Join Algorithms I

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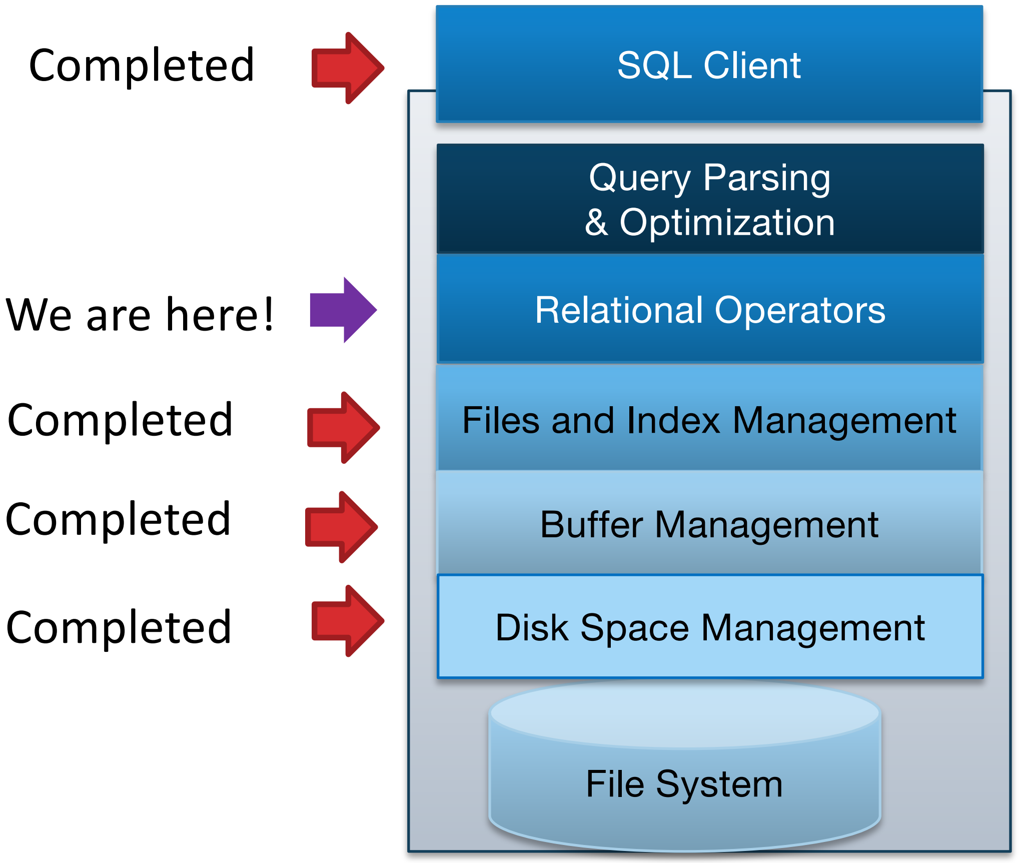
R&G Chapter 14

Architecture of a DBMS: What we've learned



Schema & Costing for Examples

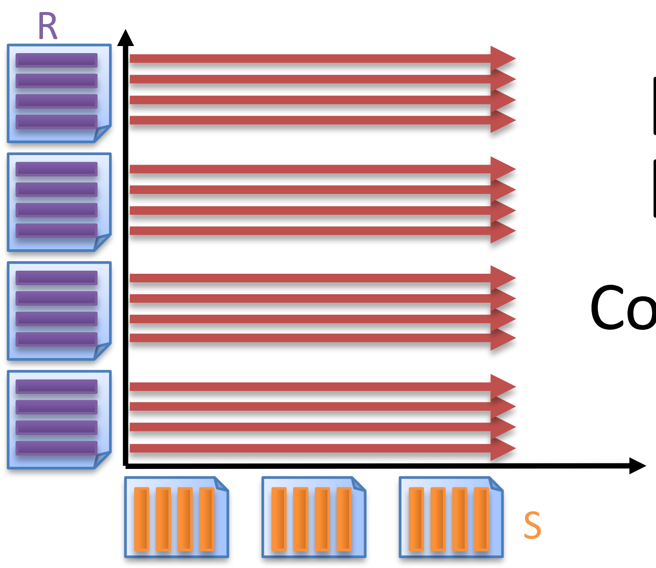
- Cost Notation
  - [R] : the number of pages to store R
  - p_R : number of records per page of R
  - |R| : the cardinality (number of records) of R
    - $|R| = p_R*[R]$

- 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

```
foreach **record** r in R do
    foreach **record** s in S do
        if θ(r, s) then add <r, s> to result buffer
```

- We will ignore write cost
- It is the same across approaches
- Tuples are often streamed to subsequent operators rather than written to disk



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

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

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

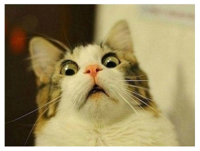
$= [R] + |R|[S]$

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

[R] : # pages to store R
p_R : # records per page of R
|R| : # records of R

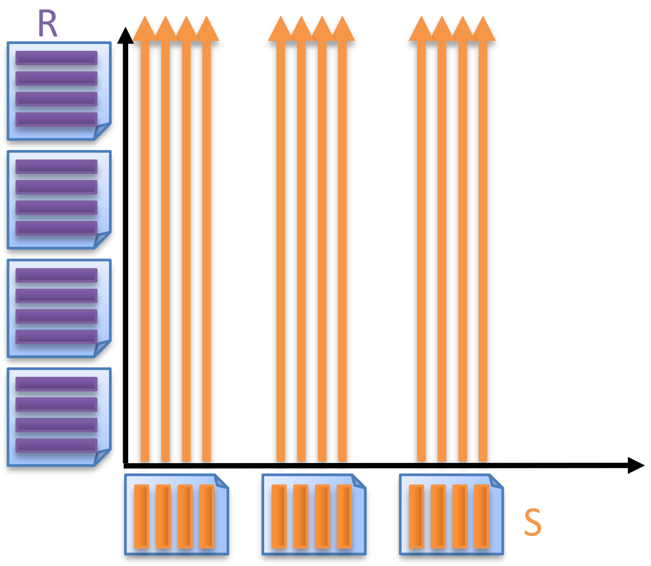
Changing the Join Order

```
foreach record s in S do
    foreach record r in R do
        if θ(r, s) then add <r, s> to result buffer
```



Join orders matter!

Q: Can we improve even more?



[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]

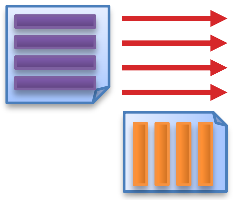
= 40,000,500

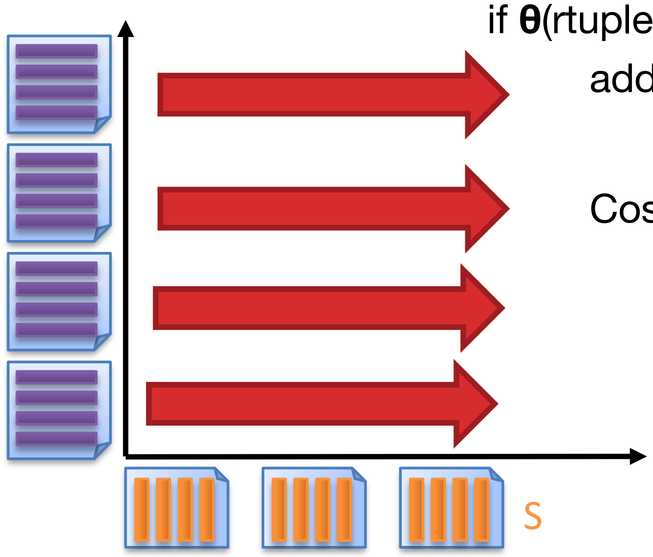
vs. 50,001,000

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
```





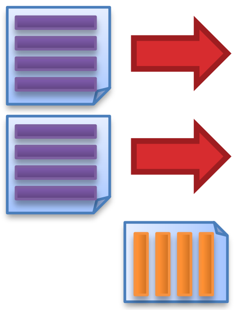
Cost = Scan R once, and scan S per page of R = [R] + ([R] * [S])
= 501,000 vs. ~40M

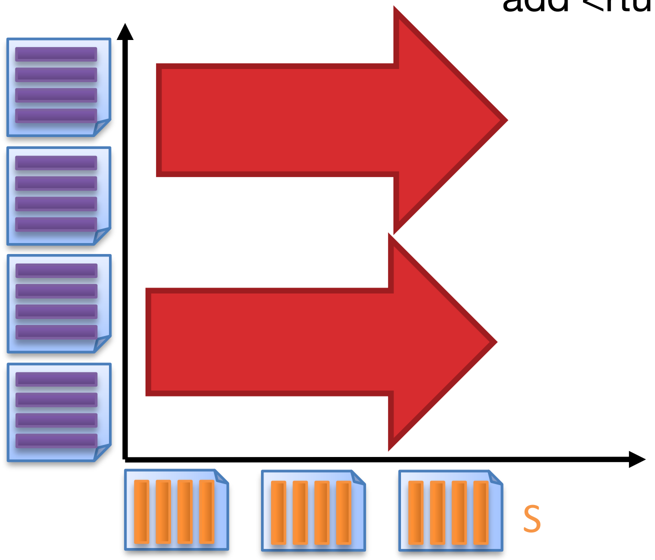
Q: Can we improve this?

“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
```





