Bloom filters

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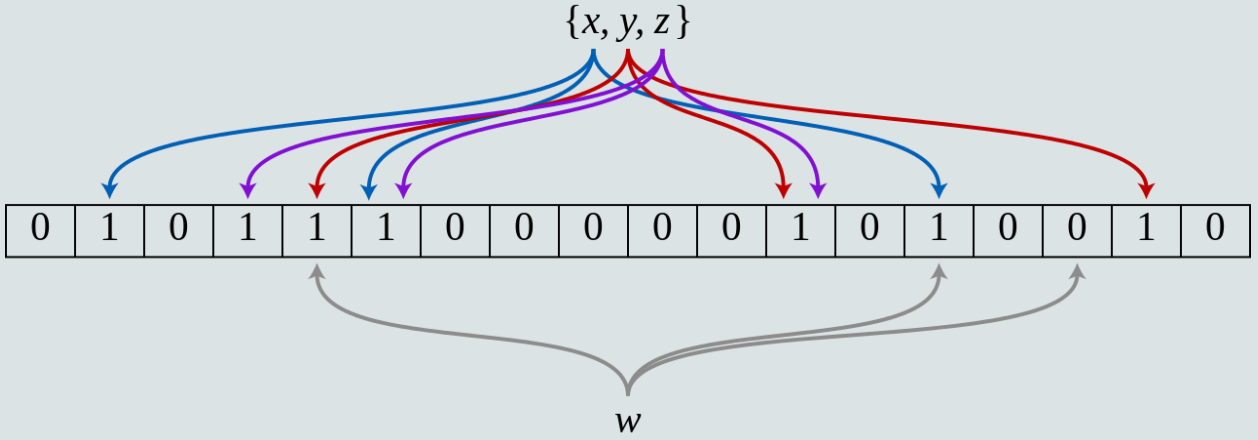
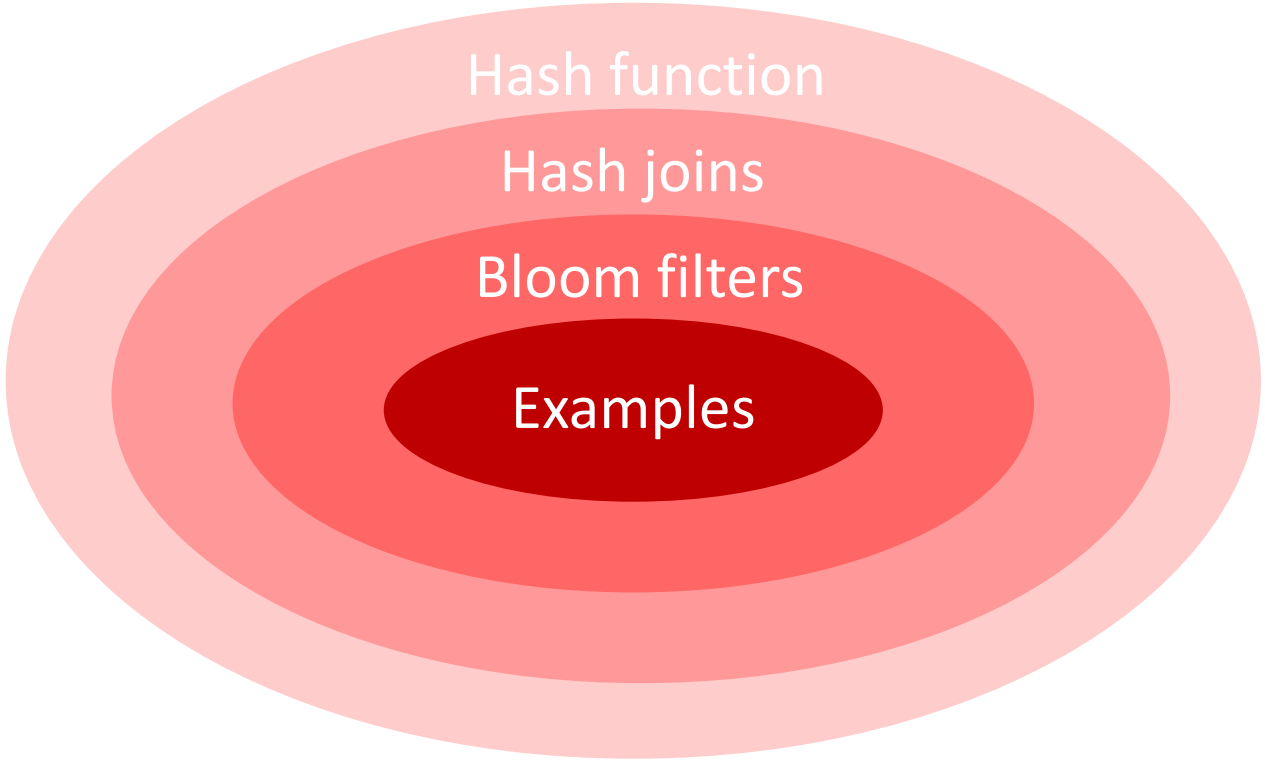
Real World Performance team
Database Server Technologies



