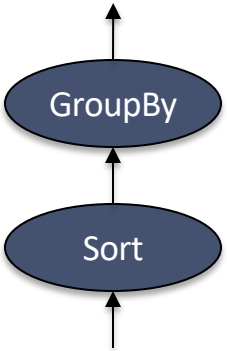


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| COUNT | count | 0 | count ++ | count |
| SUM | sum | 0 | sum += x | sum |
| AVG | [count, sum] | [0, 0] | [count++, sum+=x] | sum / count |
| MIN | min | +infinity | min > x ? x : min | min |

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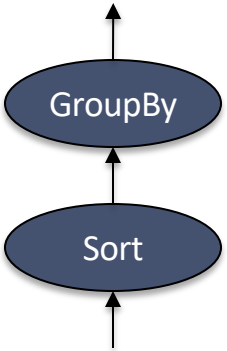


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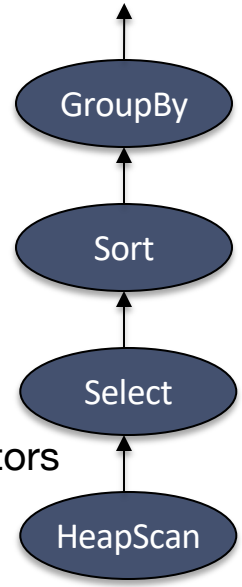
- `init(group_keys, aggs):`
  `child.init()`
  `cur_group = NULL;`
- `next():`

```
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 cur. group
        cur_group = group(tup);                        // Initialize new group
        call init() on all the aggs
     }
     call merge(tup) on all the aggs
} while (!result);                                     // Exit if cur. grp 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
- Note how 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
  - The iterator framework itself is lightweight
- Next: Binary Iterators

# Join Operators

R&G 14.4

# Schema & Costing for Examples

- Cost Notation
  - [R] : the number of pages to store R
  - $p_R$ : number of records per page of R
  - |R| : the cardinality (number of records) of R
    - $|R| = p_R * [R]$

- Reserves (sid: int, bid: int, day: date, rname: string)
  - [R]=1000, $p_R$=100, |R| = 100,000
- Sailors (sid: int, sname: string, rating: int, age: real)
  - [S]=500, $p_S$=80, |S| = 40,000

# Simple Nested Loops θ Join

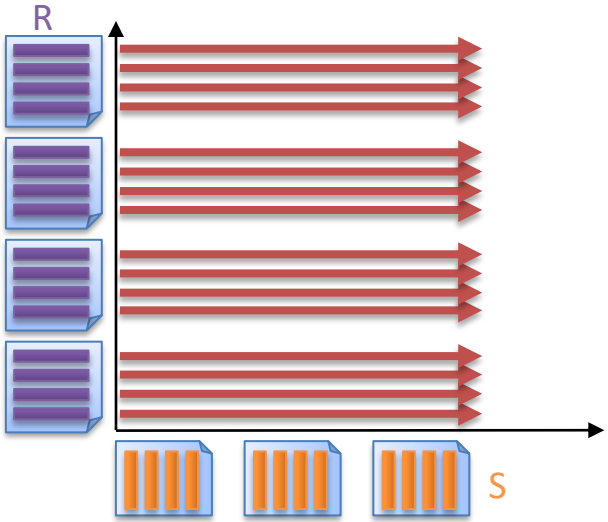
*Note: for simplicity we do not present iterator implementations for the join algorithms*

*Note: ignore cost of writing out; it is constant across approaches; plus in many cases data streams through them via next()*

foreach **record** r in R do

  foreach **record** s in S do

    if **θ(r, s)** then add <r, s> to result buffer




$[R]=1000,\ p_R=100,\ |R| = 100{,}000$

$[S]=500,\ p_S=80,\ |S| = 40{,}000$

Cost: scan R once + scan S once per R tuple

$= [R] + |R|[S]$

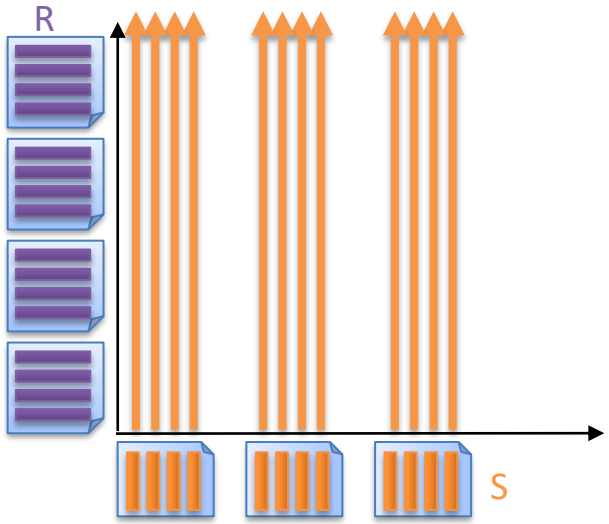
$= 50{,}001{,}000$

# Changing the Join Order

foreach **record** s in S do

  foreach **record** r in R do

    if **θ(r, s)** then add <r, s> to result buffer




$[R]=1000, p_R=100, |R| = 100{,}000$

$[S]=500, p_S=80, |S| = 40{,}000$

Cost: scan S once + scan R once per S tuple

$= [S] + |S|[R]$

$= 40{,}000{,}500$

vs. 50,001,000

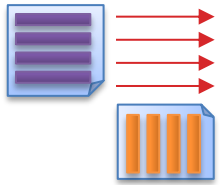
Join orders matter!

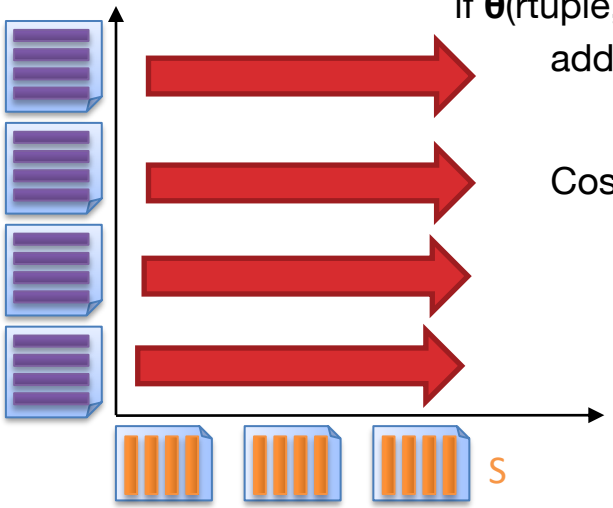
Q: Can we improve this?

# Page Nested Loop Join

**Idea: previous algo was inefficient w.r.t. I/O: operate at granularity of pages!**