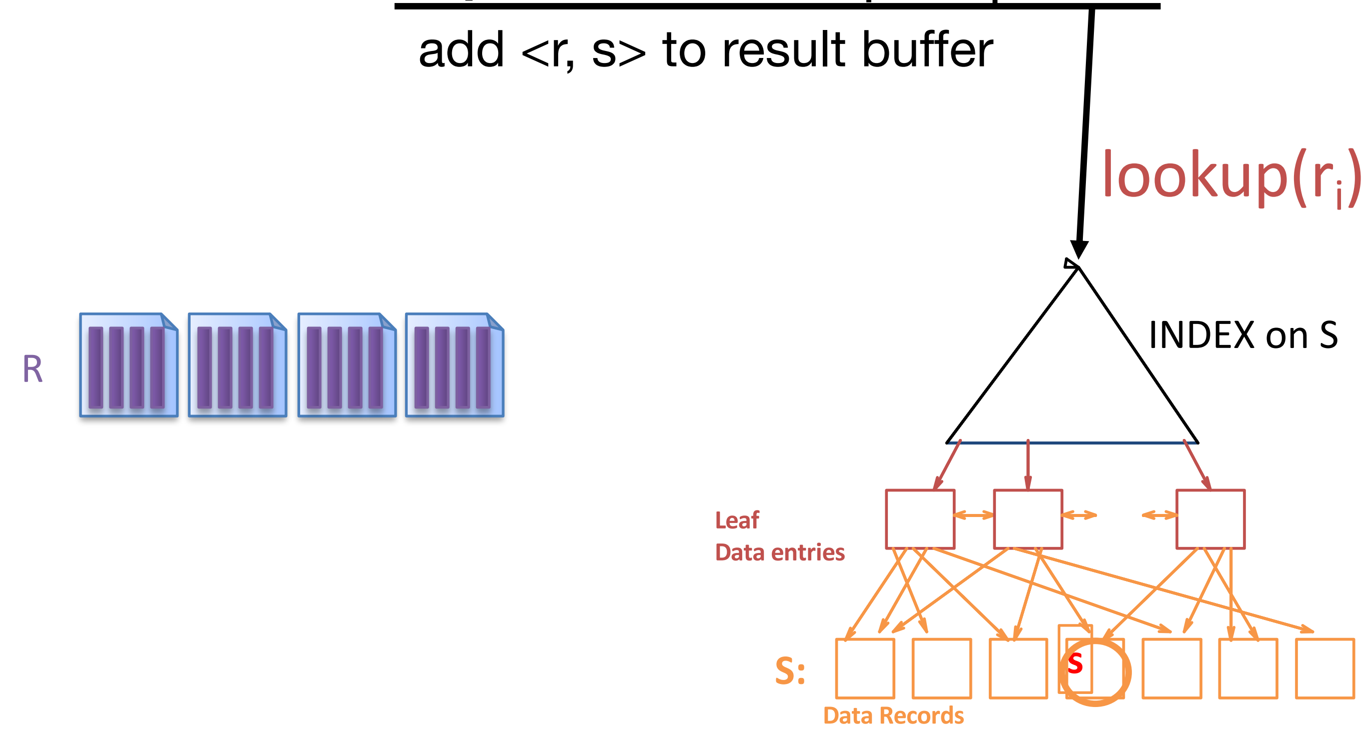
Cost = Scan R once, plus scan S as many times as there are chunks
= [R] + ⌈ [R]/(B-2) ⌉ * [S]
= 1000 + ⌈ 1000/(B-2) ⌉ * 500
= 6,000 for B=102 (~100x better than Page NL!)

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

Index Nested Loops Join

Consider when we have equijoin on $r_i = s_j$

```
for each tuple r in R:
        for each tuple s in S where $r_i == s_j$:
                add <r, s> to result buffer
```



Index Nested Loops Join Cost

```
for each tuple r in R:
        for each tuple s in S where $r_i == s_j$:
                add <r, s> to result
```

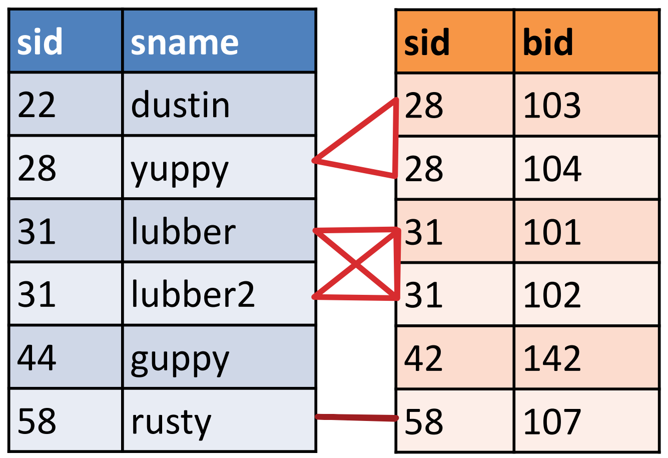
Cost = [R] + |R| * cost to find matching S tuples

- 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
- Output is sorted on join attribute
- Two Stages:
  - Sort: sort tuples in R and S by join key
    - All tuples with same key in consecutive order
    - Input might already be sorted … say from an earlier sort merge/index scan
  - Join: Merge-scan the sorted partitions and emit tuples that match
    - Each tuple in R may match multiple tuples in S
    - 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
- Will discuss some pseudocode – but may not cover all cases (beware!)

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

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

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

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

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

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

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

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

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

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

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

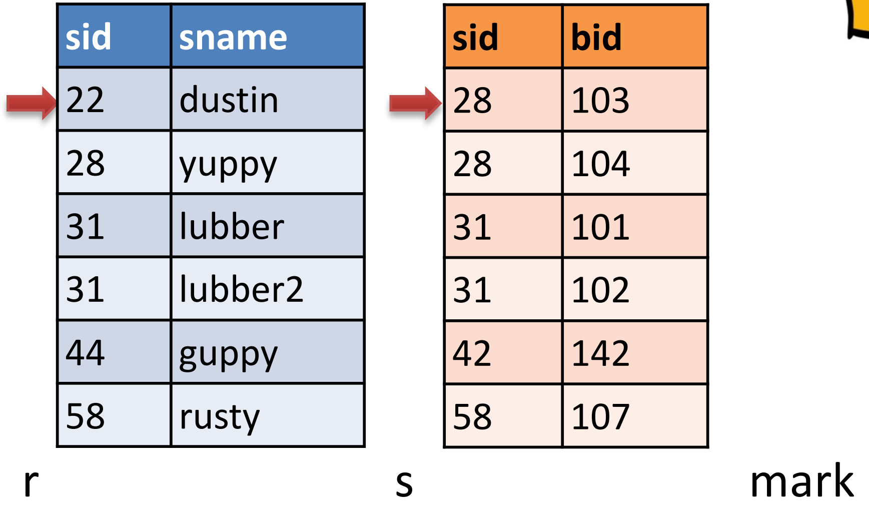
r

s

mark

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
  }
}
```

r

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

s

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

mark

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

r

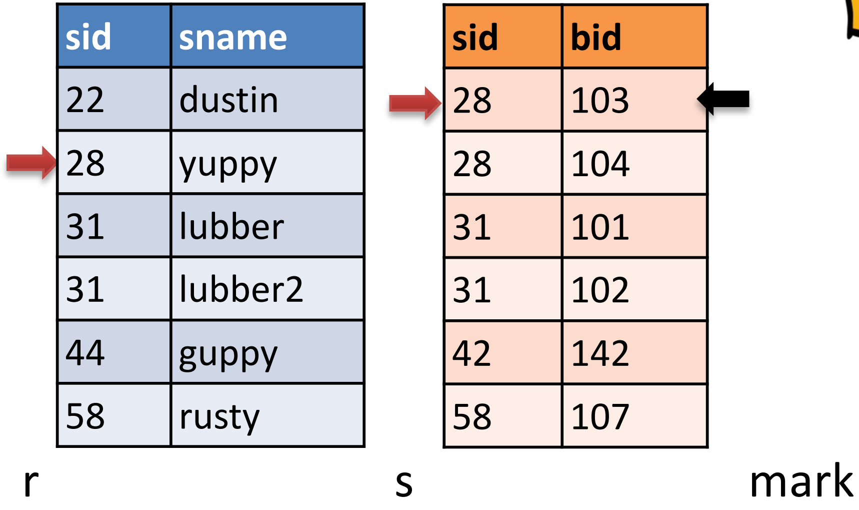
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

s

mark

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
  }
}
```



