THE UNIVERSITY *of* EDINBURGH

Advanced Database Systems

Spring 2026

Lecture #15:

Query Optimisation: Plan Space Example

R&G: Chapter 15

The Plan Space of a Simple Query

EXAMPLE DATABASE

Reserves

sid	bid	day	rname

1000 pages, 100 tuples per page

Each tuple is 40 bytes long

Assume 100 boats (each equally likely)

Sailors

sid	sname	rating	age

500 pages, 80 tuples per page

Each tuple is 50 bytes long

Assume 10 different ratings (each equally likely)

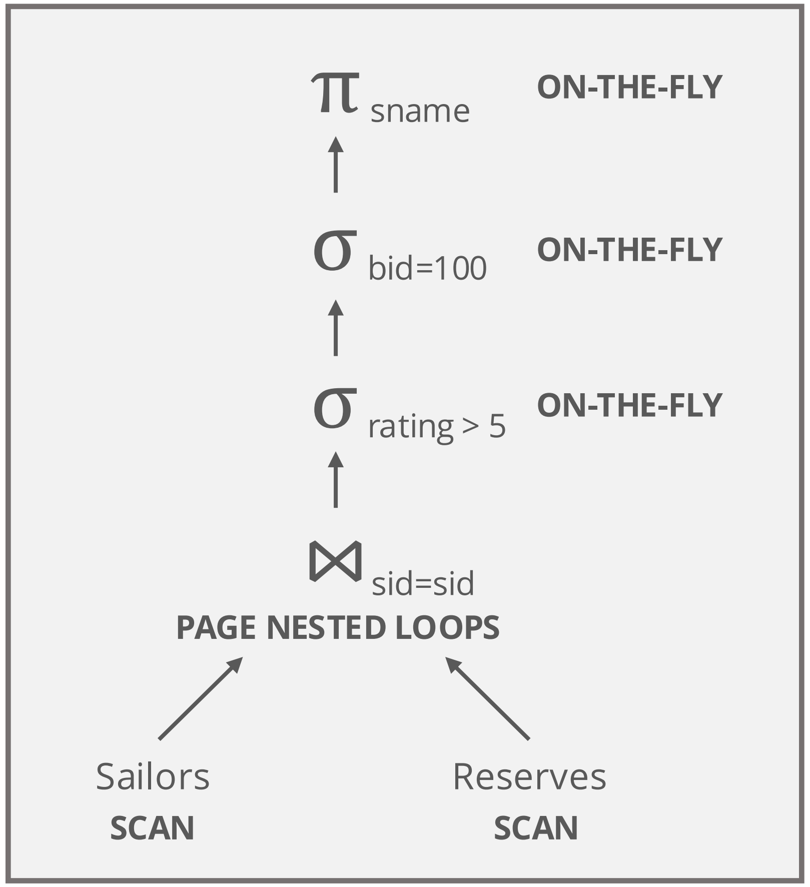
Assume we have ***B* = *5*** pages to use for joins

Remember: just counting I/Os

QUERY PLAN 1

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

Here's a reasonable query plan ⇒



Query Plan 1 Cost

Cost estimation:

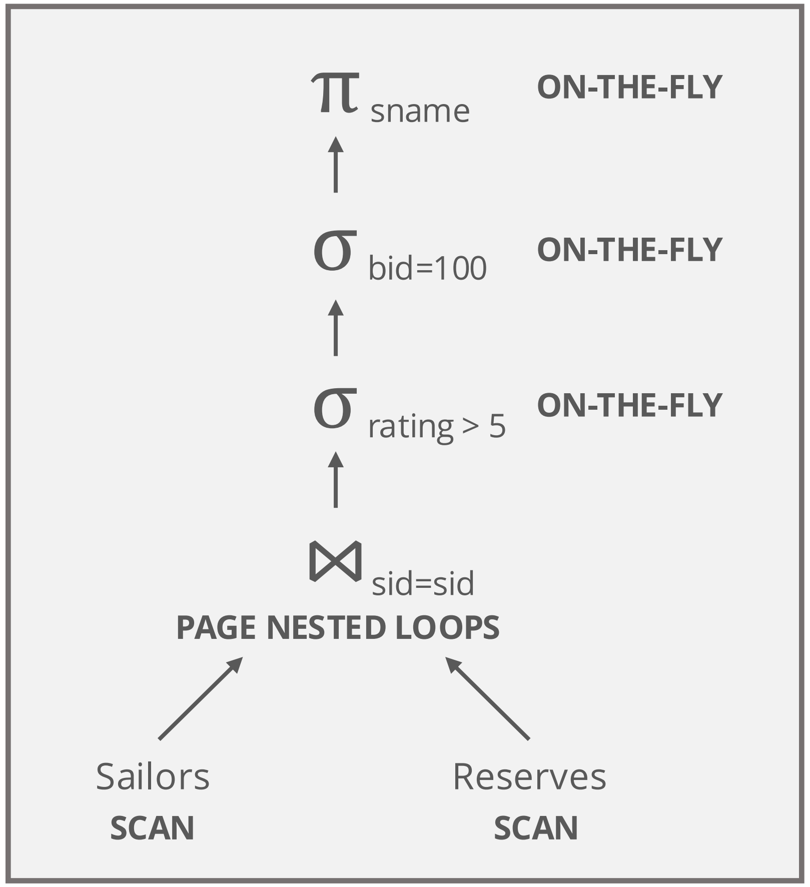
Scan Sailors: **500 I/Os**

For each page of Sailors

Scan Reserves: **1000 I/Os**

Total = 500 + 500 · 1000

= **500,500 I/Os**



Query Plan 1 Cost Analysis

Cost: 500,500 I/Os

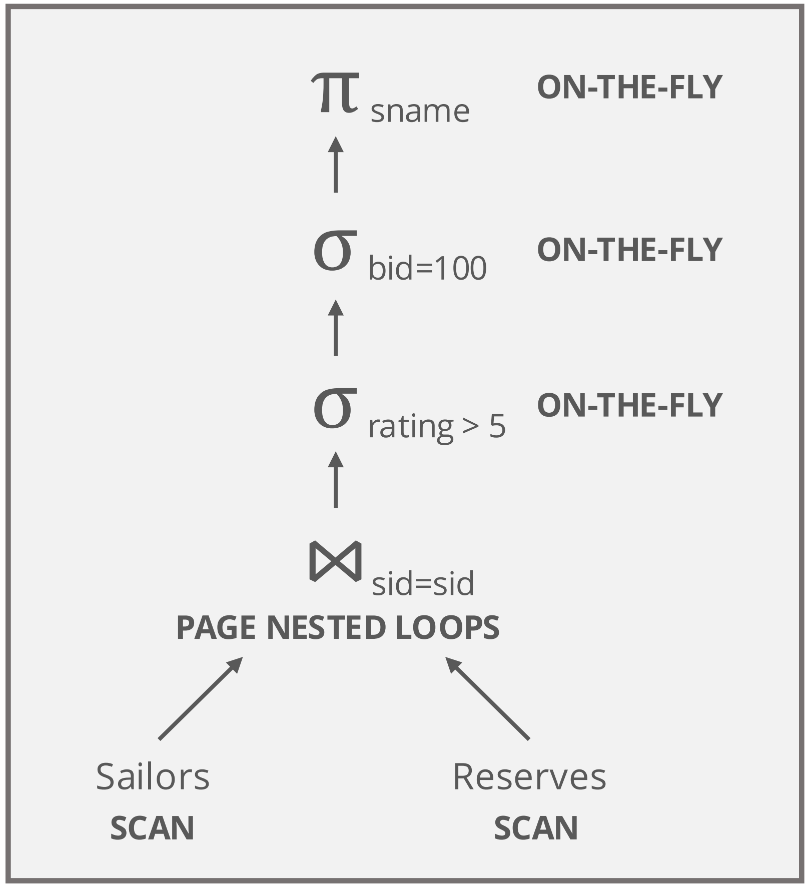
By no means a terrible plan!

Misses several opportunities

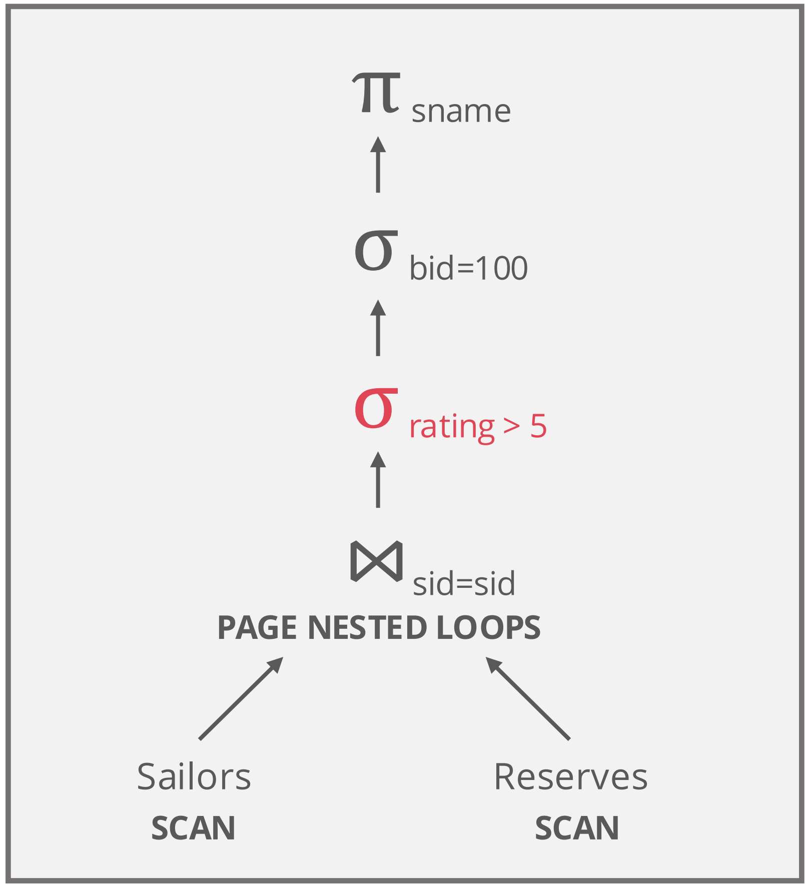
- Selections could be 'pushed' down
- No use of indexes

Goal of optimisation

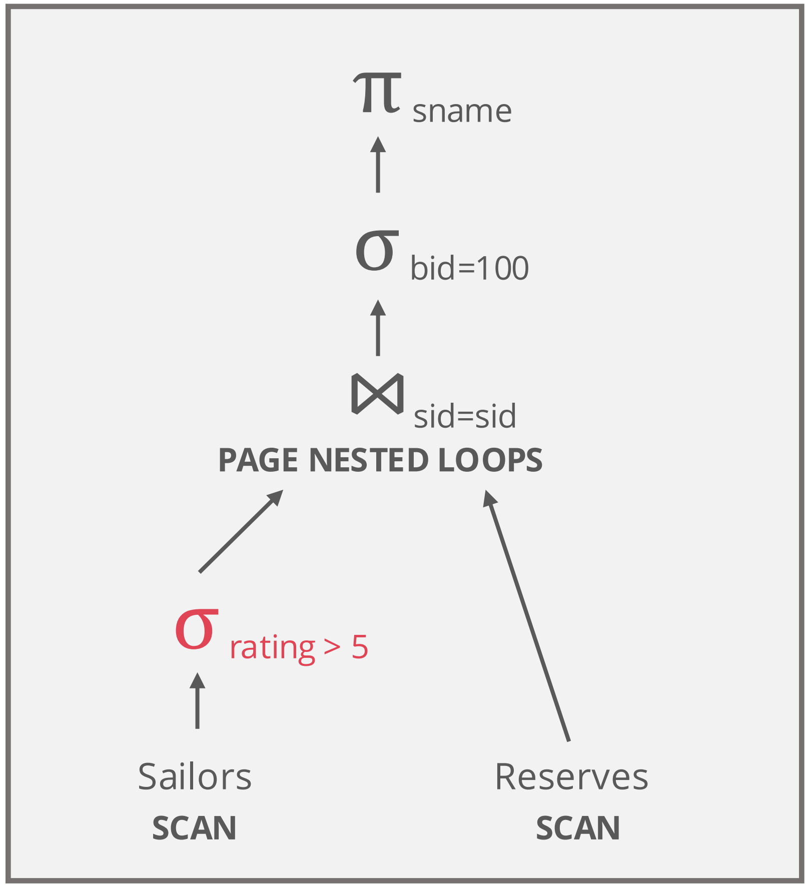
- Find faster plans that compute the same answer



Selection Pushdown



500,500 I/Os



Cost?