Agenda



Hash joins and Bloom filters

- Bloom filters (BF) introduced in 10gR2
  - Enable CBO to “filter early” in hash joins
  - Used automatically, visible in execution plan
- Implemented to speed up large parallel hash joins (DWH/BI)
  - BF’s prevent unnecessary row-transport between parallel query slave sets
- As of 11.2.0.4 BF’s may also show up in serial plans

Hash joins explained

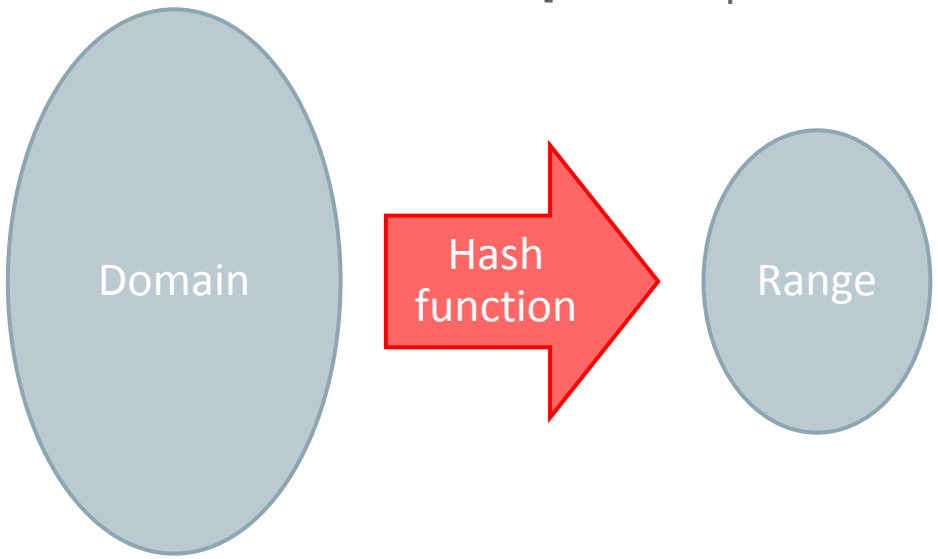
```
select *
from emp e, dept d
where d.deptno = e.deptno
```

```
-----------------------------------
| Id  | Operation          | Name |
-----------------------------------
|   0 | SELECT STATEMENT   |      |
|*  1 |  HASH JOIN         |      |
|   2 |   TABLE ACCESS FULL| DEPT |
|   3 |   TABLE ACCESS FULL| EMP  |
-----------------------------------
Predicate Information
---------------------------------------
  1 - access("D"."DEPTNO"="E"."DEPTNO")
```