r

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

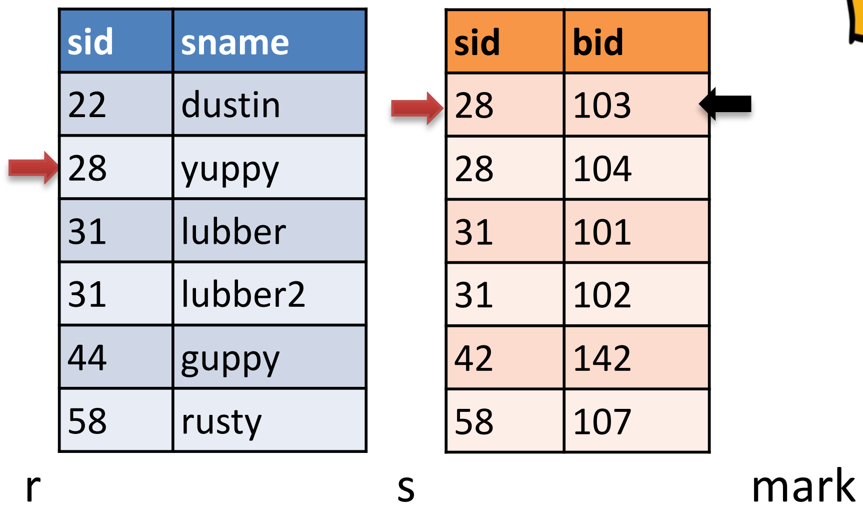
s

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

mark

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
  }
}
```

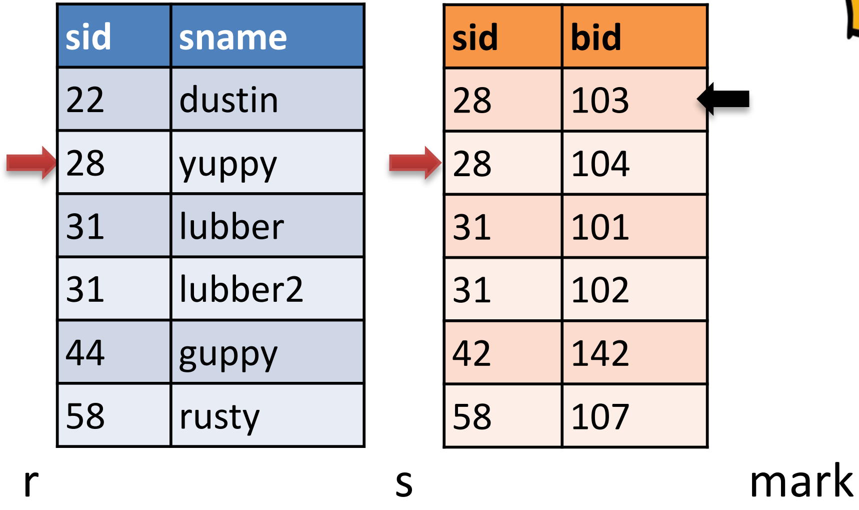


sid	sname
22	dustin
28	yuppy
31	lubber
31	lubber2
44	guppy
58	rusty

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

r s mark

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

r

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

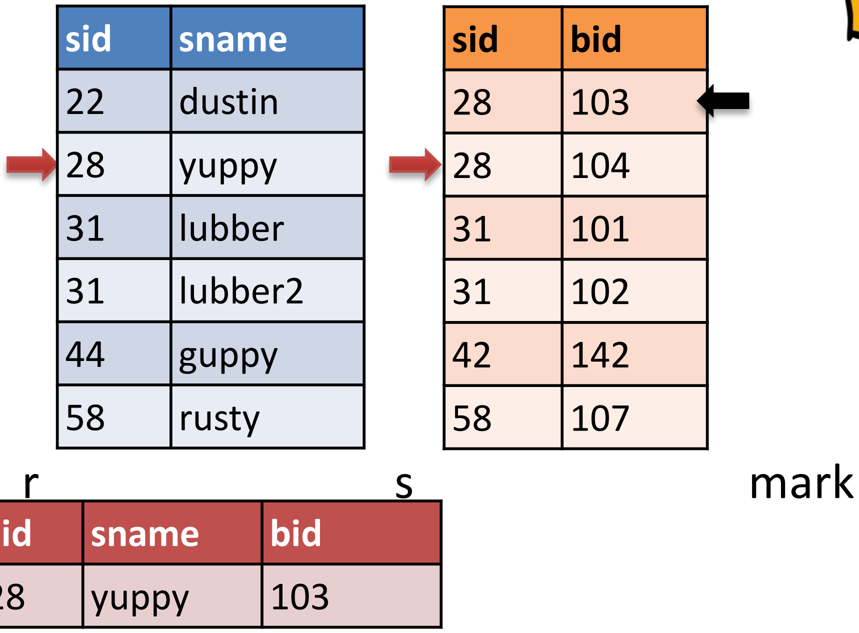
s

mark

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
  }
}
```

r

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

s

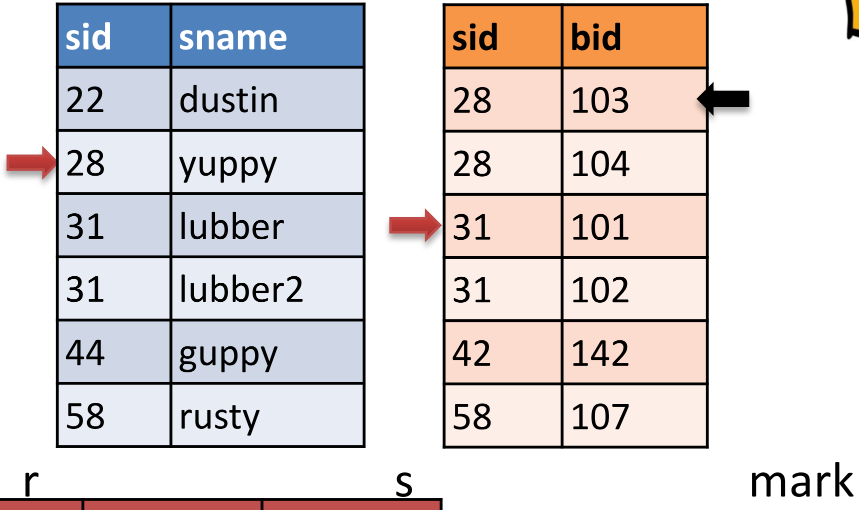
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