```
for each rpage in R:
    for each spage in S:
        for each rtuple in rpage:
            for each stuple in spage:
                if θ(rtuple, stuple):
                    add <rtuple, stuple> to result buffer
```





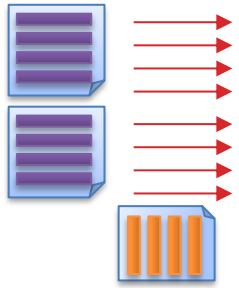

Cost = Scan R once, and scan S per page of R = [R] + ([R] * [S])
= 501,000 vs. ~40M

Q: Can we improve this?

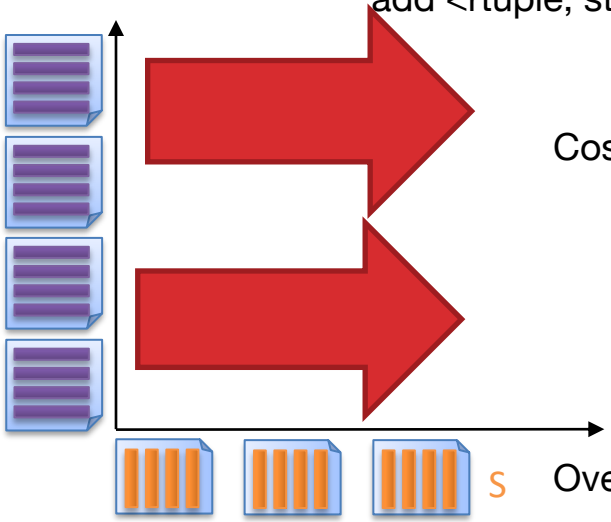
"Chunk"

# ~~"Block"~~ Nested Loop Join

**Idea: Extending even further using a "block" or a "chunk" of S pages at a time**