Query Plan 2 Cost

Cost estimation:

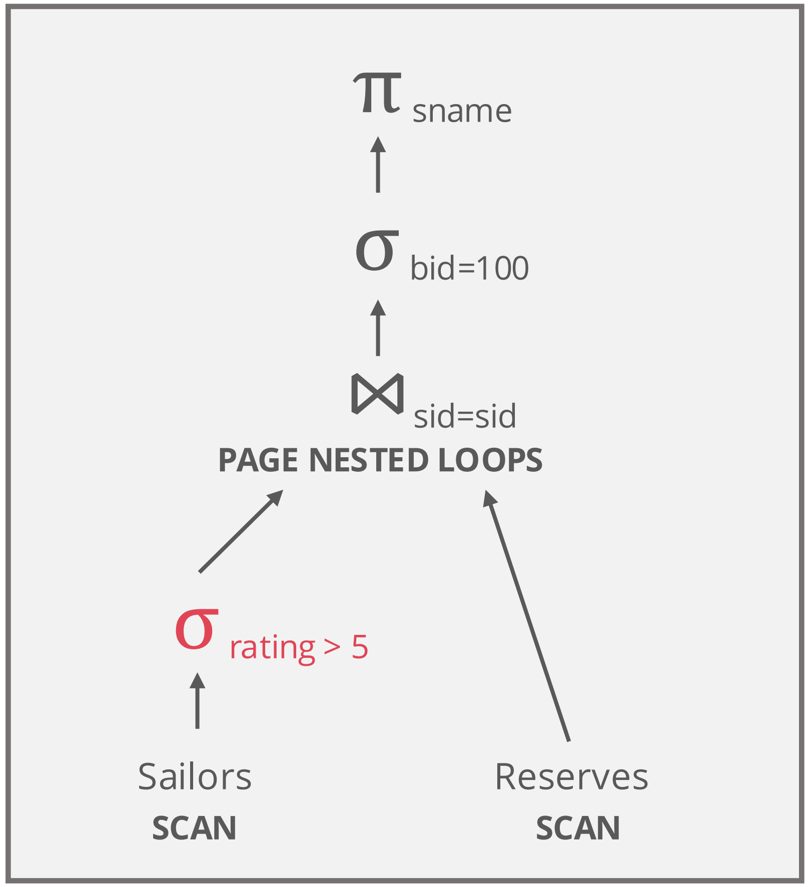
Scan Sailors: **500 I/Os**

For each page of high-rated Sailors
    Scan Reserves: **1000 I/Os**

Total = 500 + ??? · 1000

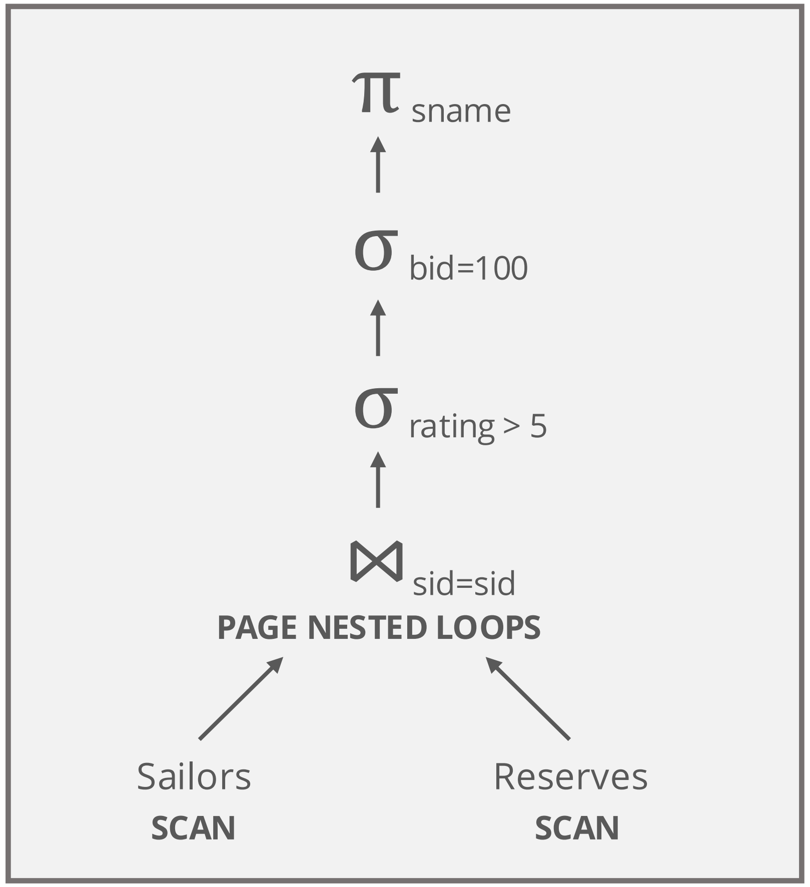
Remember: 10 ratings, all equally likely

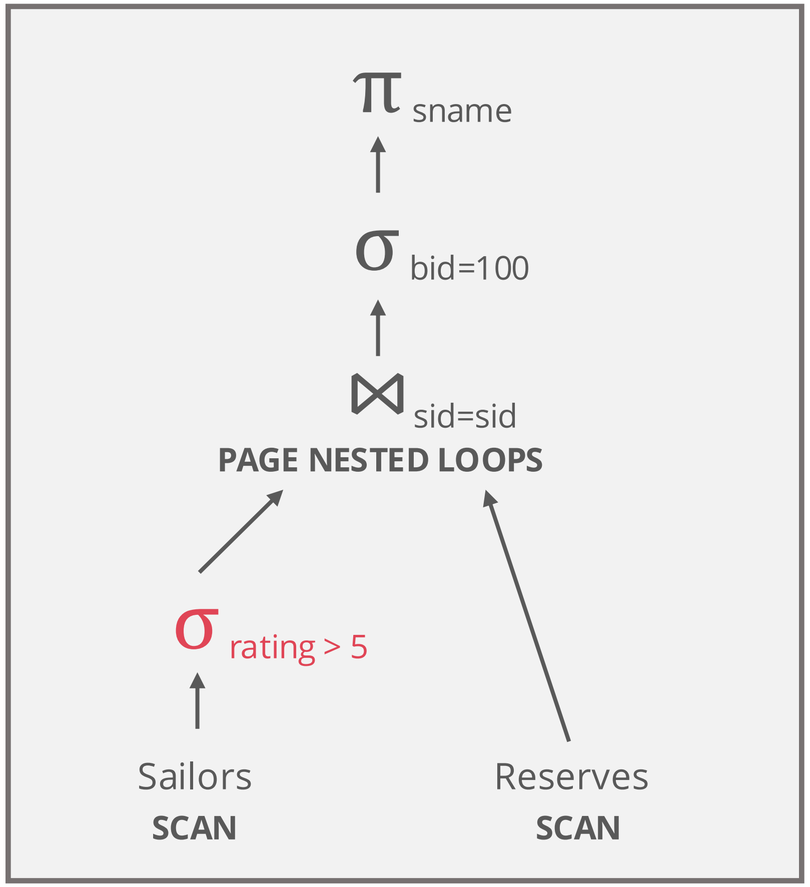
Total = 500 + (500 / 2) · 1000
    = **250,500 I/Os**



π_{sname}
$\sigma_{\text{bid=100}}$
$\bowtie_{\text{sid=sid}}$
PAGE NESTED LOOPS
$\sigma_{\text{rating > 5}}$
Sailors
SCAN
Reserves
SCAN

Decision 1

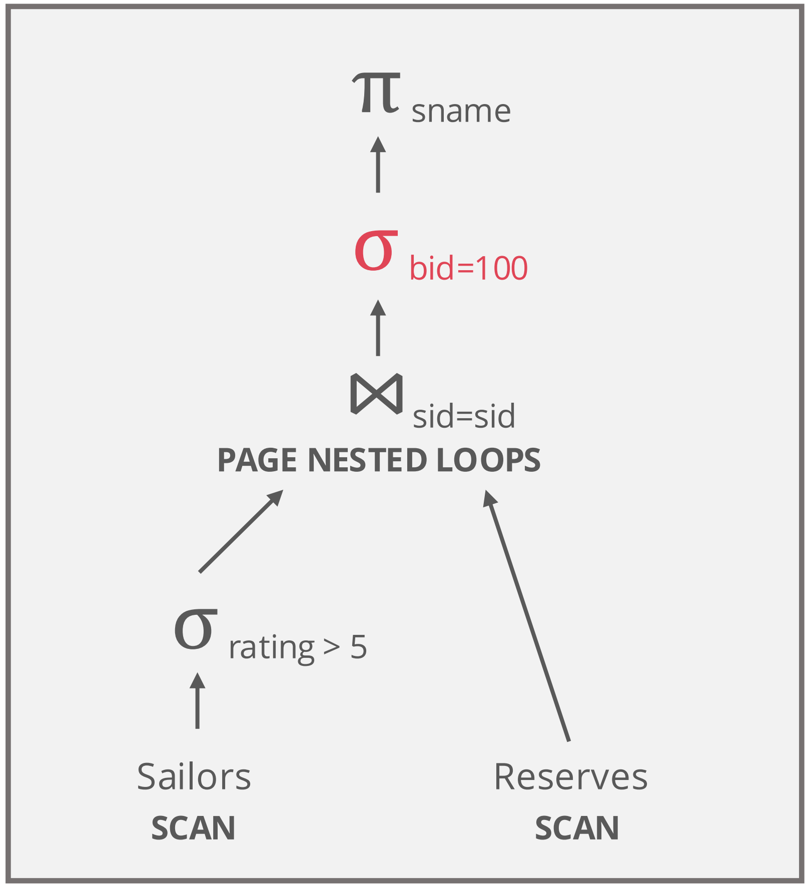




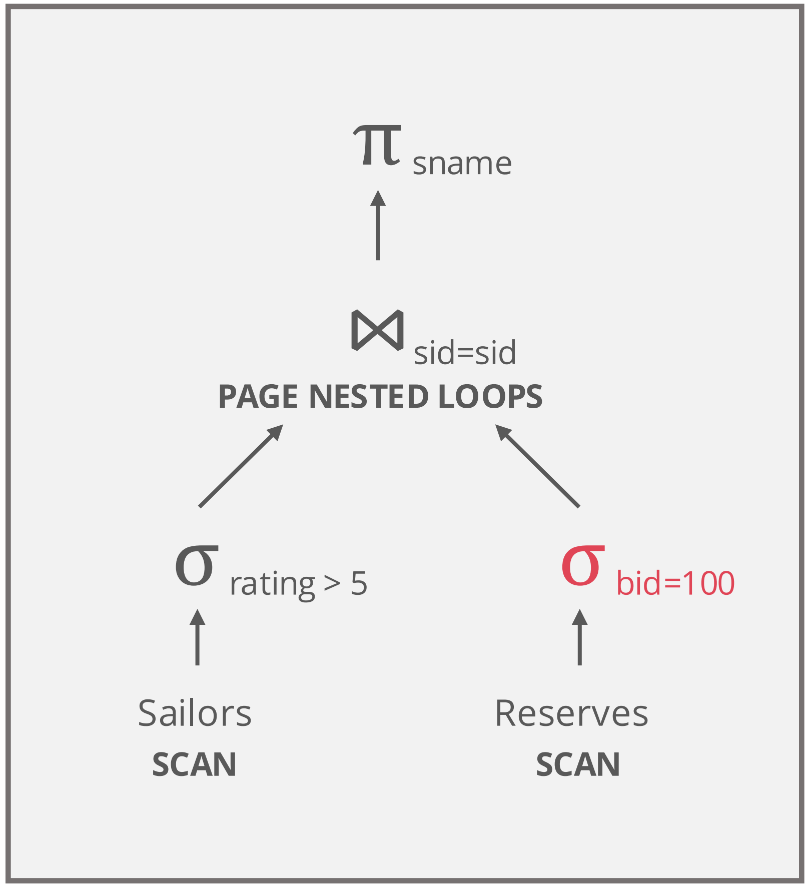
500,500 I/Os

250,500 I/Os

MORE SELECTION PUSHDOWN



250,500 I/Os



Cost?

Query Plan 3 Cost

Cost estimation:

Scan Sailors: **500 I/Os**

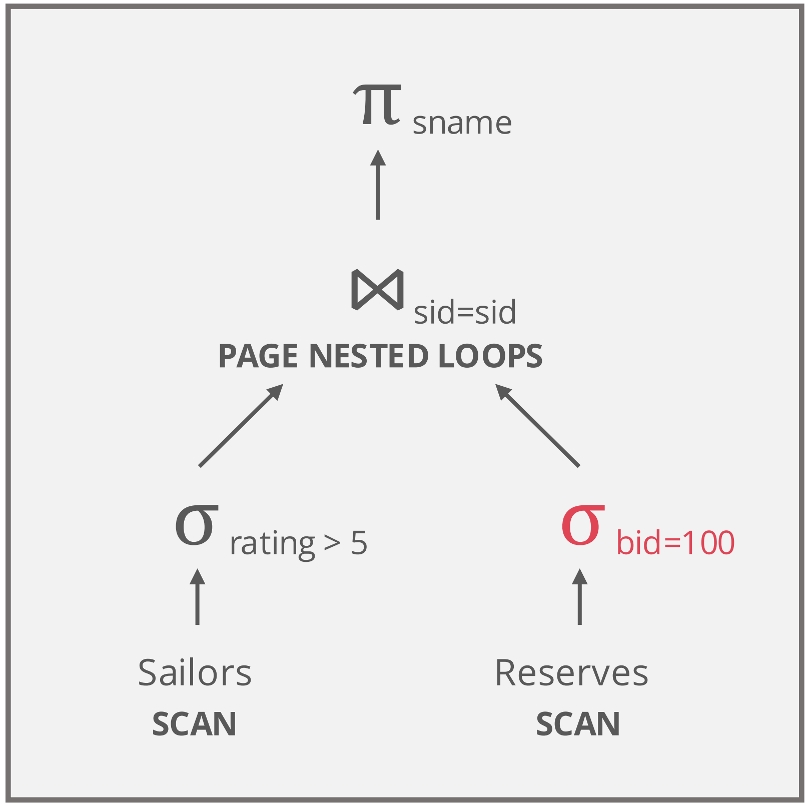
For each page of high-rated Sailors
Read through Reserves tuples that match

Total = 500 + 250 · ???