mark

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

r

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

s

mark

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

r

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

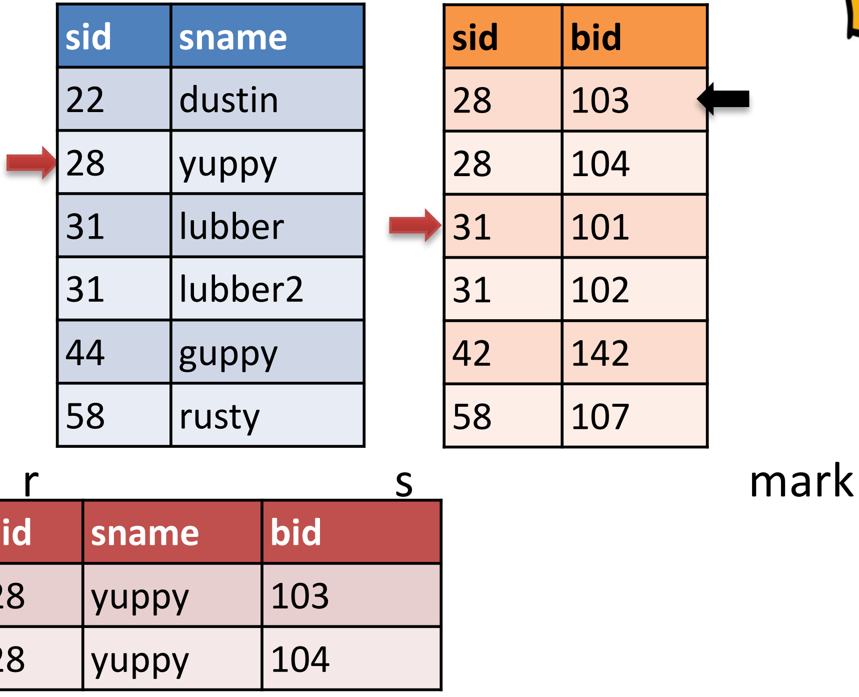
s

mark

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

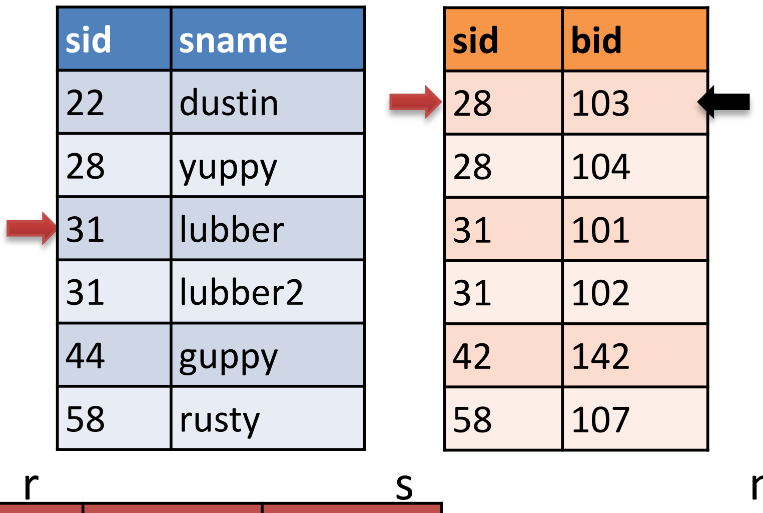
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

r s mark

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

r

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

s

mark

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

r

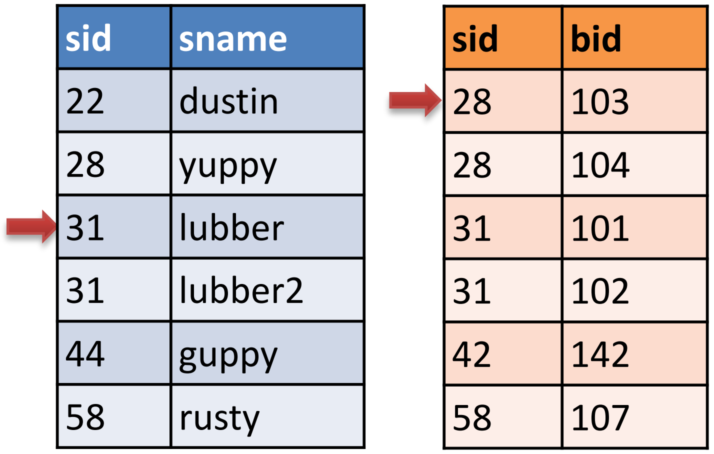
s

mark

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
  }
}
```



r

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

s

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

mark

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

r

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

s

mark

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

r

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

s

mark

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

r s mark

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

r

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

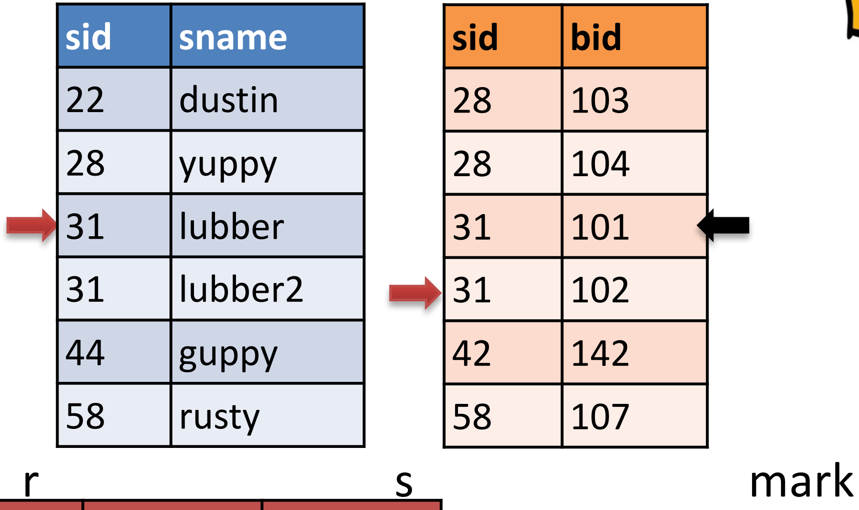
s

mark

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
  }
}
```



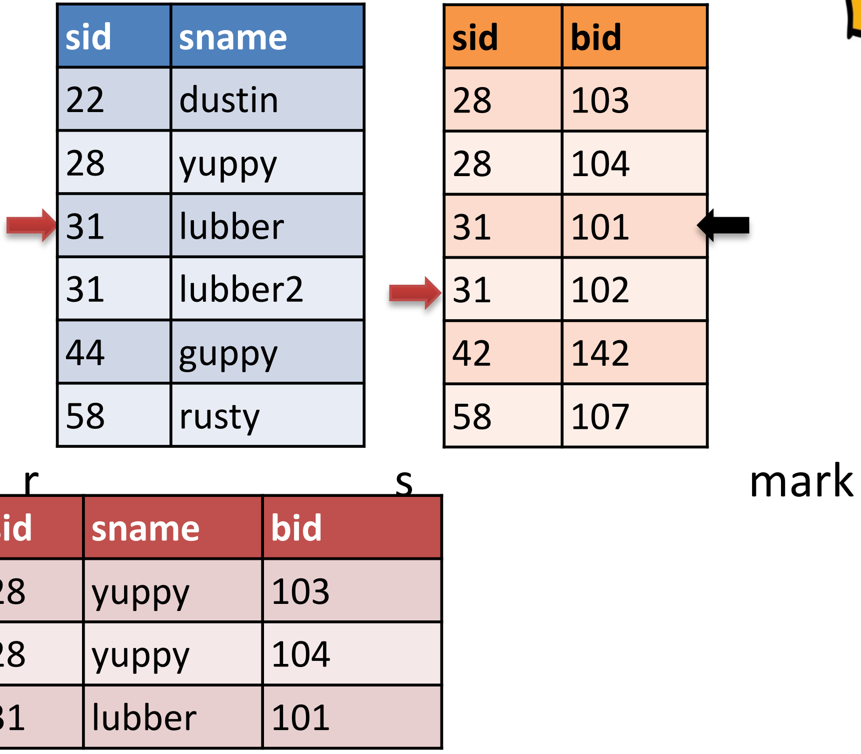
sid	sname
22	dustin
28	yuppy
31	lubber
31	lubber2
44	guppy
58	rusty

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

r

s

mark

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

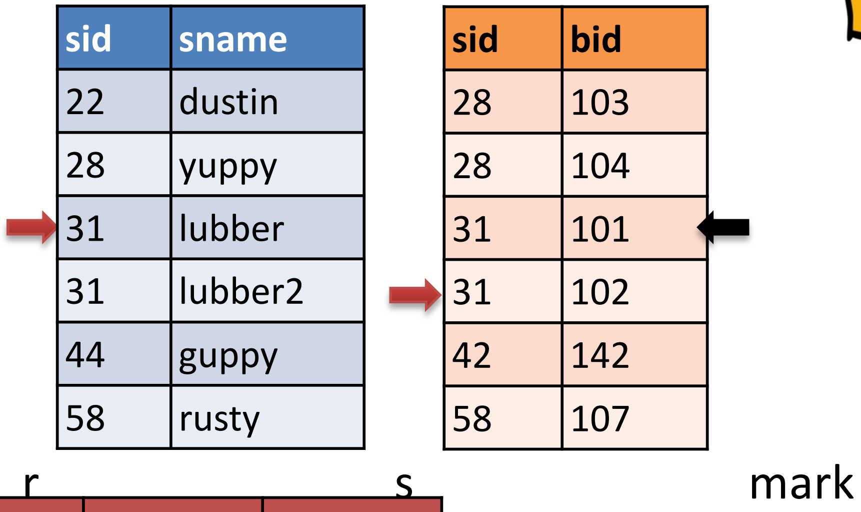
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