```
for each rchunk of B-2 pages of R:
        for each spage of S:
                for all matching tuples in spage and rchunk:
                        add <rtuple, stuple> to result buffer
```




Cost = Scan R once, plus scan S as many times as there are chunks
= [R] + [ [R]/(B-2) ] * [S]
= 1000 + [ 1000/(B-2) ] * 500
= 6,000 for B=102 (~100x better than Page NL!)

Overall, a frequently used join algorithm, esp. for non-eq. predicates

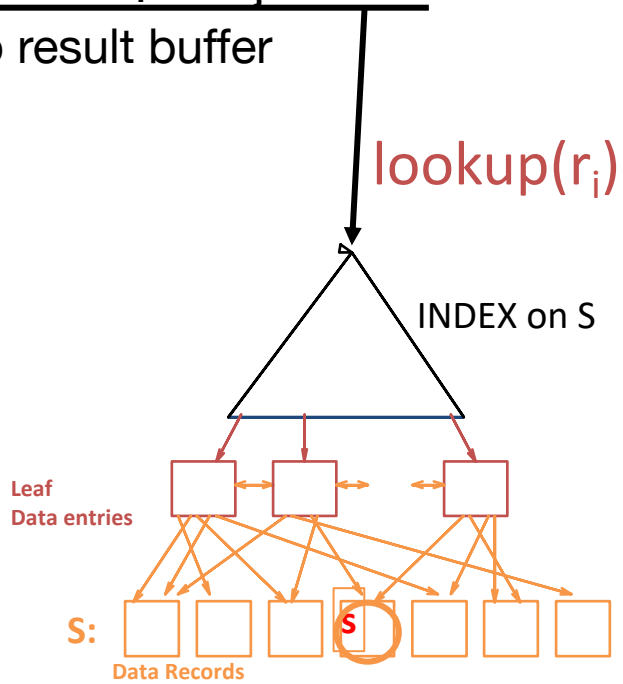
# Index Nested Loops Join

Consider when we have equijoin on $r_i = s_j$

foreach **tuple** r in R do

foreach **tuple** s in S where **$r_i$ == $s_j$** do

add <r, s> to result buffer



# Index Nested Loops Join Cost

foreach **tuple** r in R do

foreach **tuple** s in S where $\mathbf{r_i == s_j}$ do

add <r, s> to result

Cost = [R] + |R| * cost to find matching S tuples

- If index uses Alt. 1 → cost to traverse tree from root to leaf. (e.g., 2-4 IOs)
- For Alt. 2 or 3:
  - Cost to lookup RID(s); typically 2-4 IOs for B+Tree.
  - Cost to retrieve records from RID(s)
    - Clustered index: 1 I/O per *page of matching S tuples*.
    - Unclustered index: up to 1 I/O per matching S tuple

# Sort-Merge Join

- Requires equality predicate:
  - Equi-Joins & Natural Joins
- Two Stages:
  - Sort tuples in R and S by join key
    - All tuples with same key in consecutive order