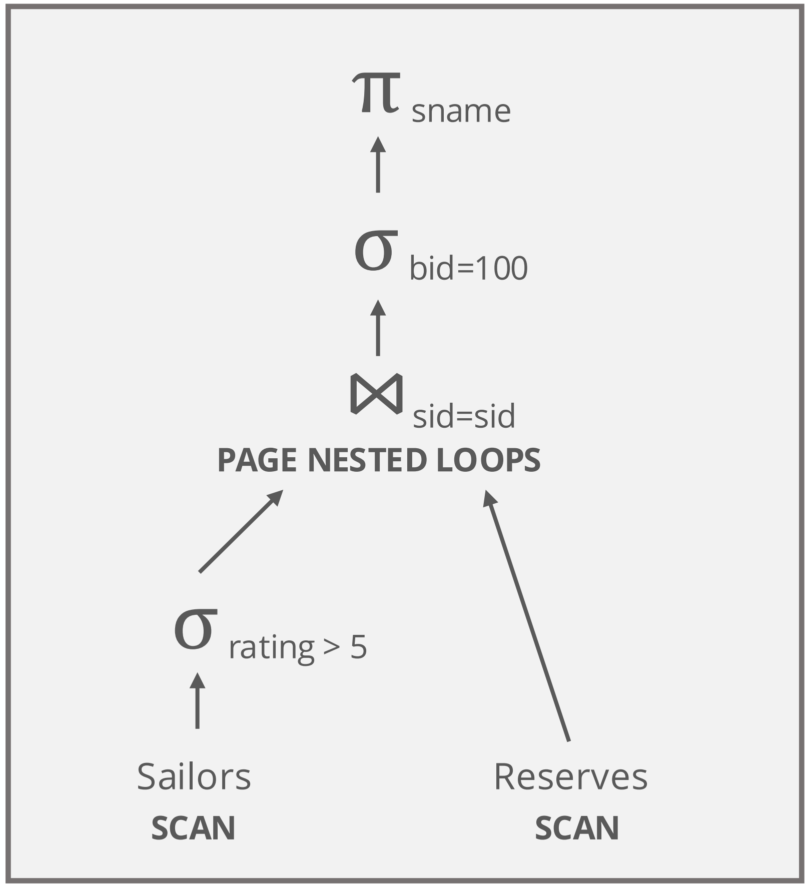
For each scan of Reserves, we filter on-the-fly

Problem: This does not actually save any I/Os

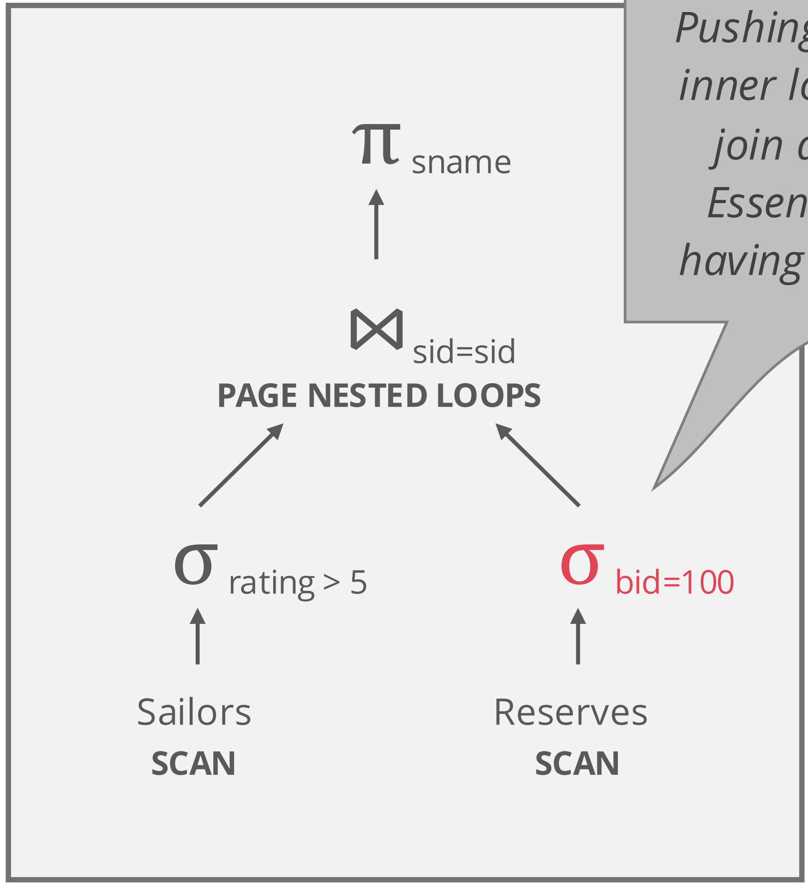
To find matching Reserves tuples, we end up scanning Reserves the same # of times (1000)



Decision 2



250,500 I/Os



Pushing a selection into the inner loop of a nested loop join does not save I/Os! Essentially equivalent to having the selection above.

250,500 I/Os

So Far, We've Tried

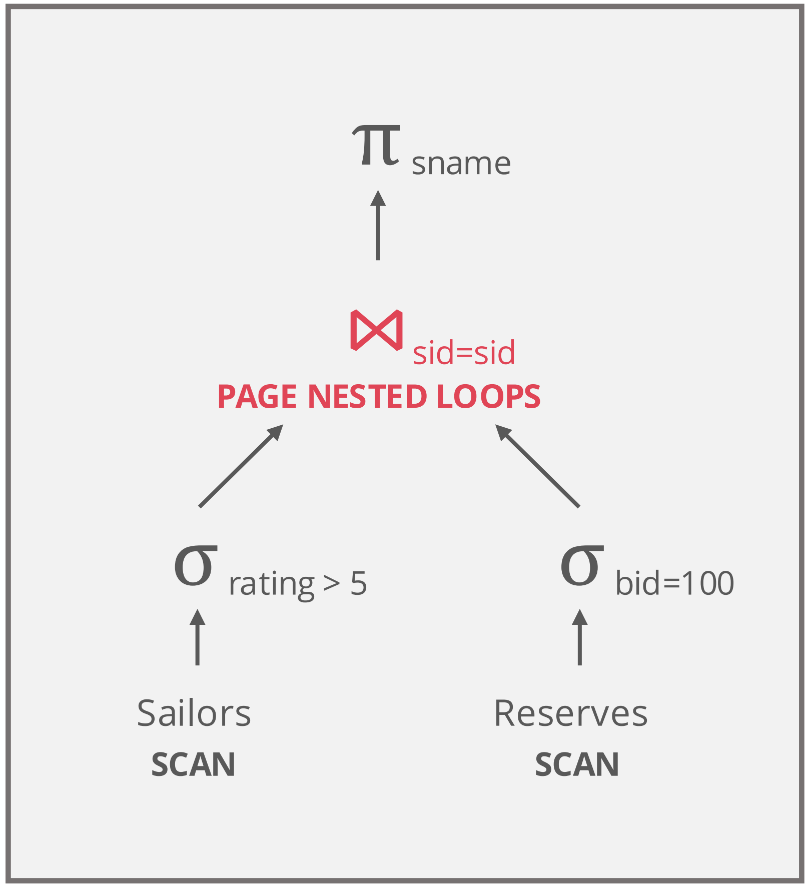
Basic page nested loops (500,500)

Selection pushdown on left (250,500)

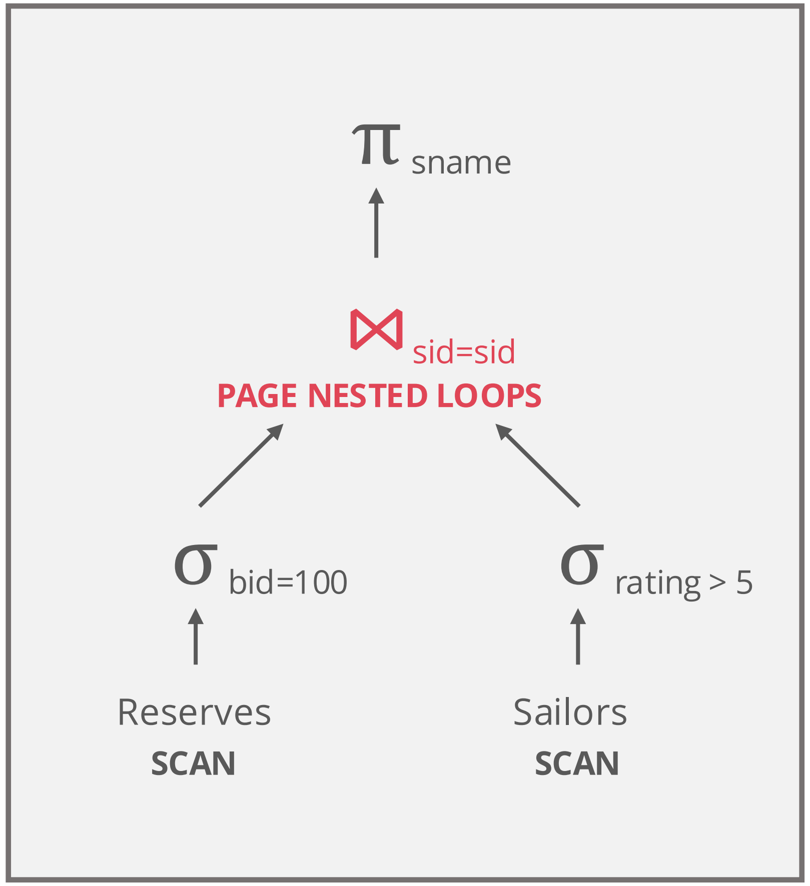
More selection pushdown on right (250,500)

Next: join ordering

Join Ordering



250,500 I/Os



Cost?

QUERY PLAN 4 COST

Cost estimation:

Scan Reserves: **1000 I/Os**

For each page of Reserves for bid 100

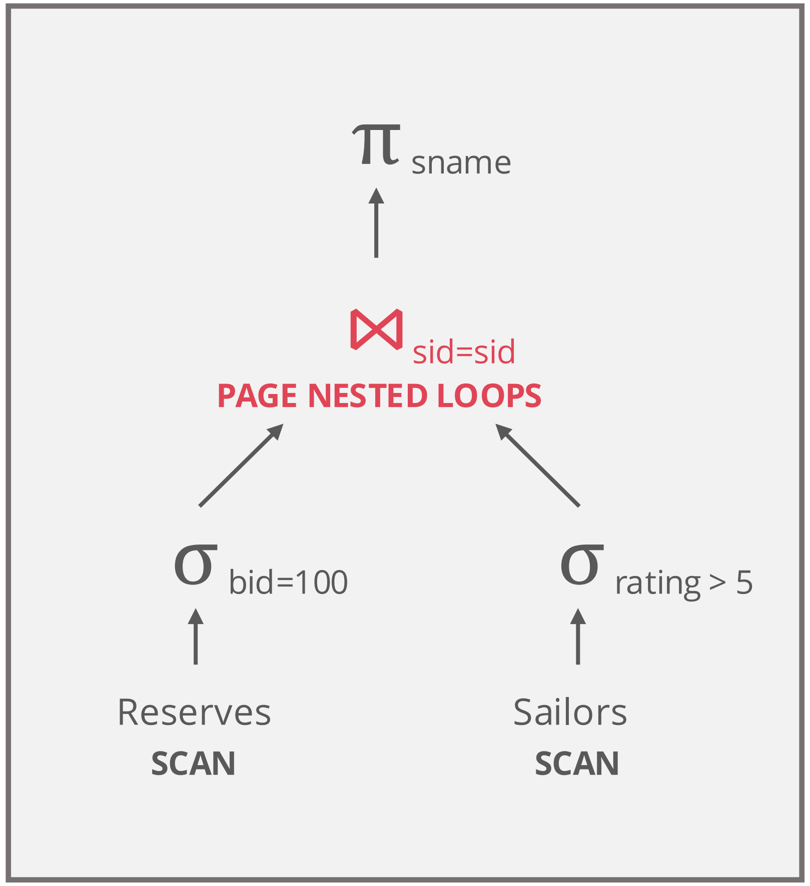
Scan Sailors: **500 I/Os**

Total = 1000 + ??? · 500

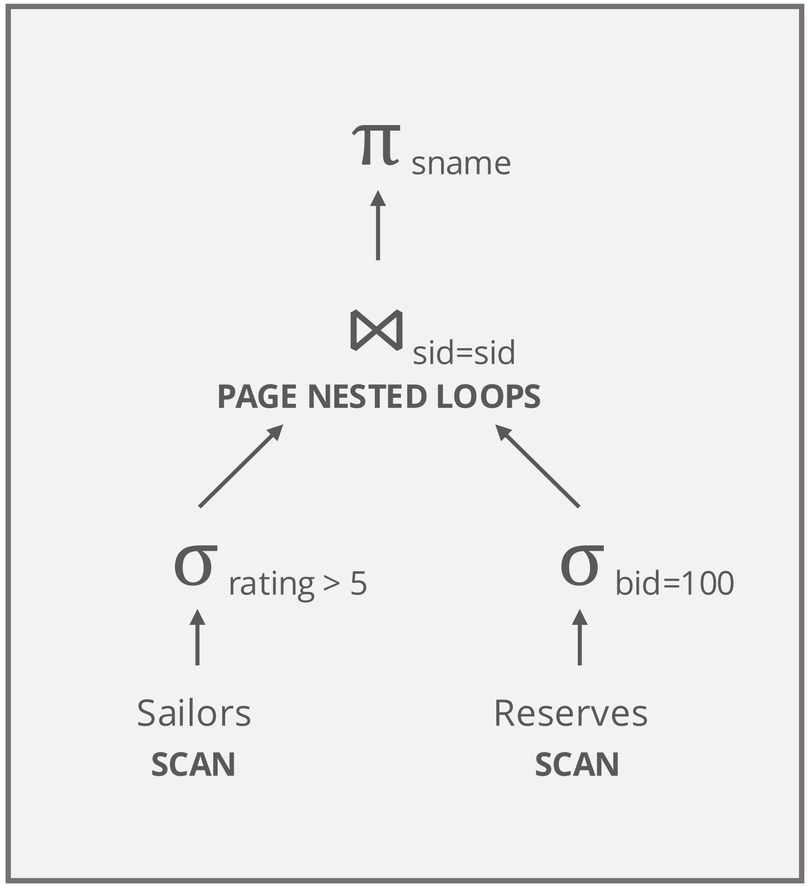
Uniformly distributed across 100 boat values