r s mark

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
  }
}
```



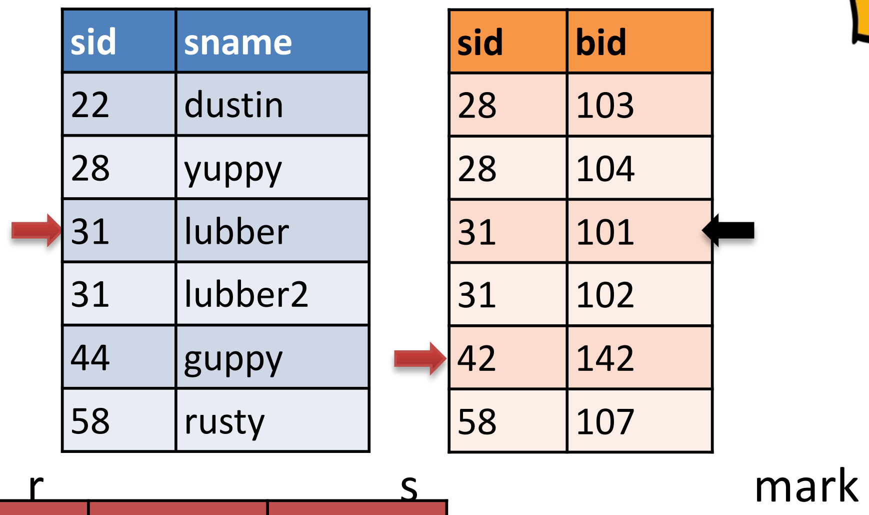
sid	sname
22	dustin
28	yuppy
31	lubber
31	lubber2
44	guppy
58	rusty

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
  }
}
```



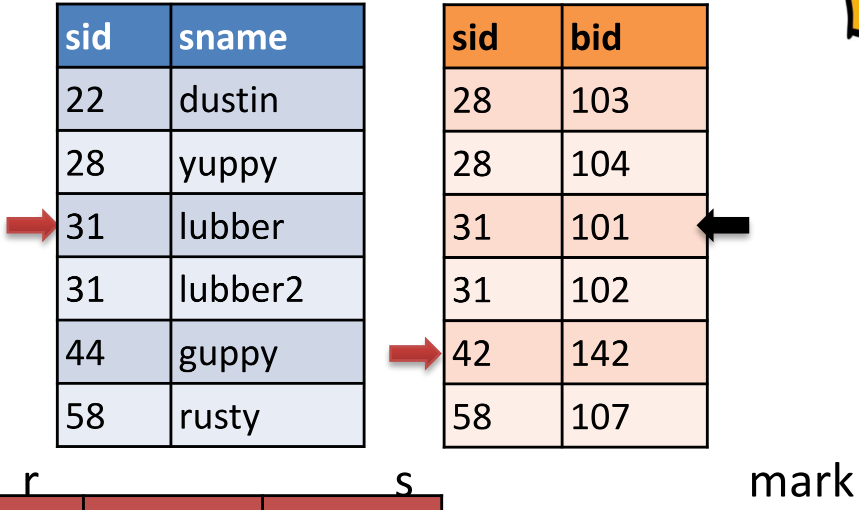
sid	sname
22	dustin
28	yuppy
31	lubber
31	lubber2
44	guppy
58	rusty

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
  }
}
```



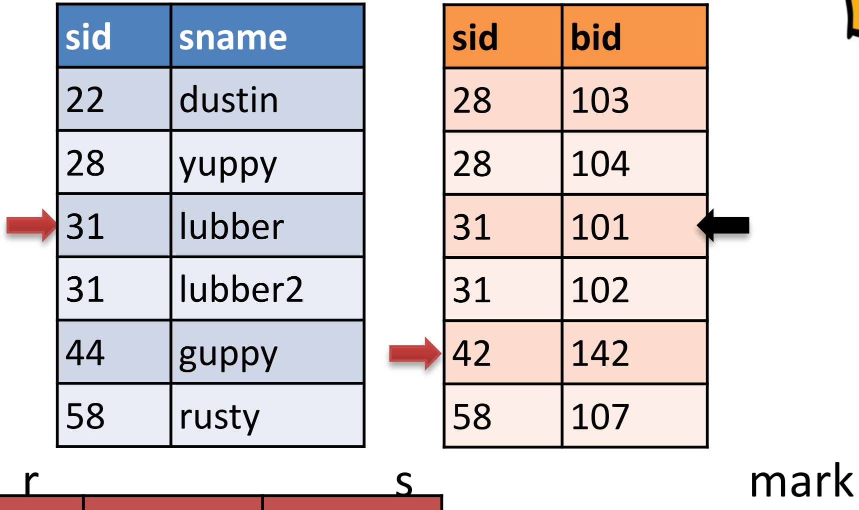
sid	sname
22	dustin
28	yuppy
31	lubber
31	lubber2
44	guppy
58	rusty

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

r

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

s

mark

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

r

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

s

mark

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

r

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

s

mark

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

r s mark

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
  }
}
```

r

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

s

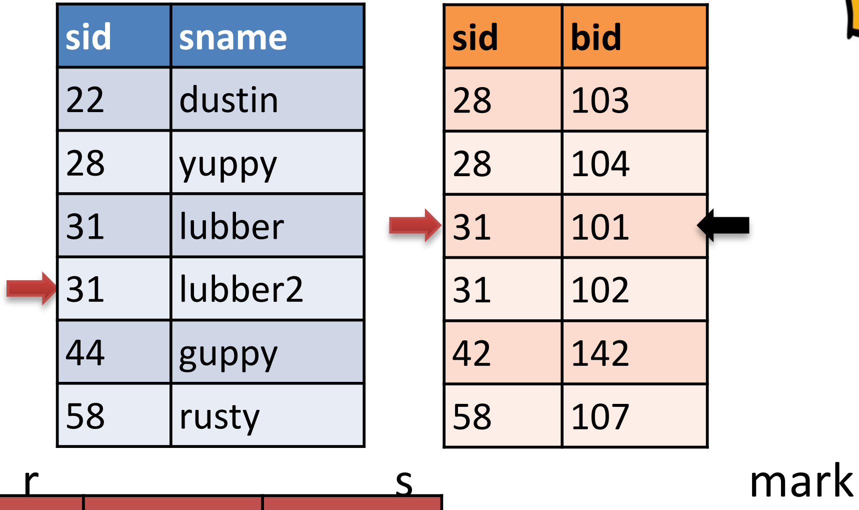
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

mark

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
  }
}
```



r

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

s

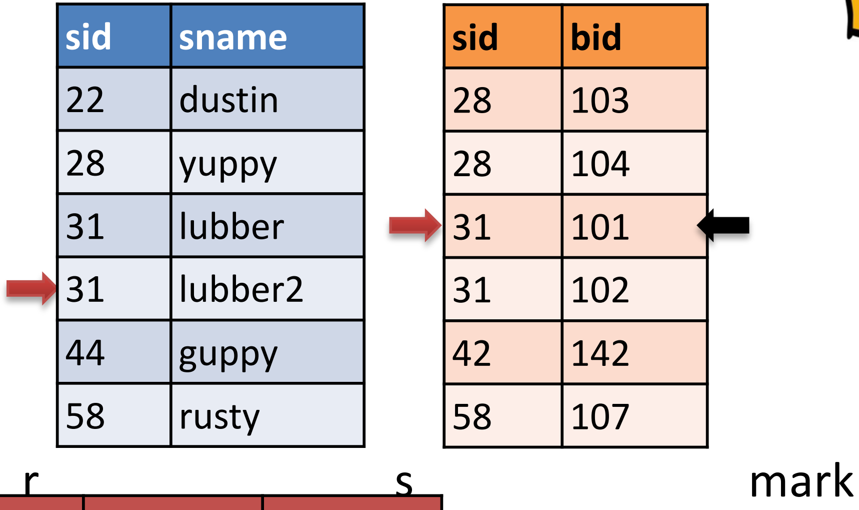
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

mark

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
  }
}
```

r

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

s

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

mark

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

r s mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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

r

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

s

mark

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

r

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

s

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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

r

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

s

mark

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

r

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

s

mark

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

r

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

s

mark

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

r

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

s

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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

r

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

s

mark

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

r

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

s

mark

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

r

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

s

mark

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

r

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

s

mark

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
  }
}
```

r

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

s

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

mark

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
  }
}
```