    - Input might already be sorted … maybe result of another sort merge/index scan?
  - Join Pass: Merge-scan the sorted partitions and emit tuples that match
    - Challenge is that each tuple in R may match multiple tuples in S
    - We keep track of the start of each block of S tuples with a “mark”
    - That way, we know where to return for the next tuple of R
    - R is “outer loop”, advances forward; S is “inner loop” forward + back to mark

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
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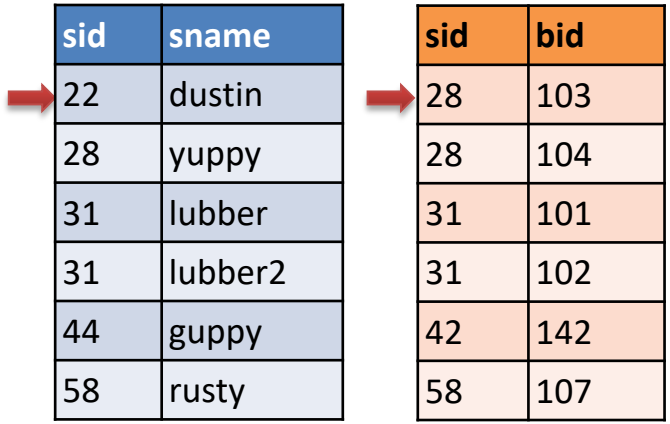

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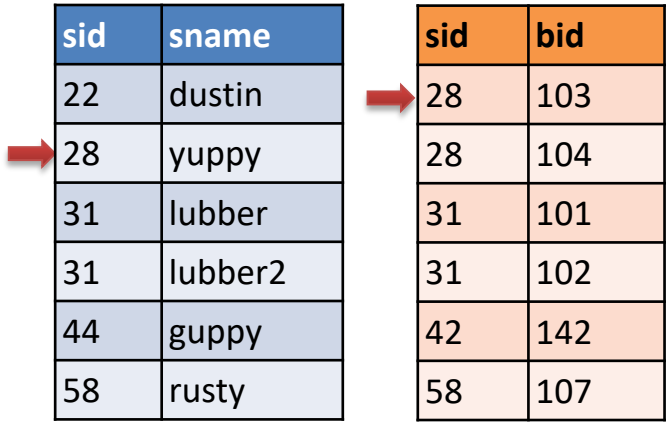

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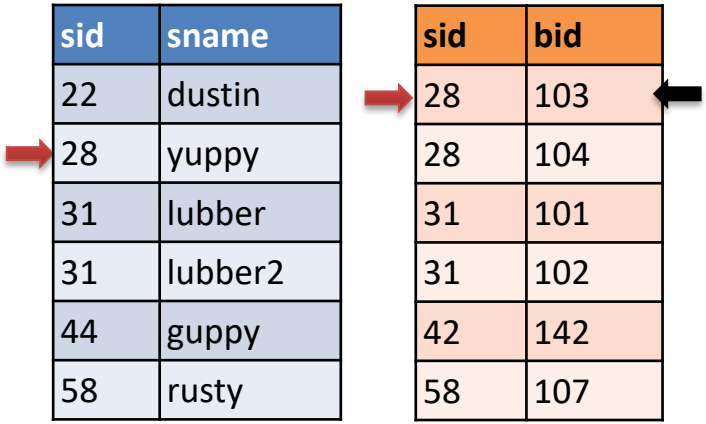

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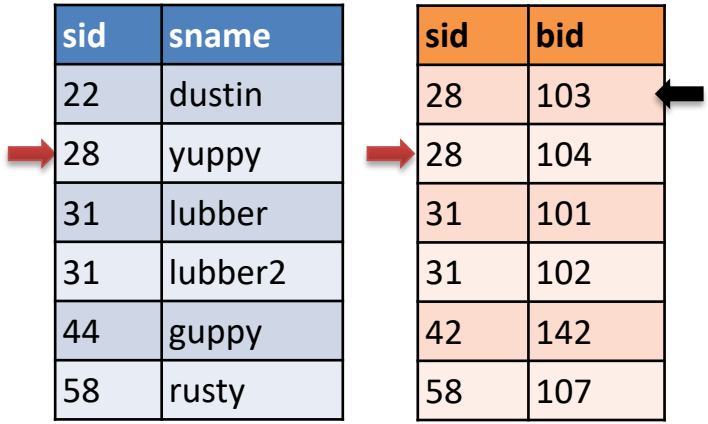

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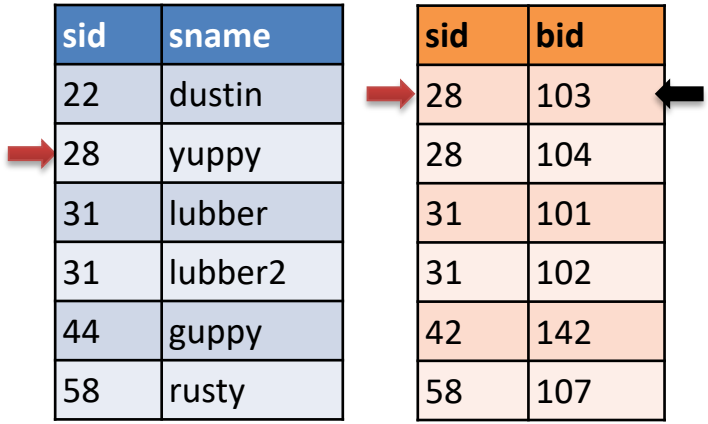

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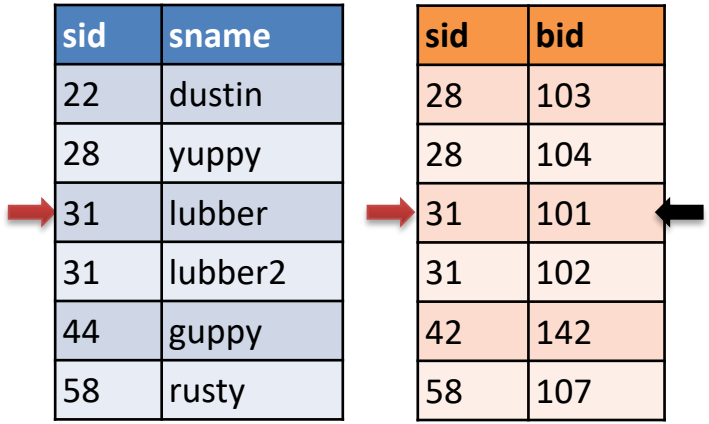

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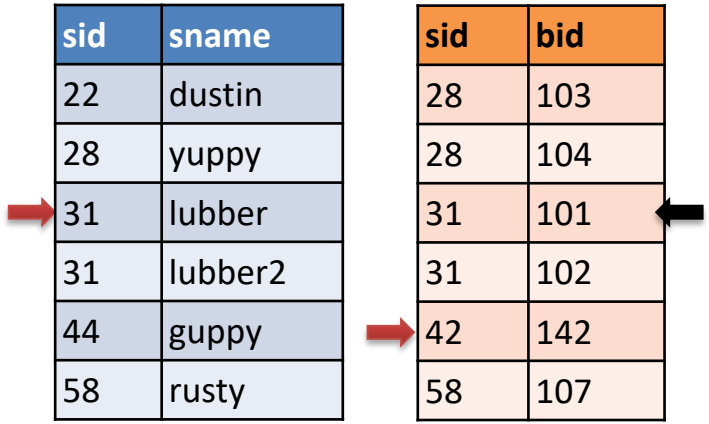
| 31 | lubber | 101 |

# Sort-Merge Join



| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |
| 58 | rusty | 107 |

# Sort-Merge Join, Part 1