Total = 1000 + (1000 / 100) · 500

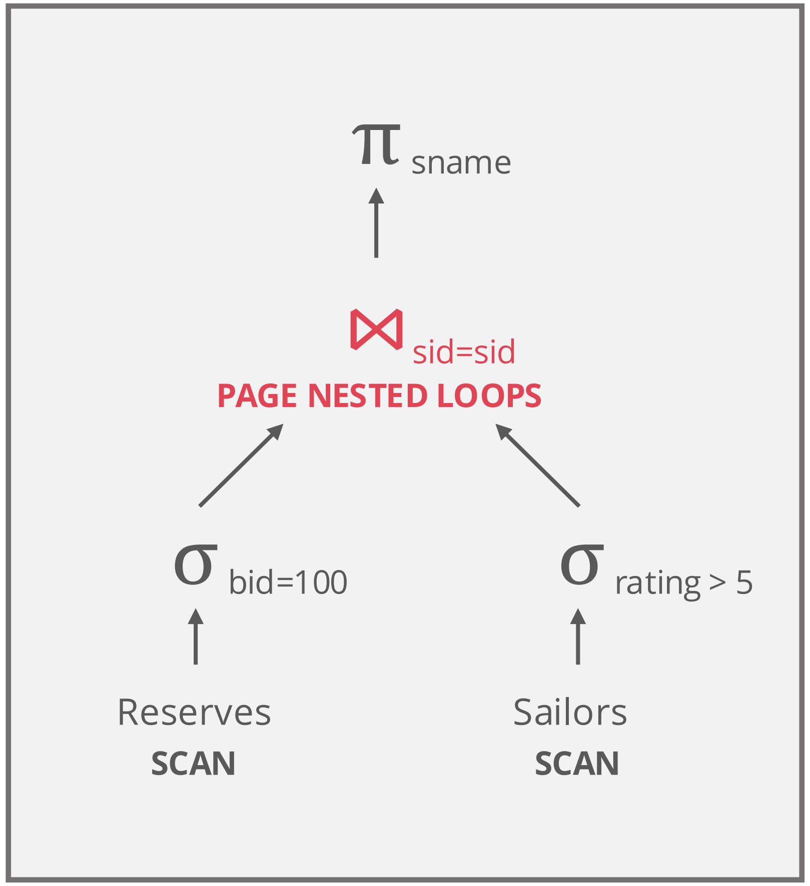
= **6000 I/Os**



Decision 3



250,500 I/Os



6000 I/Os

So Far, We've Tried

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

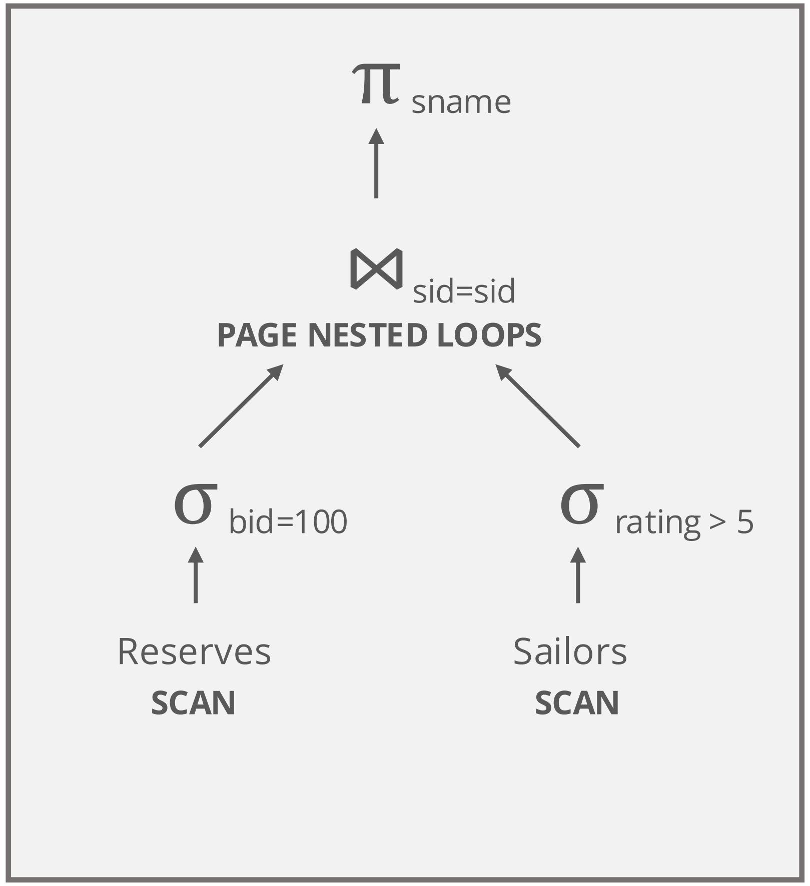
Join ordering (6000)

Next: materialisation

Materialising Inner Loops

If you recall, selection pushdown on the right doesn't help because it is done on the fly.

What if we materialize the result after the selection?



6000 I/Os

Query Plan 5 Cost

Cost estimation:

Scan Reserves: **1000 I/Os**

Scan Sailors: **500 I/Os**

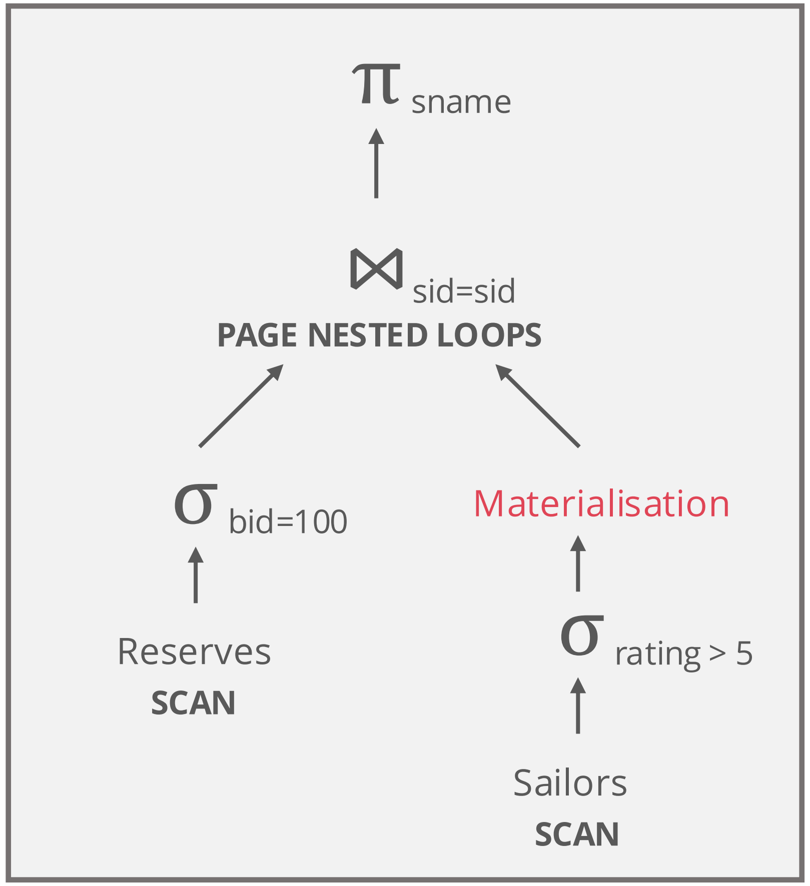
Materialise temp table T1: ??? **I/Os**

For each page of Reserves for bid 100
    Scan T1: ??? **I/Os**

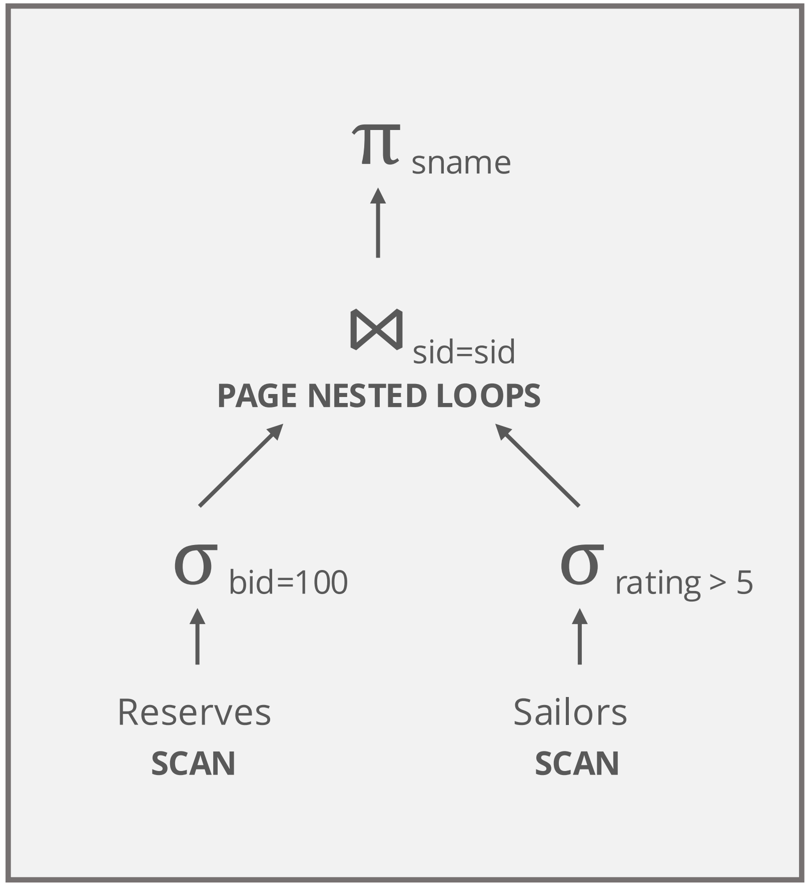
Total = 1000 + 500 + ??? + 10 · ???

Ratings from 1 to 10, uniformly distributed

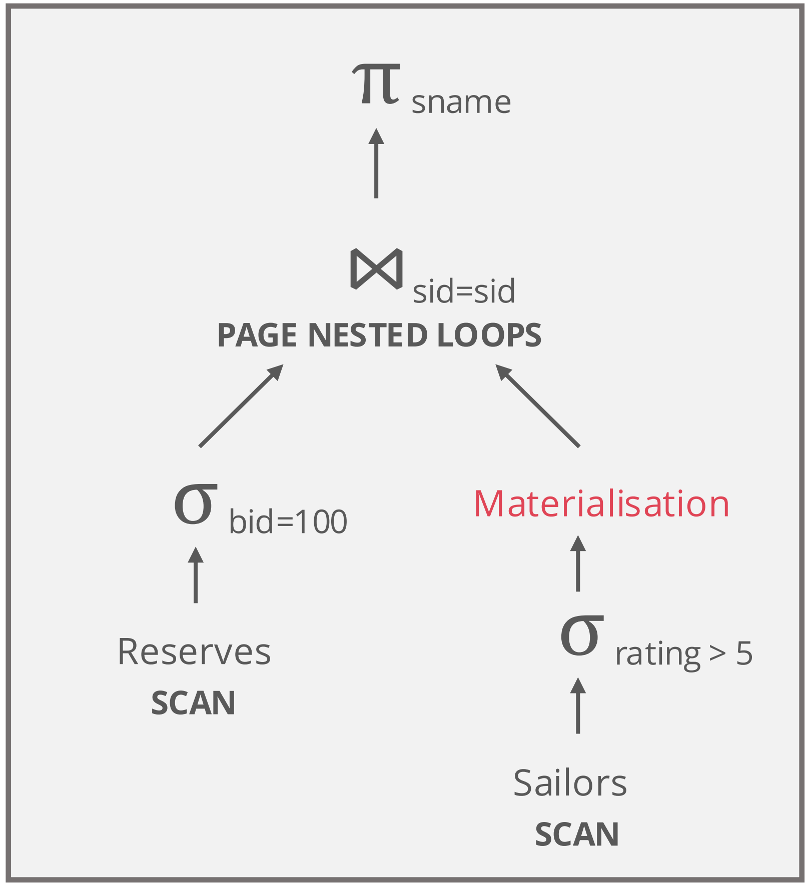
Total = 1000 + 500 + 250 + 10 · 250 = **4250 I/Os**



Decision 4



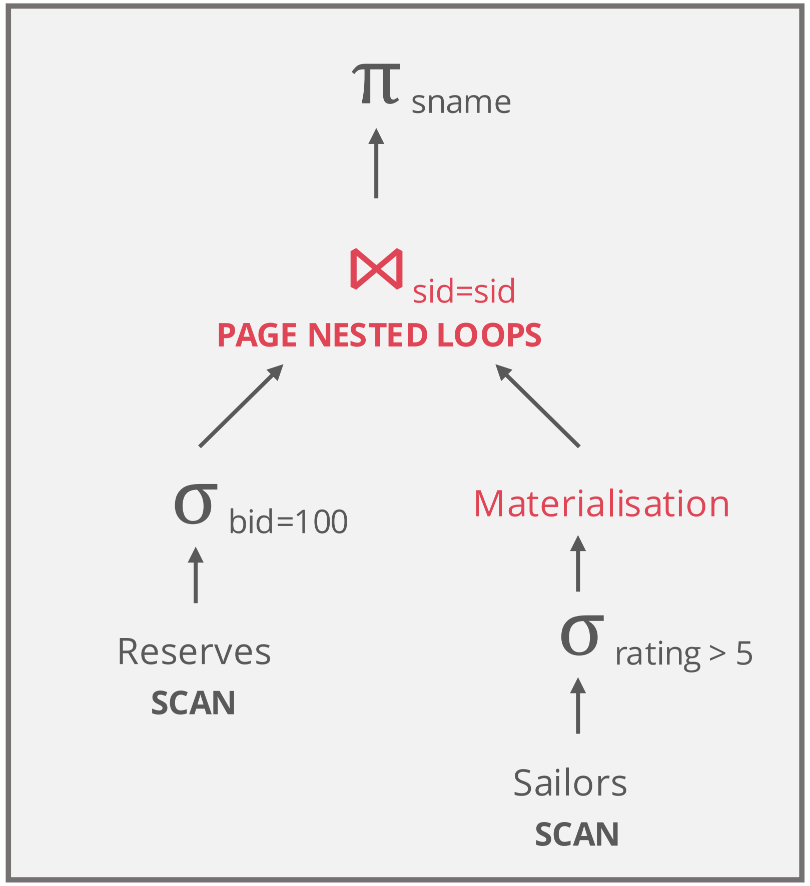
6000 I/Os



4250 I/Os

Join Ordering Again

Let's try flipping the join order again with materialisation trick



4250 I/Os

Query Plan 6 Cost

Cost estimation:

Scan Sailors: **500 I/Os**

Scan Reserves: **1000 I/Os**

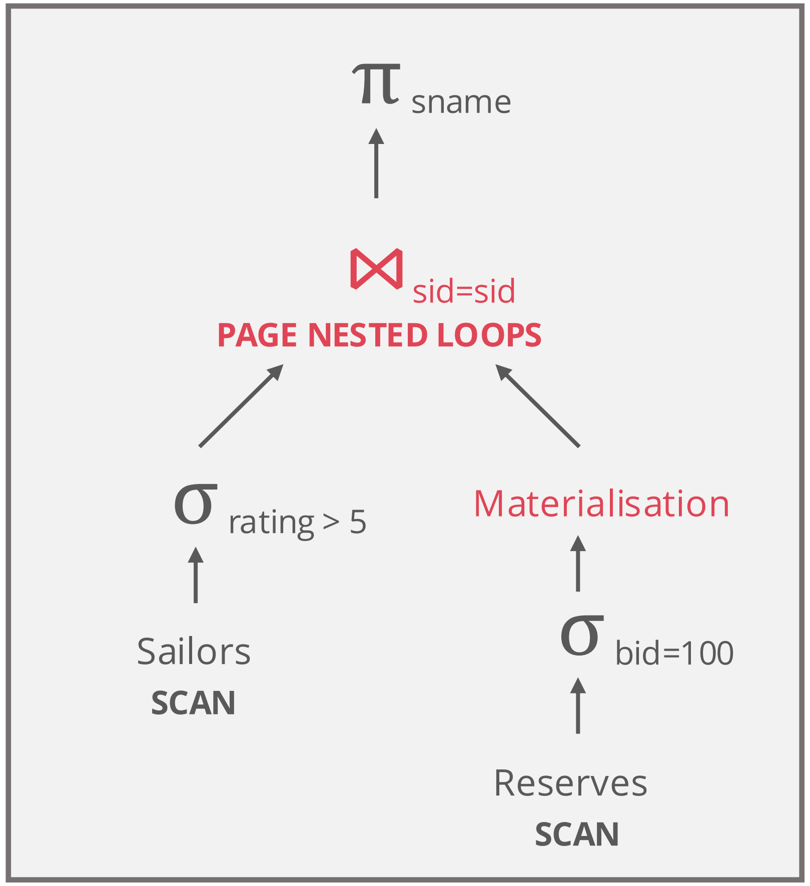
Materialise temp table T1: ??? **I/Os**

For each page of high-rated Sailors
Scan T1: ??? **I/Os**

Total = 500 + 1000 + ??? + 250 · ???