r

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

s

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

mark

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

r

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

s

mark

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
  }
}
```

r

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

s

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

mark

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

r

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

s

mark

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

r

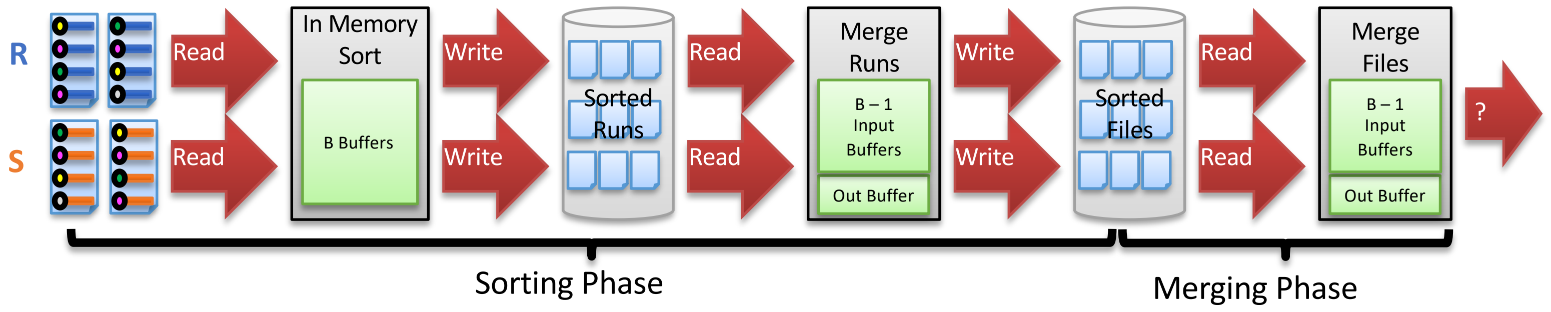
sid	bid
28	103
28	104
31	101
31	102
42	142
58	107

s

mark

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



- Best case 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: To sort both R and S in two passes each, how big does the buffer have to be?

- Suppose buffer B > $\sqrt{(\max([R], [S]))}$
  - Both R and S can be sorted in 2 passes
  - Cost is then 4*1000 + 4*500 + (1000 + 500) = 7500

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

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)
- Special case: every reservation matches exactly one sailor
  - Output has |R| tuples
- Block NLJ
  - Join: [S] + ([S]/(B-2))*[R] = 5500
  - Sort: 4 * [R] (2 passes are enough) = 4000
  - Total: 5500 + 4000 = 9500

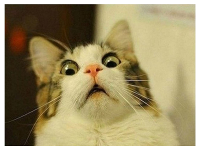
Sort First, Join Later

```
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

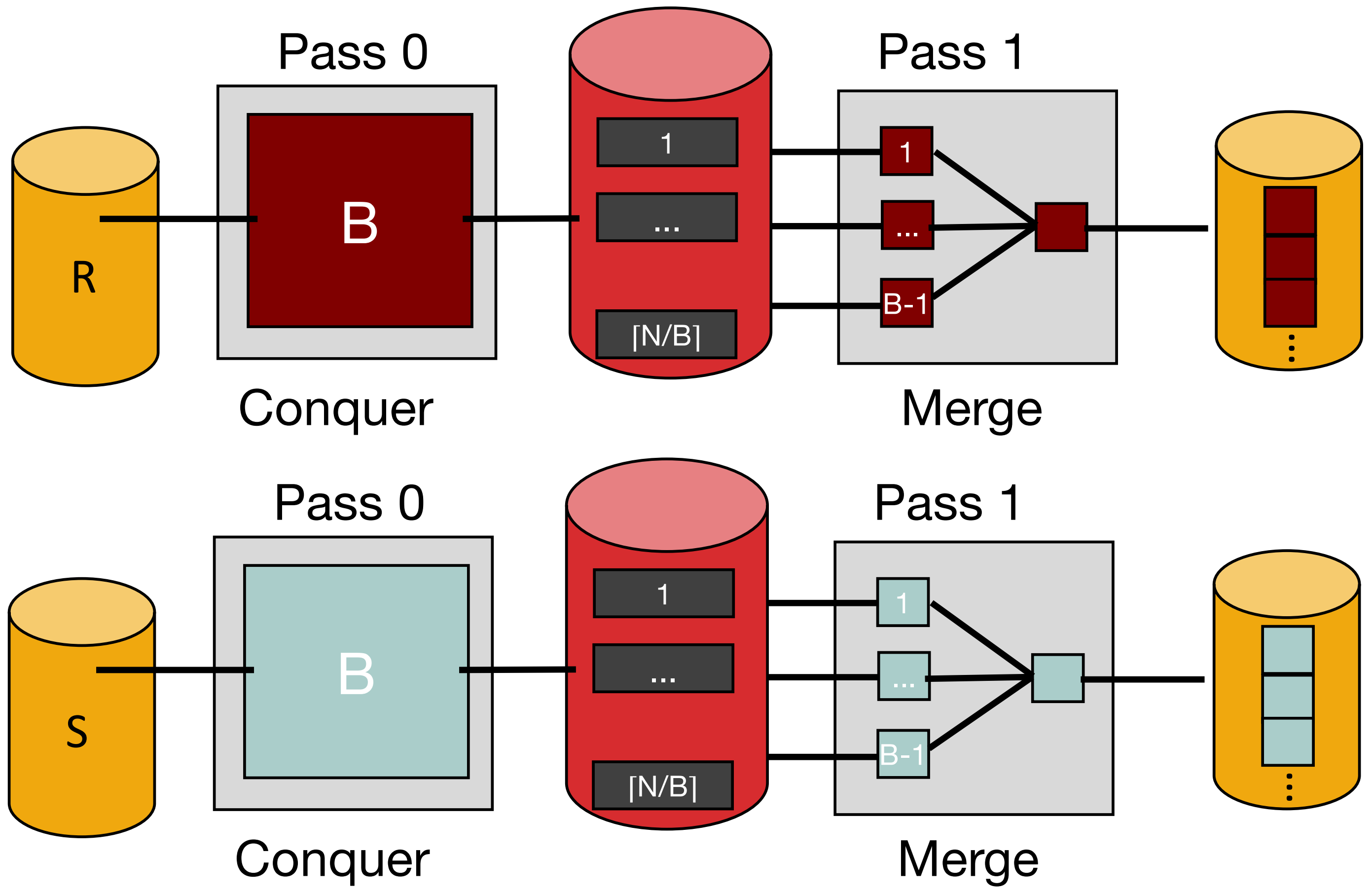
- Reserves (<u>*sid*</u>: int, <u>*bid*</u>: int, <u>*day*</u>: date, *rname*: string)
- Sailors (<u>*sid*</u>: int, *sname*: string, *rating*: int, *age*: real)
- Special case: every reservation matches exactly one sailor
    - Output has |R| tuples

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

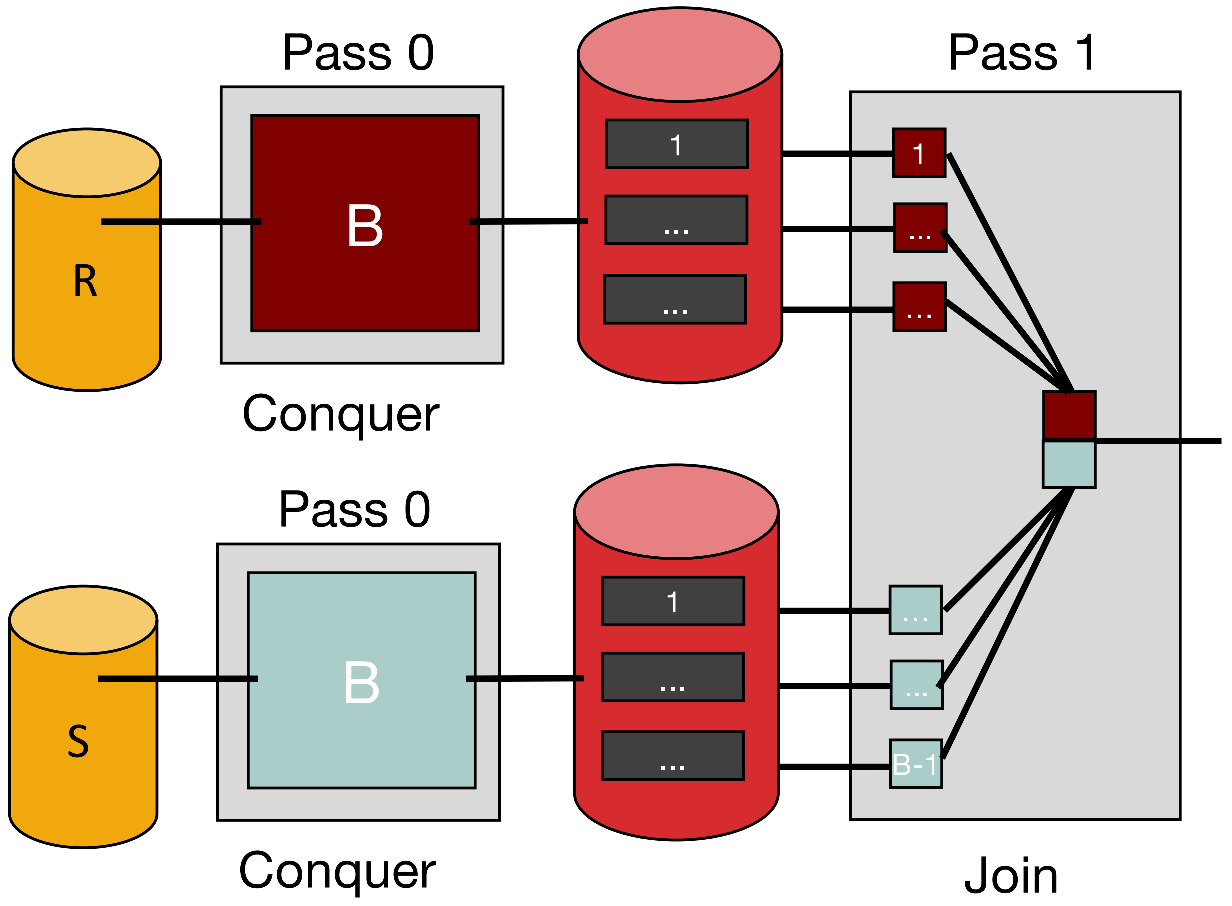


Operator order matters!