```
do {
   if (!mark) {
     while (r < s) { advance r }
     while (r > s) { advance s }
     // mark start of "block" of S
     mark = s
   }
   if (r == s) {
     result = <r, s>
     advance s
     return result
   }
   else {
     reset s to mark
     advance r
     mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 2

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 3

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 4

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 5

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 6

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 7

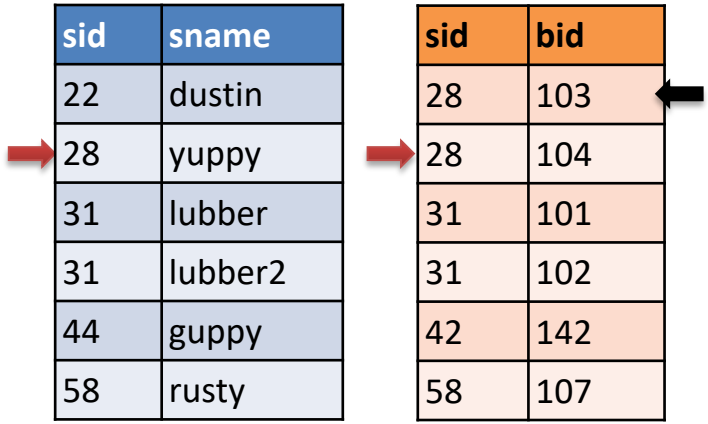
```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

# Sort-Merge Join, Part 8