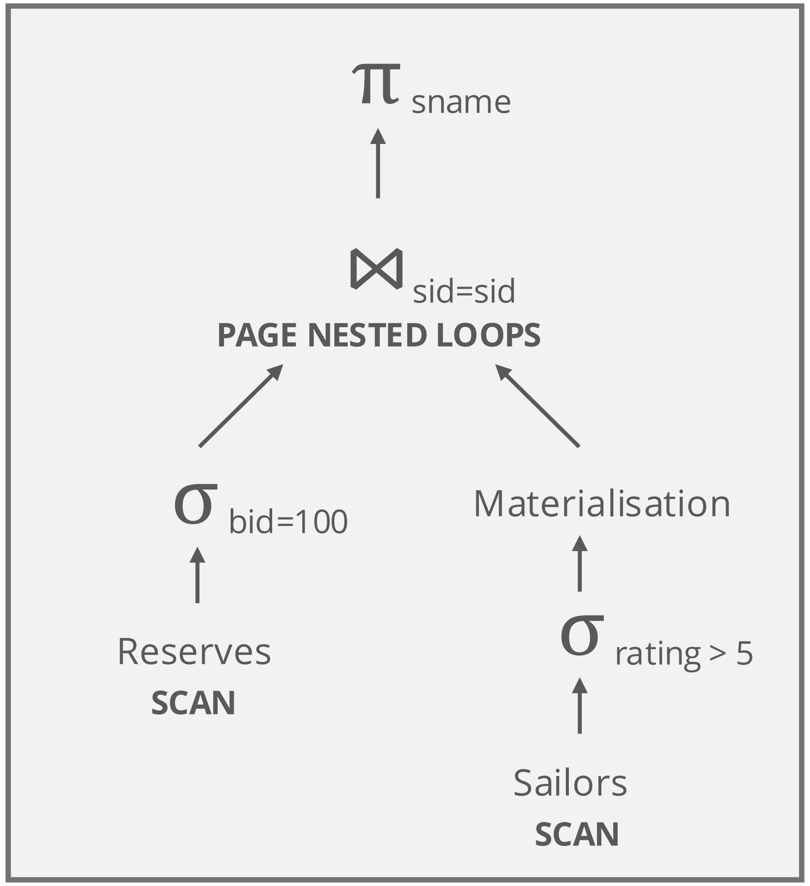
100 boat values, uniformly distributed

Total = 500 + 1000 + 10 + 250 · 10 = **4010 I/Os**

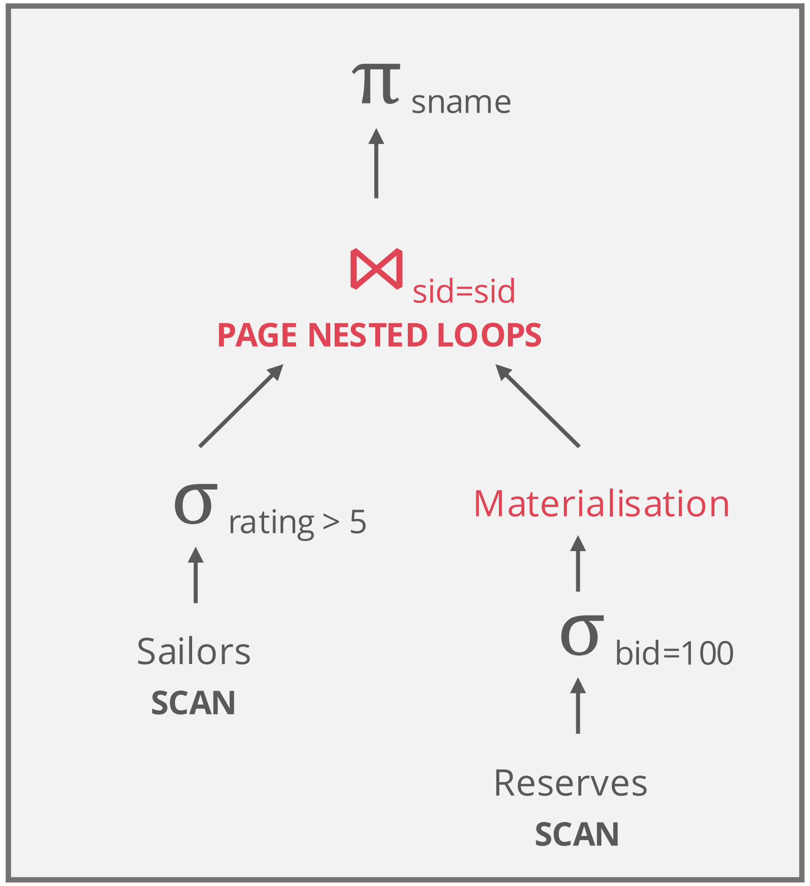


π_{sname}
$\bowtie_{\text{sid=sid}}$
PAGE NESTED LOOPS
$\sigma_{\text{rating > 5}}$
Materialisation
Sailors
SCAN
$\sigma_{\text{bid=100}}$
Reserves
SCAN

Decision 5



4250 I/Os



4010 I/Os

So Far, We've Tried

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

Join ordering (6000)

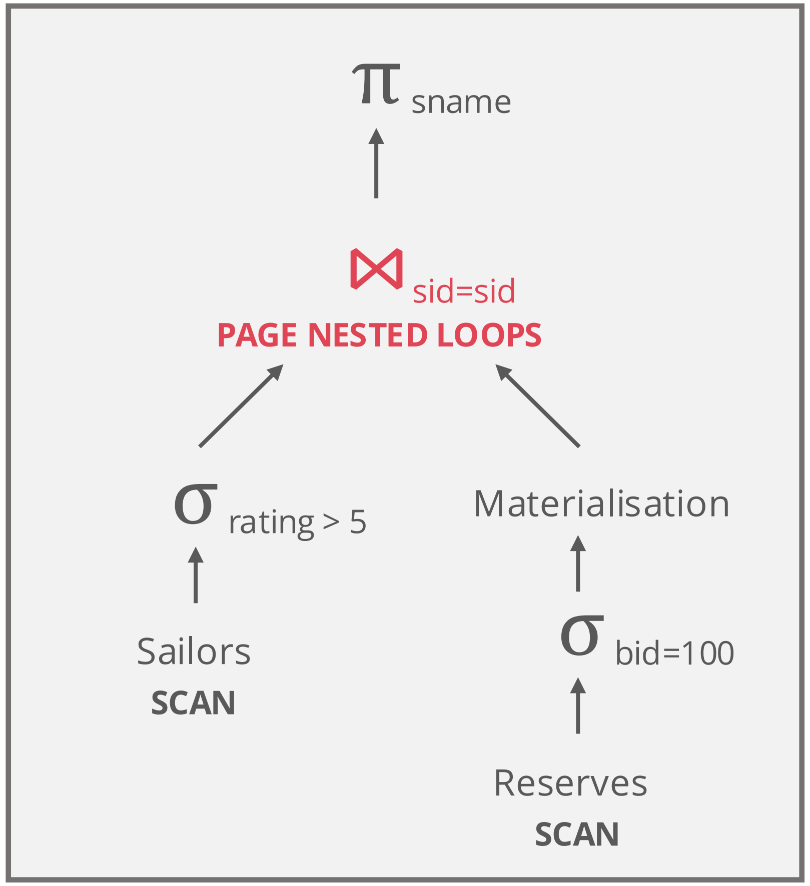
Materialising inner loop (4250)

Join ordering again with materialisation (4010)

Next: sort merge join

Join Algorithm

What if change the join algorithm?



QUERY PLAN 7 COST

Cost estimation with 5 buffers:

Scan Sailors: **500 I/Os**

Scan Reserves: **1000 I/Os**

Sort high-rated Sailors: ??? **I/Os**

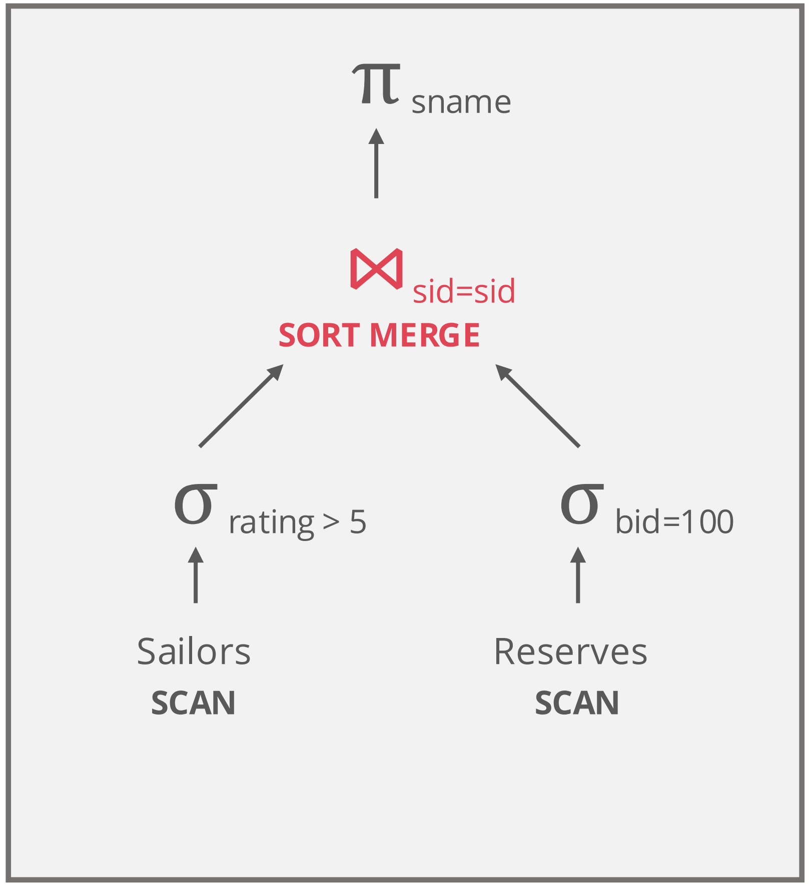
Pass 0 doesn't do read I/O, just gets input from select

Sort reservations for boat 100 : ??? **I/Os**

Pass 0 doesn't do read I/O, just gets input from select

How many passes for each sort?

Merge: (10 + 250) = **260 I/Os**



Query Plan 7 Cost, Part 2

External sort with 5 buffers:

$1 + \lceil \log_4(10/5) \rceil = 2$ passes for Reserves

Pass 0 = **10** to write

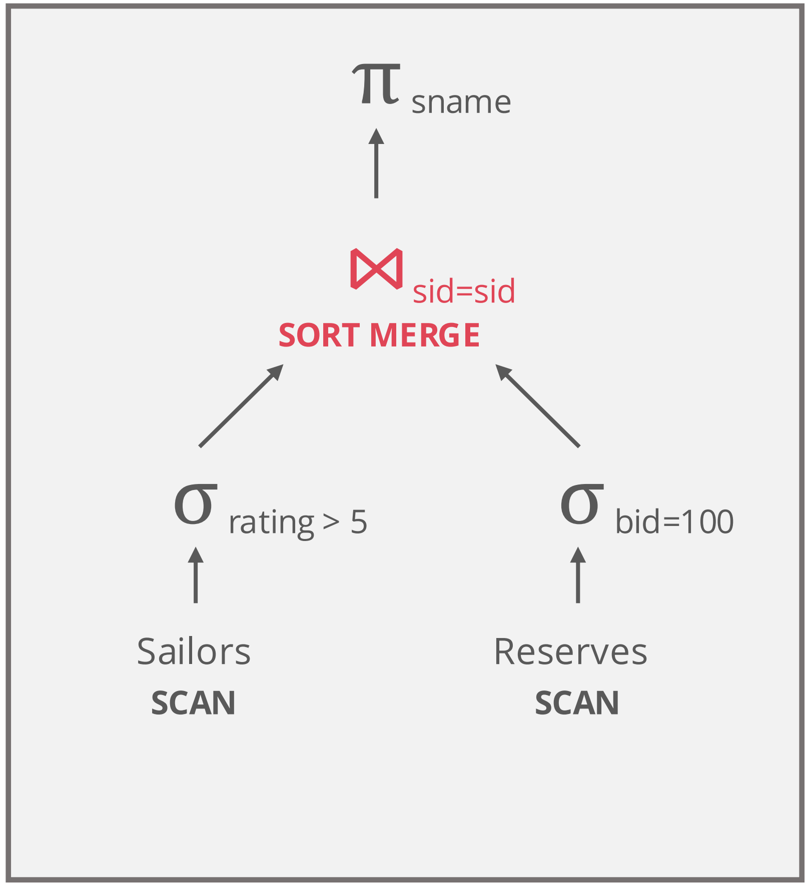
Pass 1 = 2 · 10 = **20** to read/write

$1 + \lceil \log_4(250/5) \rceil = 4$ passes for Sailors

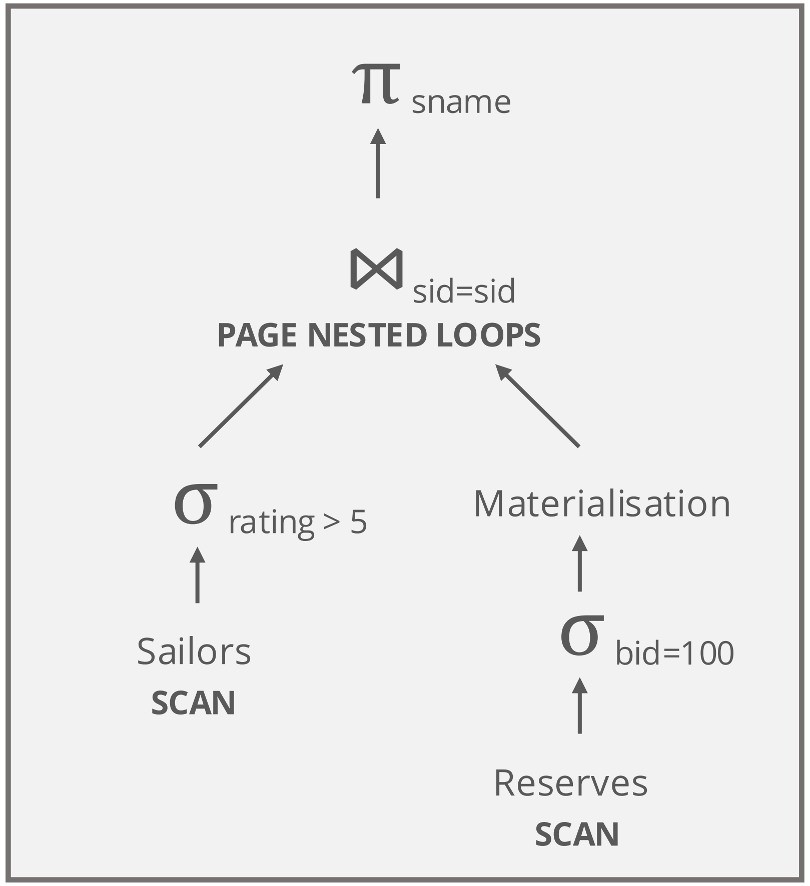
Pass 0 = **250** to write

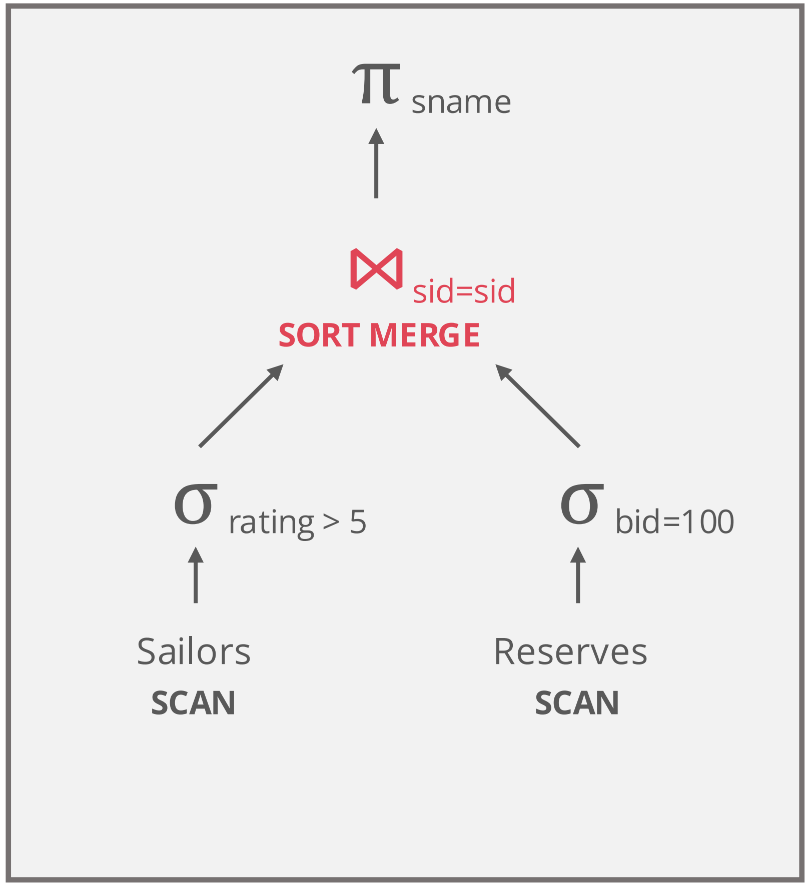
Pass 1, 2, 3 = 2 · 250 = **500** to read/write

Total = scan both (1000 + 500) +
sort Reserves (10 + 20) +
sort Sailors (250 + 3 · 500) + merge (260) = **3540 I/Os**



Decision 6





4010 I/Os

3540 I/Os

So Far, We've Tried

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

Join ordering (6000)

Materialising inner loop (4250)

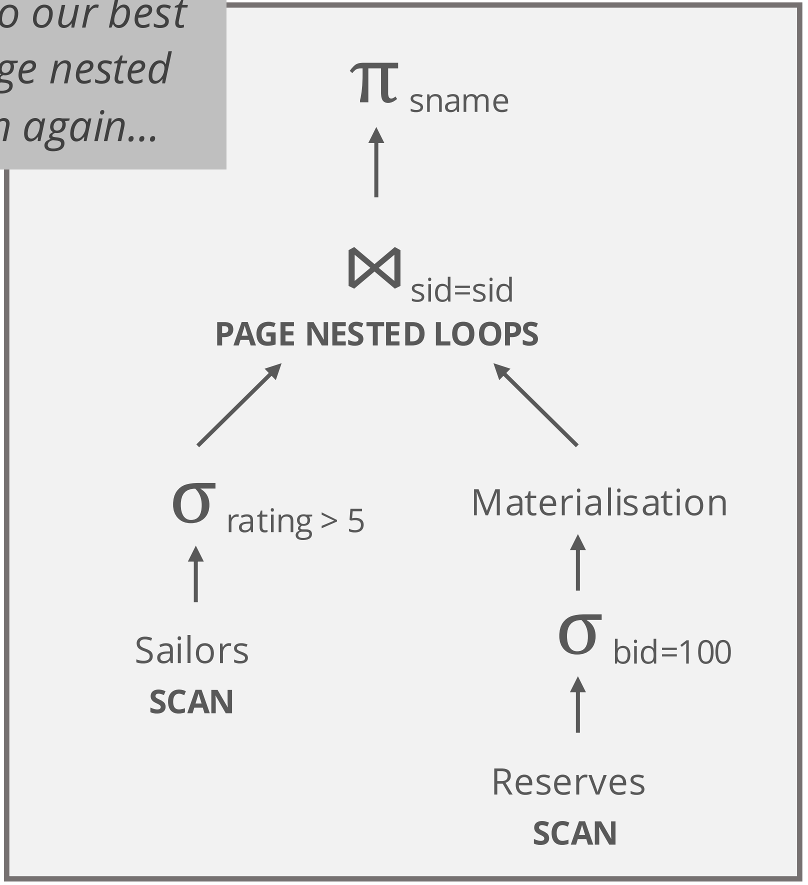
Join ordering again with materialisation (4010)

Sort merge join (3540)

Next: block nested loops join

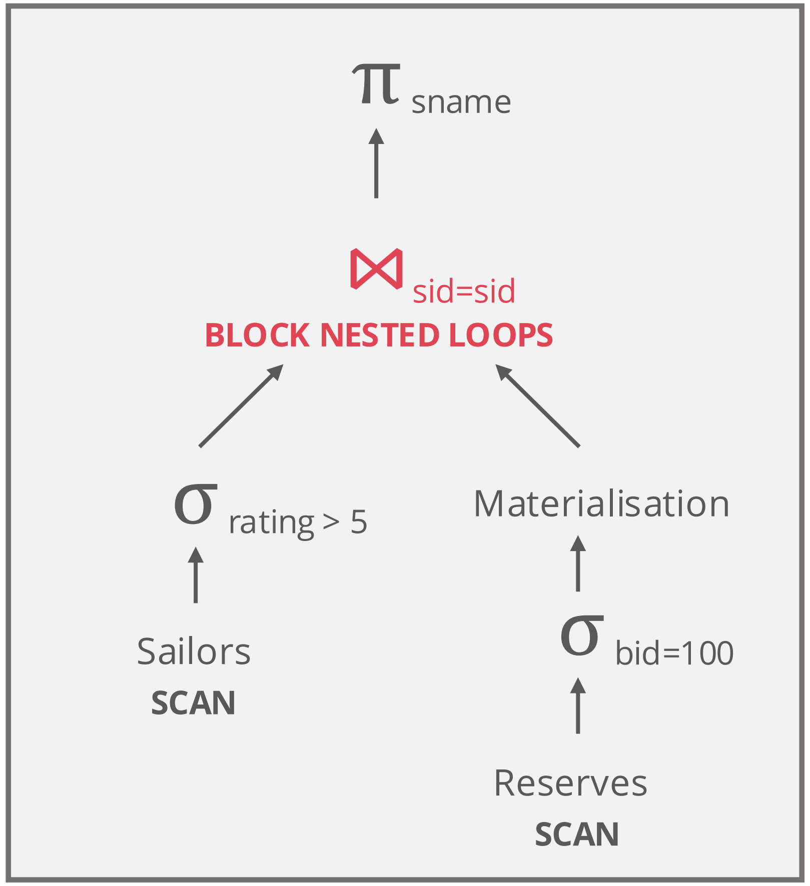
Join Algorithm Again, Again

Returning to our best (so far) page nested loops plan again…



4010 I/Os

(and sort merge at 3510 I/Os)



Cost?

QUERY PLAN 8 COST

Cost estimation with 5 buffers:

Scan Sailors: **500 I/Os**

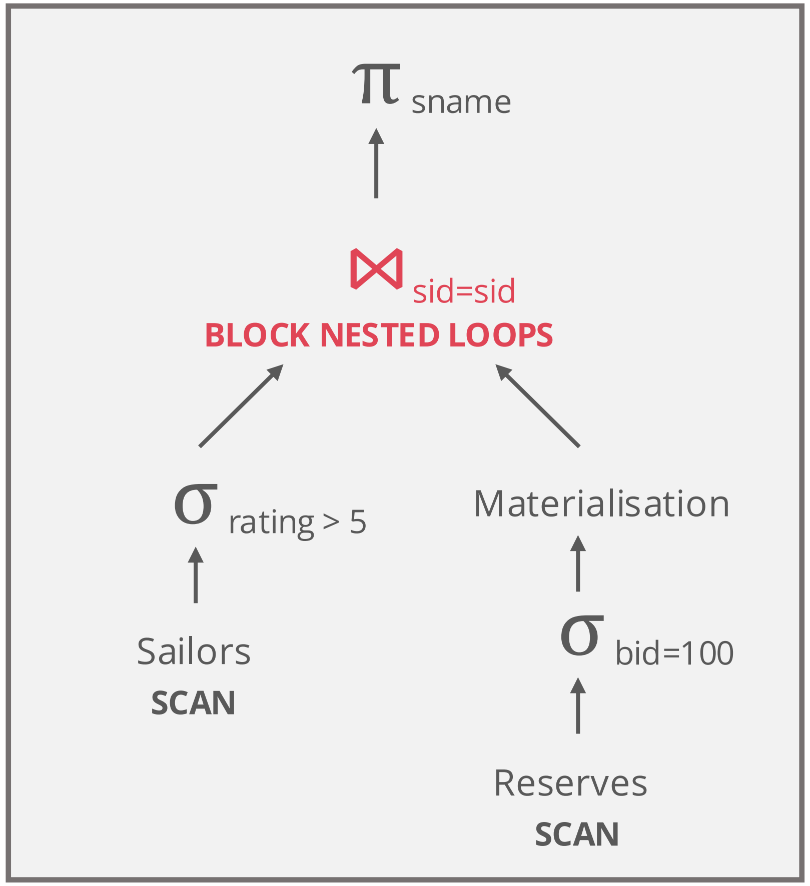
Scan Reserves: **1000 I/Os**

Write temp table T1: **10 I/Os**

For each block of high-rated Sailors
    Iterate over T1: ??? · **10 I/Os**

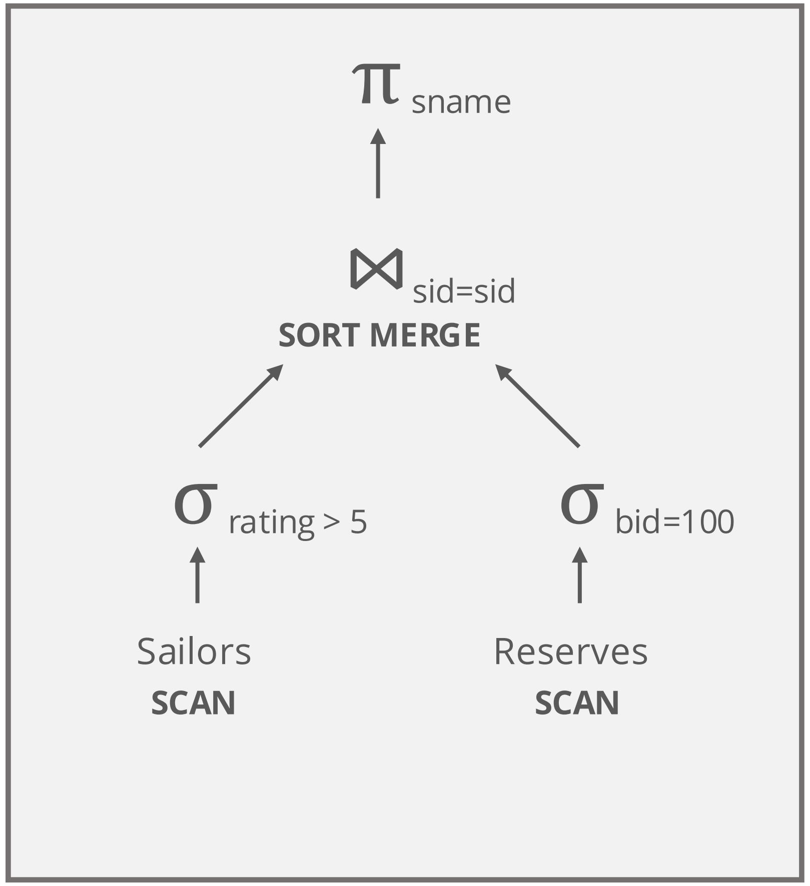
Block size = 3, #blocks (???) = ceil(250/3) = 84