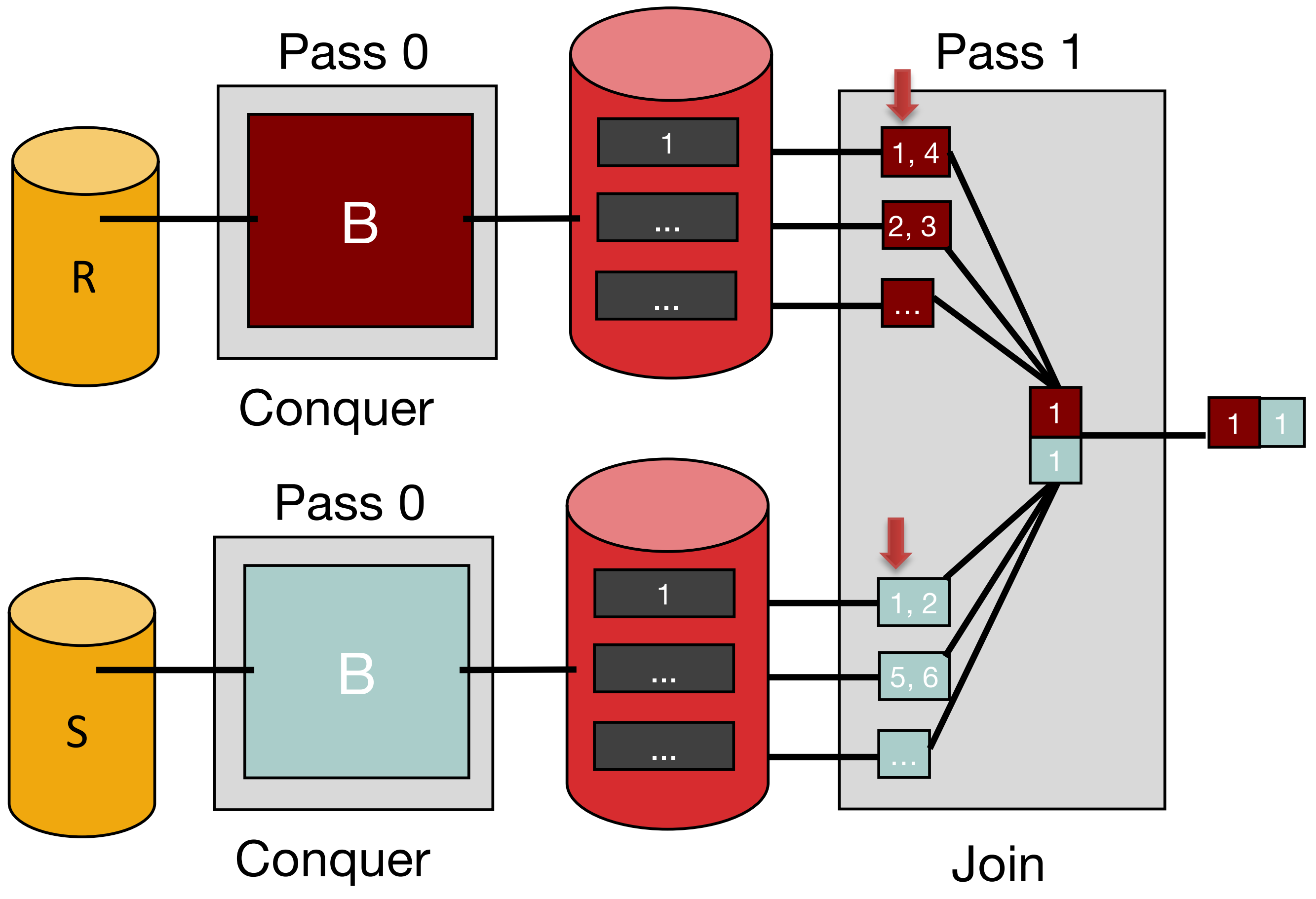
Recall: 2-Pass External Merge Sort



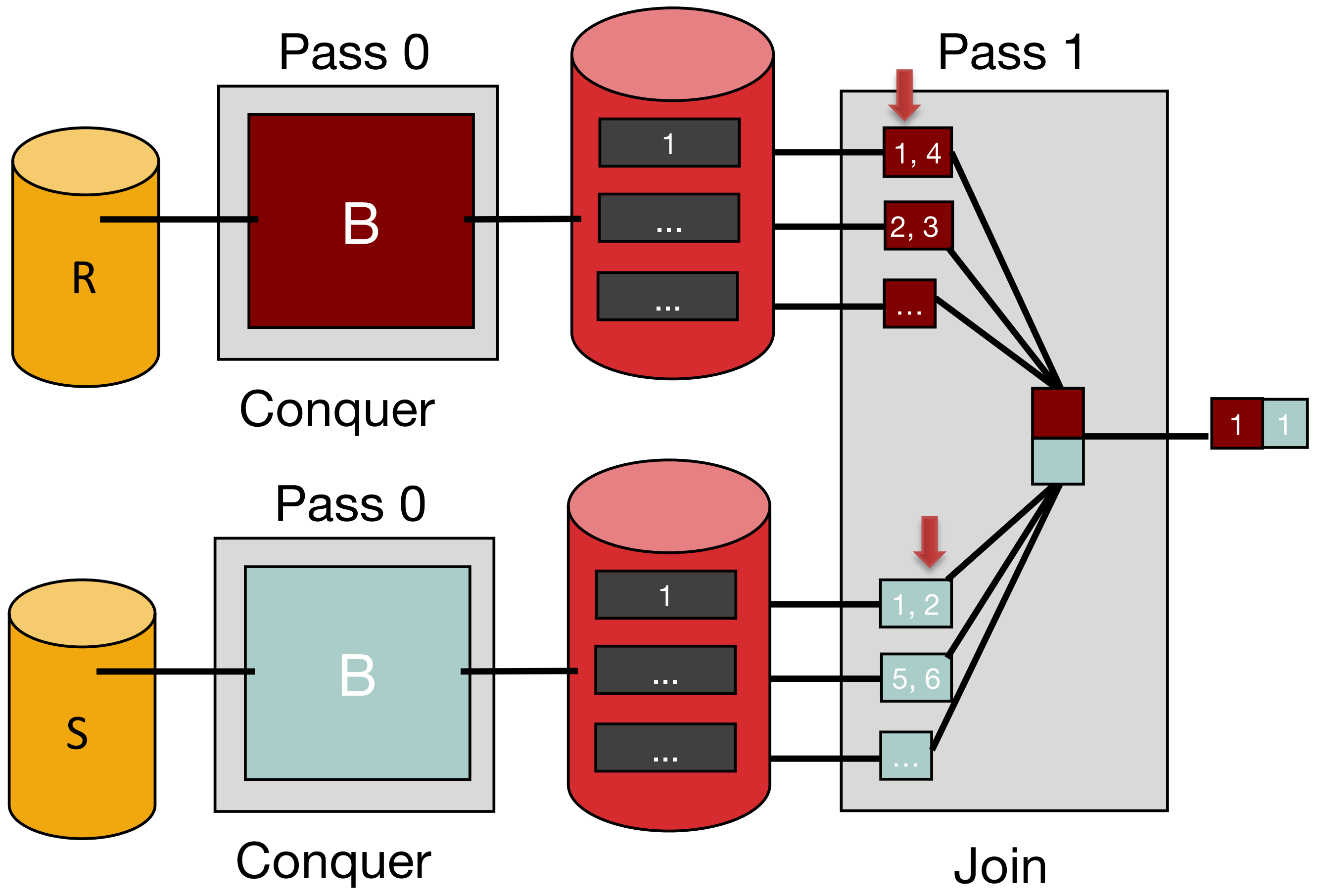
Combining Merge Sort and Join



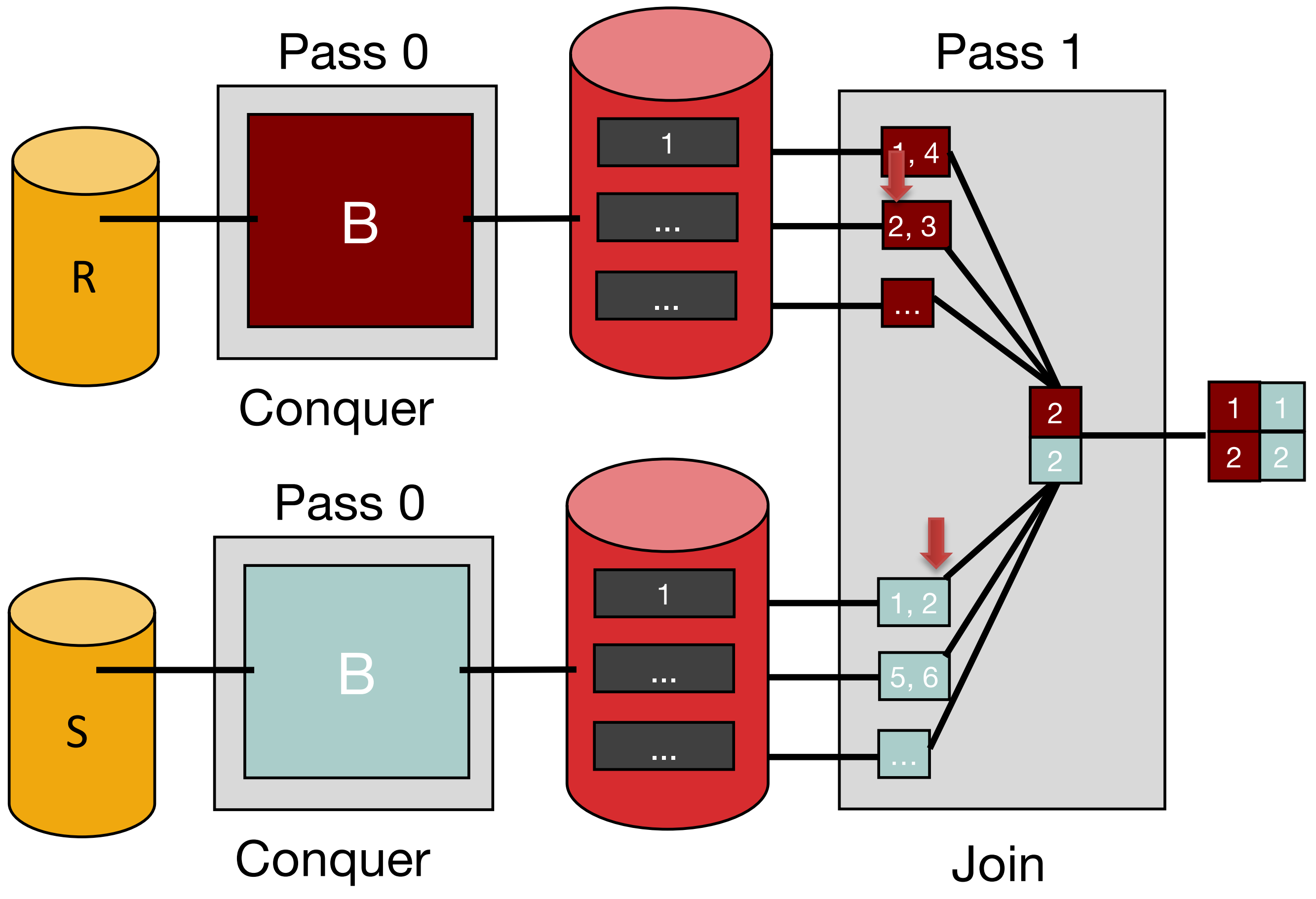
Combining Merge Sort and Join



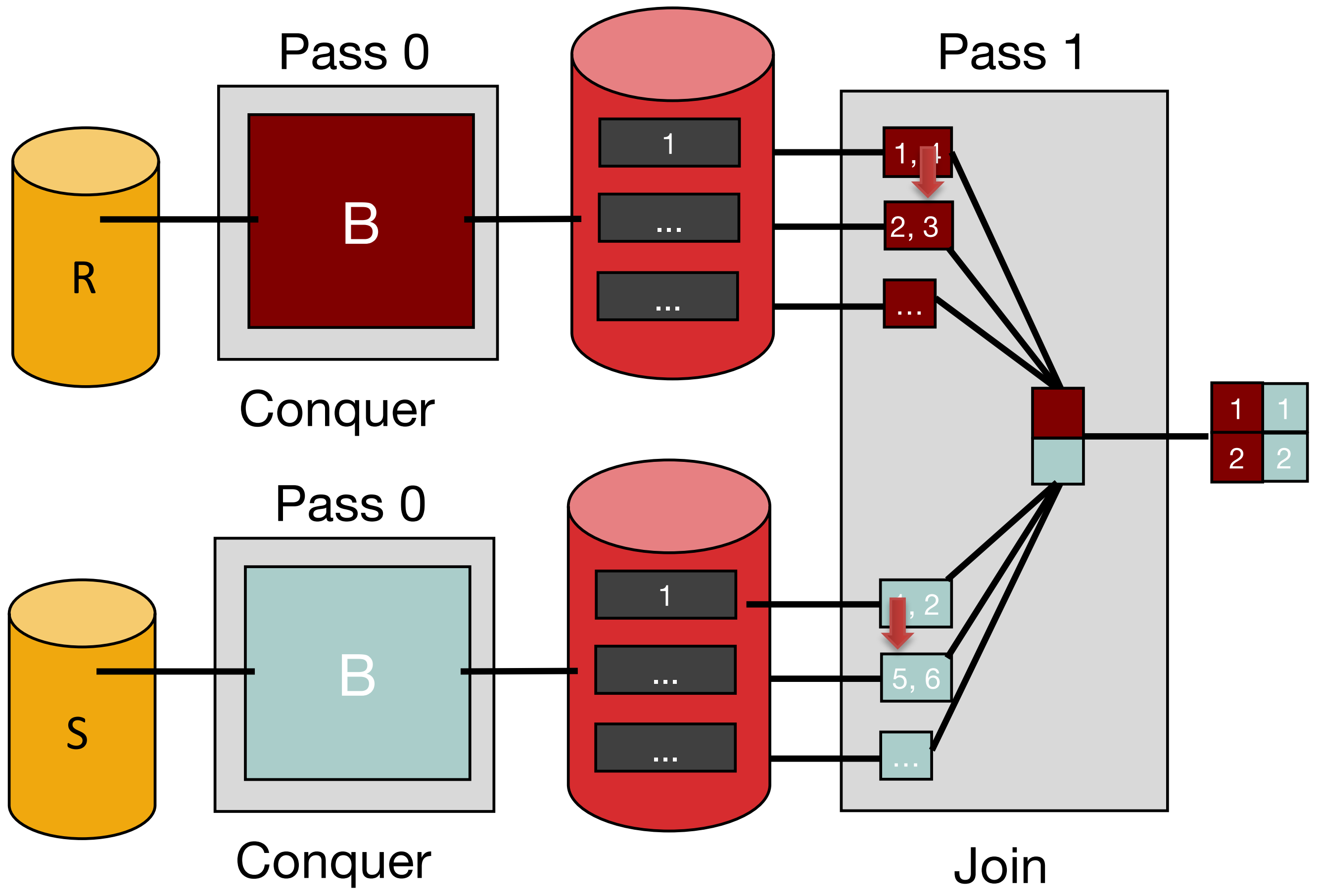
Combining Merge Sort and Join



Combining Merge Sort and Join



Combining Merge Sort and Join



- Need enough buffers for 1 page from each run in R and S in the last merge pass
- 2-pass Cost = 3*[R] + 3*[S] = 3000+1500 = 4500 Even less than sort-merge join!
- In general, we need # runs in last merge pass for R + # runs in last merge pass for S ≤ B - 1

Summary: Join algorithms

- Page / Block nested loop join
  - Order of relations matters!
- Index nested loop join
  - Need index built on at least one of the inputs
- Sort-merge join
  - Similar to external sort algorithm
  - Output is sorted