```
do {
   if (!mark) {
     while (r < s) { advance r }
     while (r > s) { advance s }
     // mark start of "block" of S
     mark = s
   }
   if (r == s) {
     result = <r, s>
     advance s
     return result
   }
   else {
     reset s to mark
     advance r
     mark = NULL
   }
}
```



| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |

# Sort-Merge Join, Part 9

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |

# Sort-Merge Join, Part 10

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

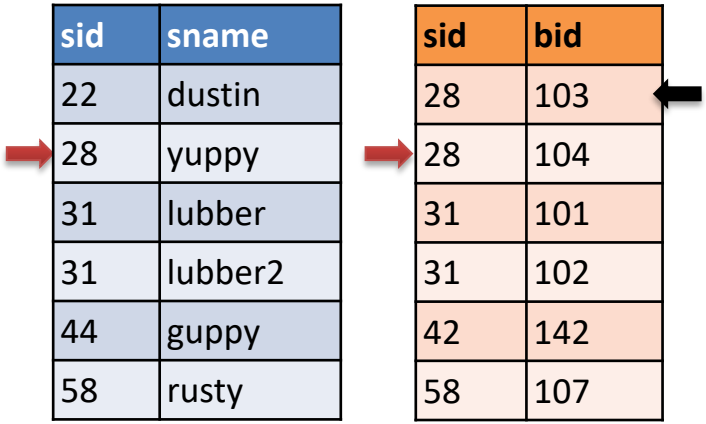
| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |

# Sort-Merge Join, Part 11

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```



| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |

# Sort-Merge Join, Part 12

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |

# Sort-Merge Join, Part 13

```
do {
   if (!mark) {
     while (r < s) { advance r }
     while (r > s) { advance s }
     // mark start of "block" of S
     mark = s
   }
   if (r == s) {
     result = <r, s>
     advance s
     return result
   }
   else {
     reset s to mark
     advance r
     mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 14

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 15

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 16

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 17

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 18

```
do {
   if (!mark) {
     while (r < s) { advance r }
     while (r > s) { advance s }
     // mark start of "block" of S
     mark = s
   }
   if (r == s) {
     result = <r, s>
     advance s
     return result
   }
   else {
     reset s to mark
     advance r
     mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 19

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 20

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 21

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 22

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 23

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 24

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 25

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |

# Sort-Merge Join, Part 26

```
do {
   if (!mark) {
     while (r < s) { advance r }
     while (r > s) { advance s }
     // mark start of "block" of S
     mark = s
   }
   if (r == s) {
     result = <r, s>
     advance s
     return result
   }
   else {
     reset s to mark
     advance r
     mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |

# Sort-Merge Join, Part 27

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |

# Sort-Merge Join, Part 28

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |

# Sort-Merge Join, Part 29

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |

# Sort-Merge Join, Part 30

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |

# Sort-Merge Join, Part 31

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 32

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 33

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

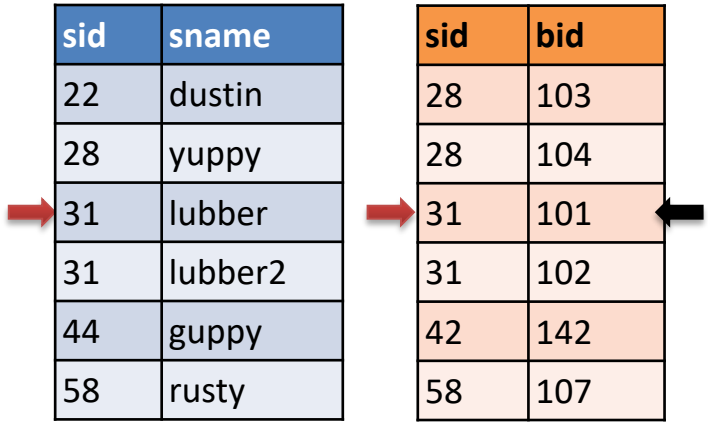
| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 34