Sailors tuples pipelined from select

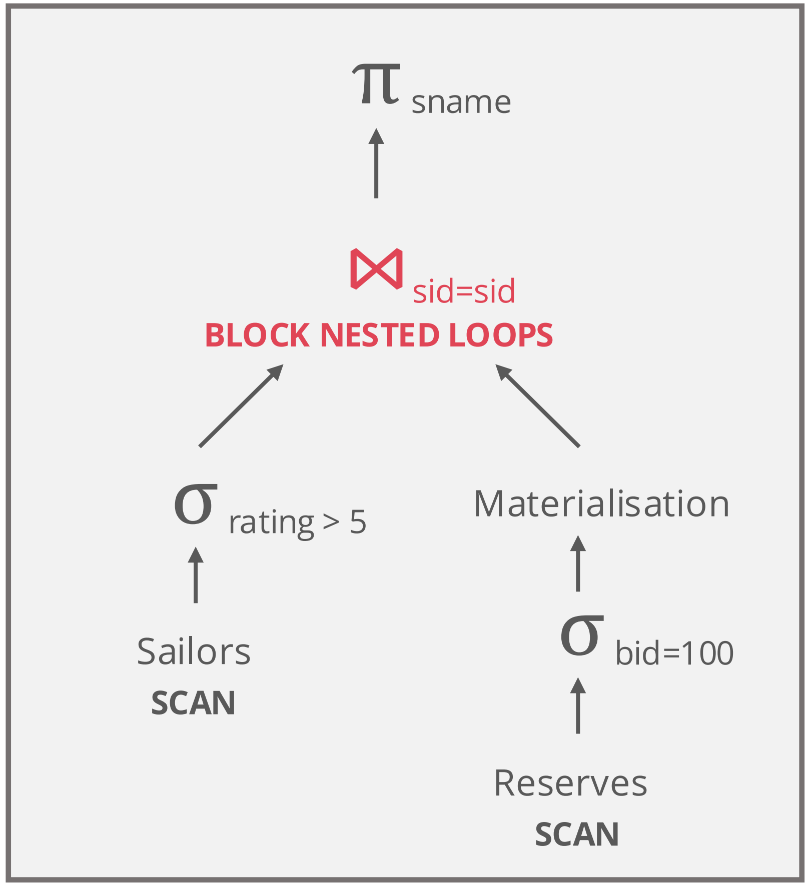


Total = scan both (500 + 1000) + write T1 (10) + BNLJ (84 · 10) = 2350 I/Os

Decision 7



3540 I/Os



2350 I/Os

So Far, We've Tried

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

Join ordering (6000)

Materialising inner loop (4250)

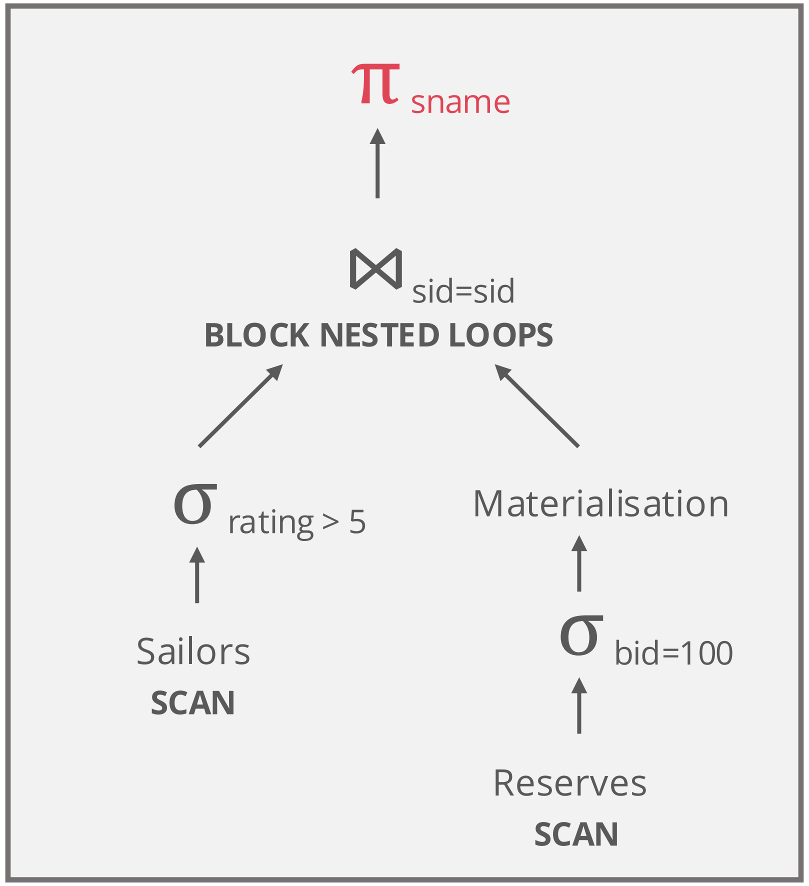
Join ordering again with materialisation (4010)

Sort merge join (3540)

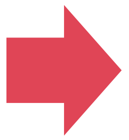
Block nested loops join (2350)

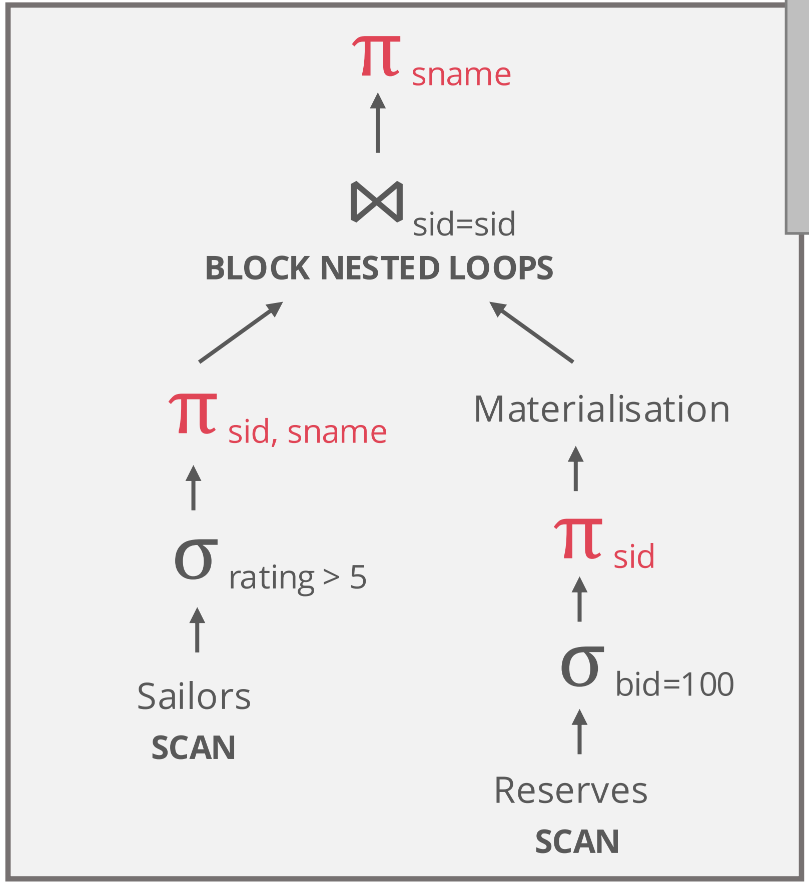
Next: projection cascade

PROJECTION CASCADE & PUSHDOWN



2350 I/Os





Super small! Just one page – can make this the outer relation in BNLJ

1 page
(4 bytes per tuple)

10 pages
(40 bytes per tuple)

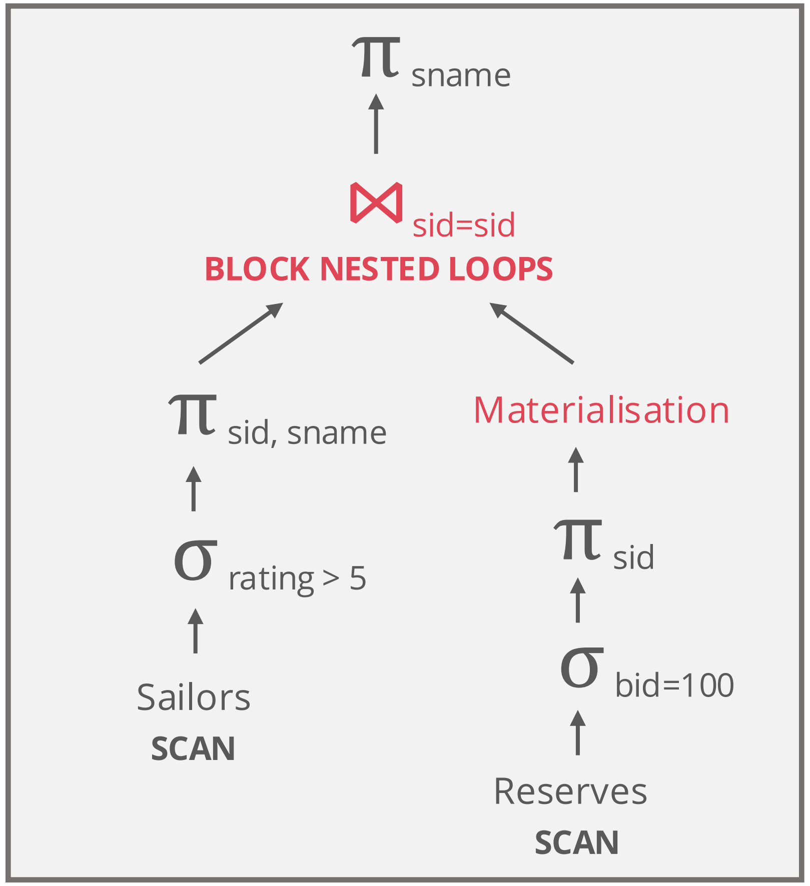
1000 pages
(40 bytes per tuple)

WITH JOIN REORDERING, NO MAT.

Will try reordering the join again

Will also skip on the materialisation for this

- Convince yourself that it doesn't help



Query Plan 9 Cost

Cost estimation with 5 buffers:

Scan Reserves: **1000 I/Os**

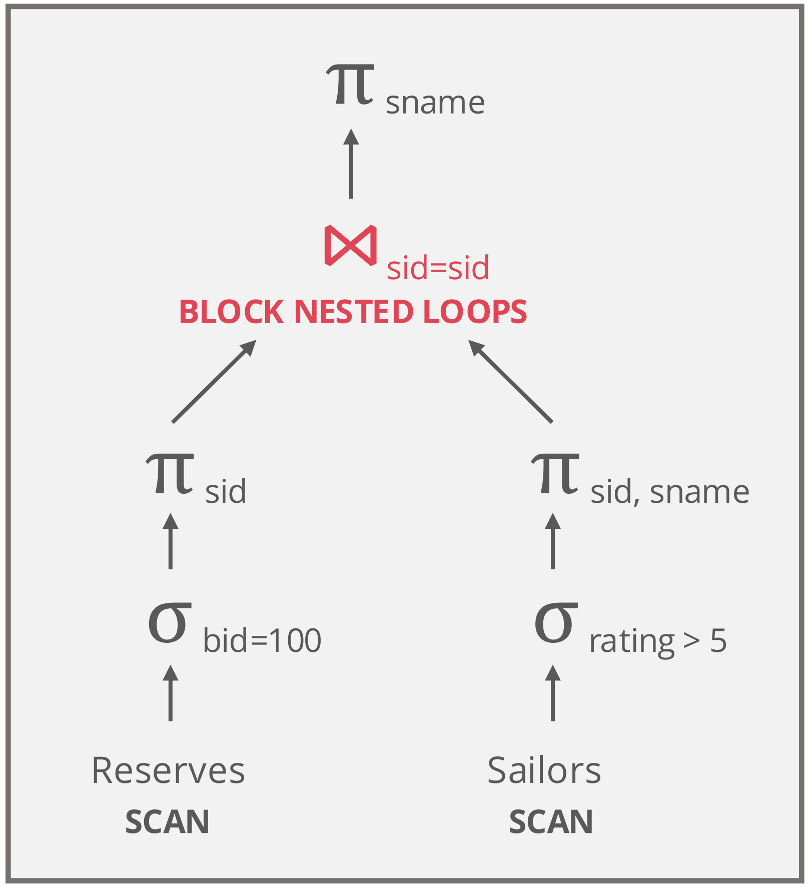
For each block of sids that rented boat 100

Iterate over Sailors: ??? · **500 I/Os**

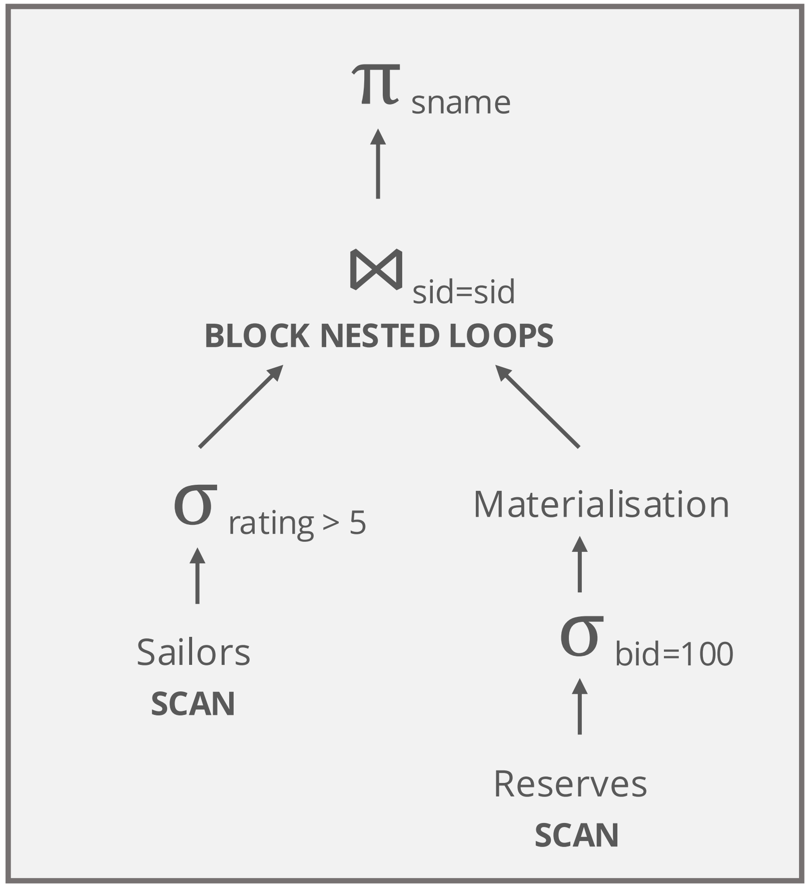
Recall: Reserves tuple is 40B, assume sid is 4B

10 pages down to 1 page

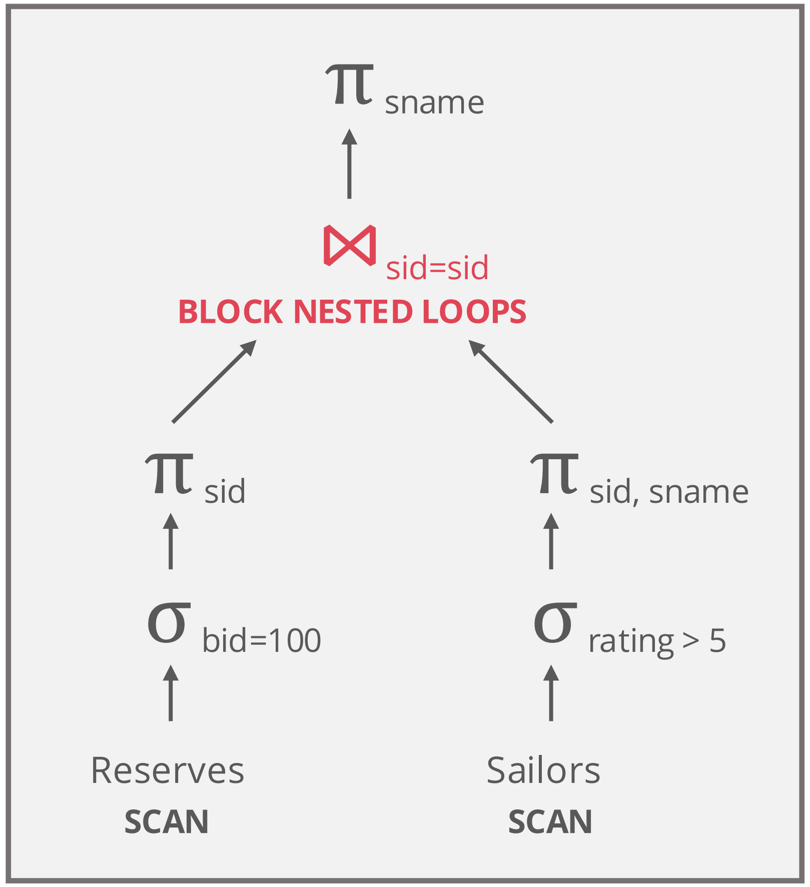
Total = 1000 + 1 · 500 = **1500 I/Os**



Decision 8



2350 I/Os



1500 I/Os

Cannot do better w/o indexes. Why?