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```



| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 35

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 36

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 37

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 38

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 39

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

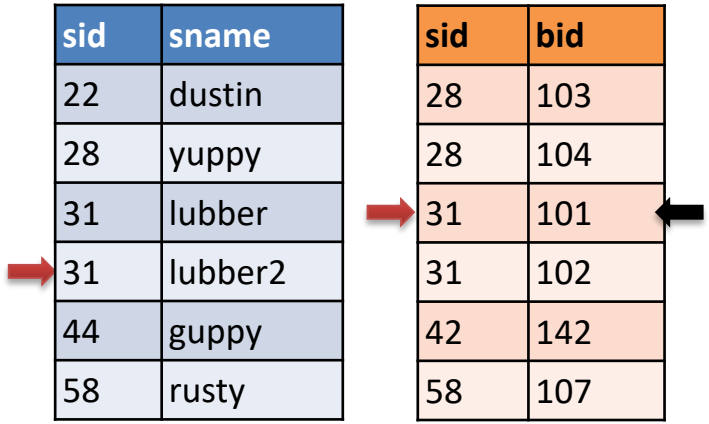
| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 40

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```



| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 41

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |

# Sort-Merge Join, Part 42

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join, Part 43

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join, Part 44

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join, Part 45

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join, Part 46

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |

# Sort-Merge Join, Part 47

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 48

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 49

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 50

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 51

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 52

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 53

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 54

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 55

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 56

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 57

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 57

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 58

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 59

```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 60

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 61

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 62

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 63

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 64

```
do {
  if (!mark) {
    while (r < s) { advance r }
    while (r > s) { advance s }
    // mark start of "block" of S
    mark = s
  }
  if (r == s) {
    result = <r, s>
    advance s
    return result
  }
  else {
    reset s to mark
    advance r
    mark = NULL
  }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |

# Sort-Merge Join, Part 65

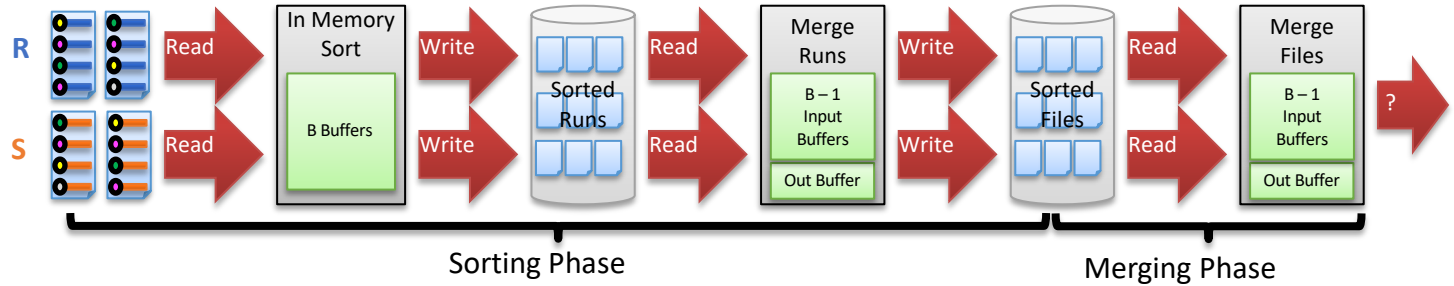
```
do {
   if (!mark) {
      while (r < s) { advance r }
      while (r > s) { advance s }
      // mark start of "block" of S
      mark = s
   }
   if (r == s) {
      result = <r, s>
      advance s
      return result
   }
   else {
      reset s to mark
      advance r
      mark = NULL
   }
}
```

| sid | sname |
|---|---|
| 22 | dustin |
| 28 | yuppy |
| 31 | lubber |
| 31 | lubber2 |
| 44 | guppy |
| 58 | rusty |

| sid | bid |
|---|---|
| 28 | 103 |
| 28 | 104 |
| 31 | 101 |
| 31 | 102 |
| 42 | 142 |
| 58 | 107 |

| sid | sname | bid |
|---|---|---|
| 28 | yuppy | 103 |
| 28 | yuppy | 104 |
| 31 | lubber | 101 |
| 31 | lubber | 102 |
| 31 | lubber2 | 101 |
| 31 | lubber2 | 102 |
| 58 | rusty | 107 |

# Cost of Sort-Merge Join




- Cost: Sort R + Sort S + ([R]+[S])
  - But in worst case, last term could be |R| *[S] (very unlikely!)
  - Q: what is worst case?
- Question: How big does the buffer have to be to sort both R and S in two passes each?
- Suppose buffer B > $\sqrt{(\max([R], [S]))}$
  - Both R and S can be sorted in 2 passes
  - 4*1000 + 4*500 + (1000 + 500) = 7500

# Alternative: Join First, Sort Later

```
SELECT sid, bid, sname, rname
FROM R, S
WHERE R.sid = S.sid
ORDER BY sid
```

[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000
B = 102

- Reserves (*sid*: int, *bid*: int, *day*: date, *rname*: string)
- Sailors (*sid*: int, *sname*: string, *rating*: int, *age*: real)
- Special case: every reservation matches exactly one sailor
  - Output has |R| tuples
- Block NLJ
  - Join: [S] + ([S]/(B-2))*[R]
  - Sort: ?

# Join First, Sort Later Part 2

```
SELECT sid, bid, sname, rname
FROM R, S
WHERE R.sid = S.sid
ORDER BY sid
```

[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000
B = 102

- Reserves (*sid*: int, *bid*: int, *day*: date, *rname*: string)
- Sailors (*sid*: int, *sname*: string, *rating*: int, *age*: real)

- Block NLJ
  - Join: [S] + ([S]/(B-2))*[R] = 5,500
  - Sort: 4 * [R] (2 passes are enough) = 4000

# Sort First, Join Later

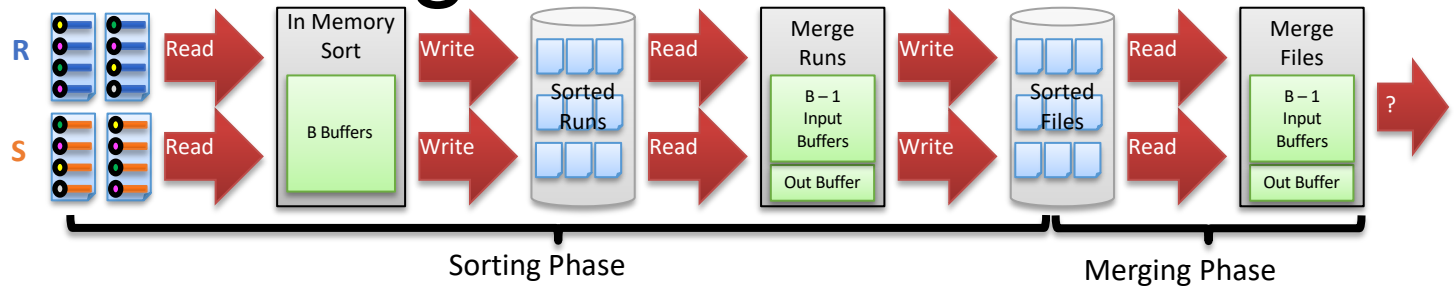
```
SELECT sid, bid, sname, rname
FROM R, S
WHERE R.sid = S.sid
ORDER BY sid
```

[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000
B = 102

- Reserves (*sid*: int, *bid*: int, *day*: date, *rname*: string)
- Sailors (*sid*: int, *sname*: string, *rating*: int, *age*: real)

Sort R: 2*[R]*(2) = 4000
Sort S: 2*[S]*(2) = 2000
R + S = 1500
Total = 7500

# Sort-Merge Refinement




- An important refinement combines last pass of merge-sort with join pass
  - Given enough buffers to accommodate all runs in R and S on the penultimate (second-to-last) pass of sorting
  - Example for 2-pass SMJ (join during the final merging pass of sort)
    - Read R and write out sorted runs (pass 0)
    - Read S and write out sorted runs (pass 0)
    - Merge R-runs and S-runs, while finding R ⋈ S matches
  - 2-pass Cost = 3*[R] + 3*[S] = 3000+1500 = 4500
  - Need 1 representative from each run from R and S in memory