So Far, We've Tried

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

Join ordering (6000)

Materialising inner loop (4250)

Join ordering again with materialisation (4010)

Sort merge join (3540)

Block nested loops join (2350)

Projection cascade, plus reordering again (1500)

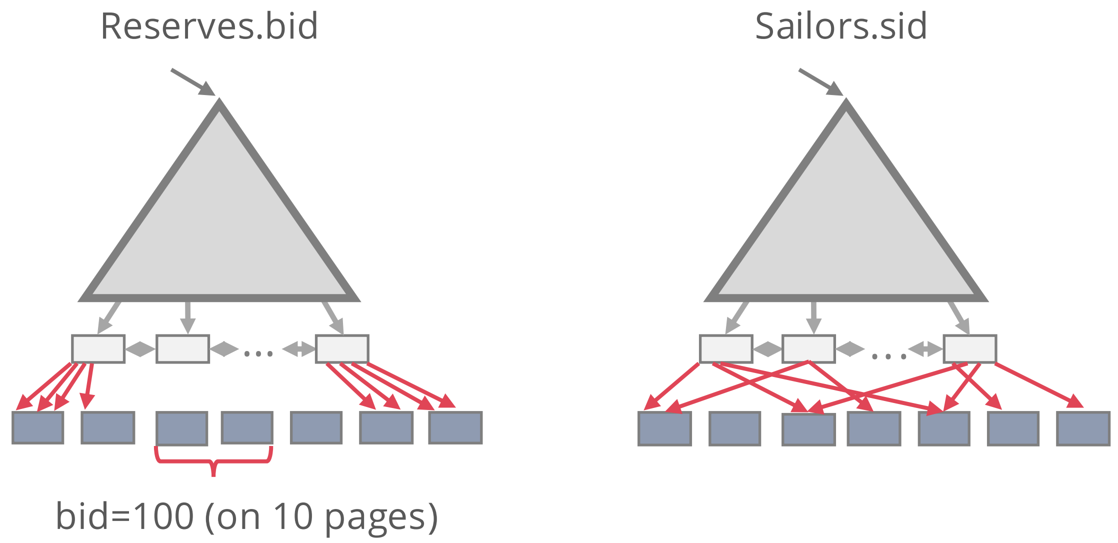
Next: indexes

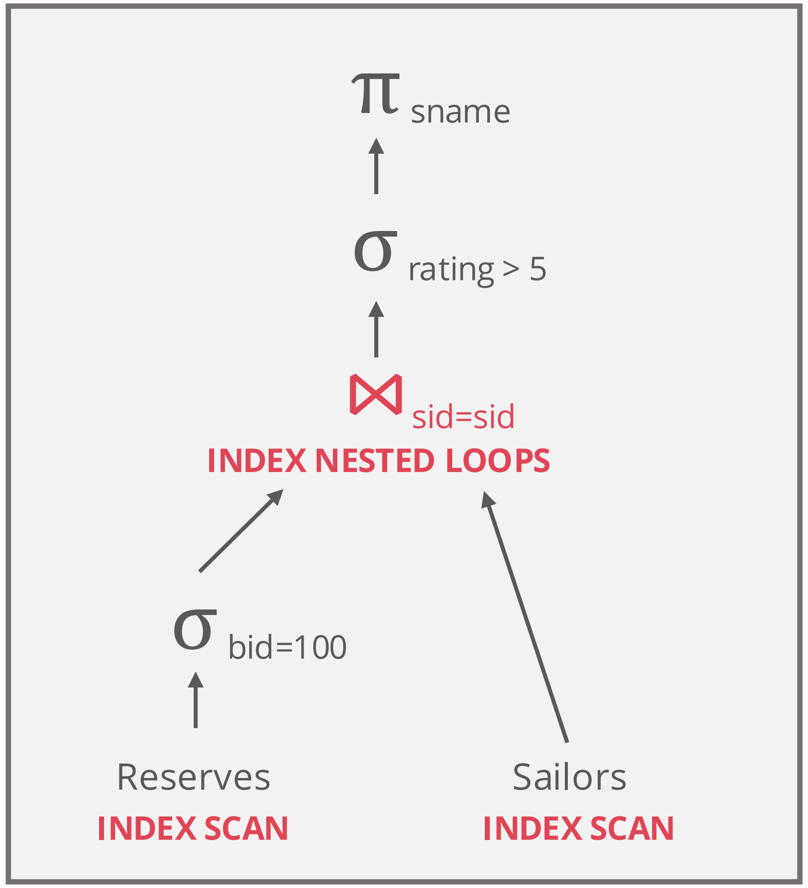
How About Indexes?

Indexes

- Clustered tree index on Reserves.bid
- Unclustered tree index on Sailors.sid

Assume indexes fit in memory





How About Indexes?

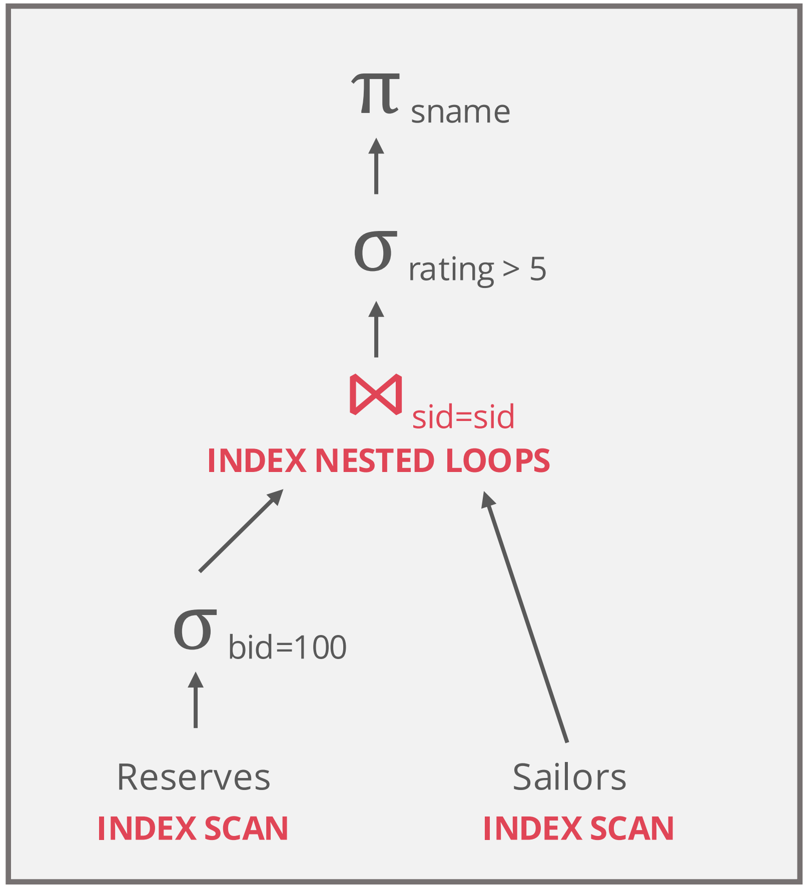
Notes about our query plan:

No projection pushdown to left for π_{sid}

Projecting out unnecessary fields from outer relation of INLJ does not make an I/O difference (still doing things per tuple)

No selection pushdown to right for $\sigma_{rating > 5}$

Does not affect Sailors.sid index lookup (I/O cost remains the same)



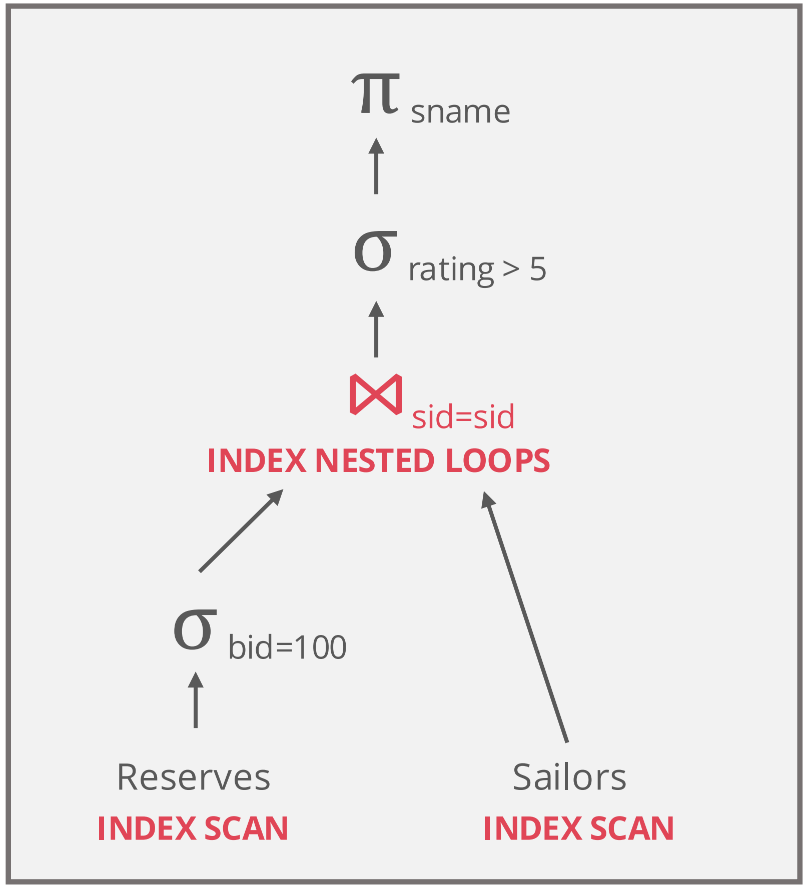
How About Indexes?

With clustered index on bid of Reserves,
we access how many pages of Reserves?

100,000/100=**1000** tuples on 1000/100=**10** pages

Join column sid is a key for Sailors

At most one matching tuple using unclustered index on sid



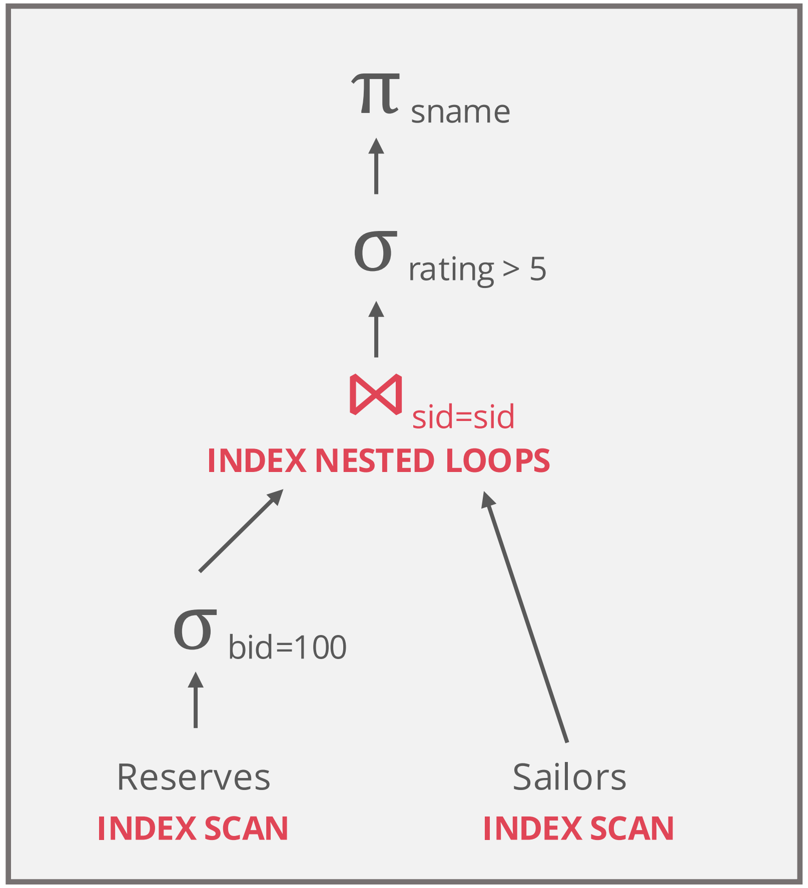
How About Indexes?

With clustered index on bid of Reserves,
we access how many pages of Reserves?

100,000/100=**1000** tuples on 1000/100=**10** pages

Foreach such Reserves tuple (1000 tuples)
Get matching Sailors tuple (1 I/O)

Total = 10 + 1000 · 1 = **1010 I/Os**



The Entire Story

Basic page nested loops (500,500)

Selection pushdown on left (250,500)

More selection pushdown on right (250,500)

Join ordering (6000)

Materialising inner loop (4250)

Join ordering again with materialisation (4010)

Sort merge join (3540)

Block nested loops join (2350)

Projection cascade, plus reordering again (1500)

Index Nested Loops Join (1010)

Still only a subset of the possible plans for this query!!!