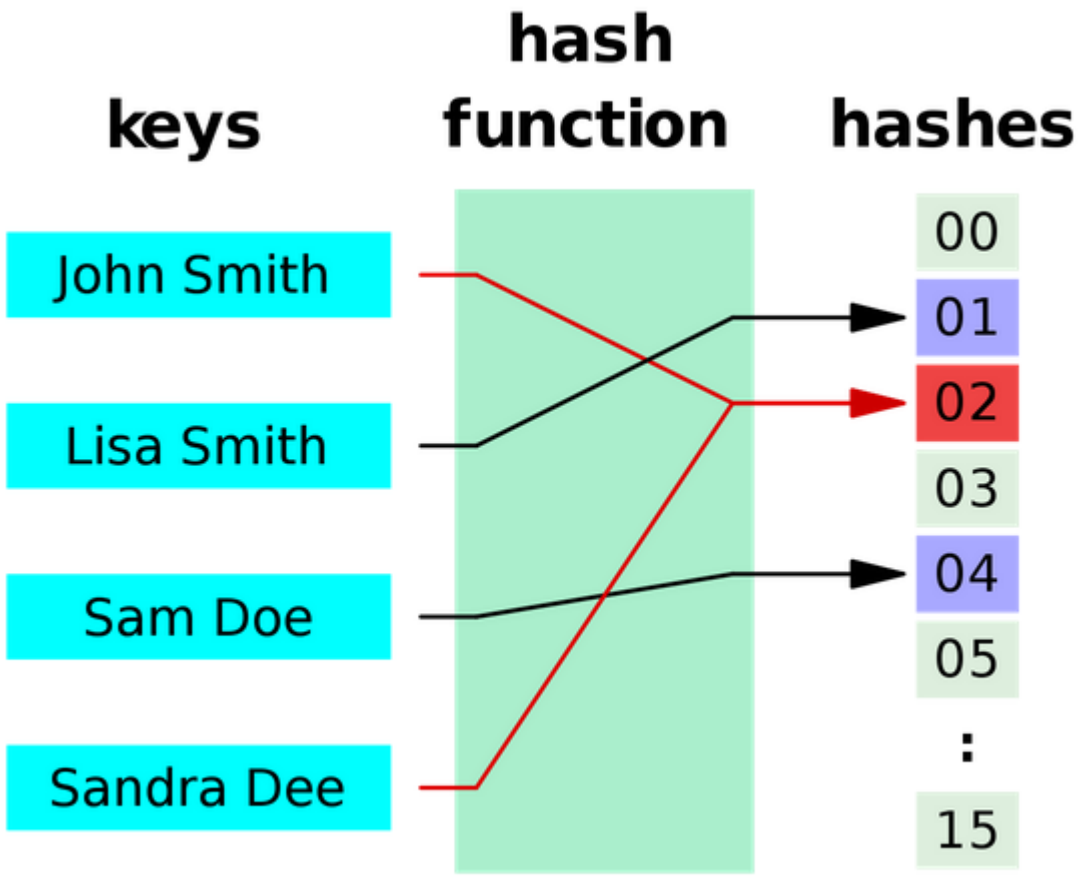
What is a hash-function?

Digital data
Byte strings of any length

"Hash values"
Offset between
[0..some-power-of-2 minus 1]



- Hash function application is cheap
- Hash values are typically "evenly distributed" in range
  - Irrespective of distribution of input values
- Collisions can occur
  - Two domain values map to same hash value
  - Since #domain >> #range



Phase 1: build hash table (DEPT)

```
select *
from emp e, dept d
where d.deptno = e.deptno
```

```
-----------------------------------
| Id  | Operation           | Name |
-----------------------------------
|   0 | SELECT STATEMENT    |      |
|*  1 |  HASH JOIN          |      |
|   2 |   TABLE ACCESS FULL | DEPT |
|   3 |   TABLE ACCESS FULL | EMP  |
-----------------------------------
Predicate Information
-----------------------------------
  1 - access("D"."DEPTNO"="E"."DEPTNO")
```

scan

DEPTNO	DNAME	LOC
1	ACCOUNTING	NEW YORK
2	RESEARCH	DALLAS
3	SALES	CHICAGO
4	OPERATIONS	BOSTON

Apply hash function to DEPT.DEPTNO to find in which bucket to store

Build phase

Bucketized hash-table in PGA memory

Phase 1 done

```
select *
from emp e, dept d
where d.deptno = e.deptno
```

```
-----------------------------------
| Id  | Operation          | Name |
-----------------------------------
|   0 | SELECT STATEMENT   |      |
|*  1 |  HASH JOIN         |      |
|   2 |   TABLE ACCESS FULL| DEPT |
|   3 |   TABLE ACCESS FULL| EMP  |
-----------------------------------
Predicate Information
---------------------------------------
  1 - access("D"."DEPTNO"="E"."DEPTNO")
```

Phase 2: probe 2nd table (EMP)

```
select *
from emp e, dept d
where d.deptno = e.deptno
```

```
-------------------------------------
| Id  | Operation           | Name  |
-------------------------------------
|   0 | SELECT STATEMENT    |       |
|*  1 |  HASH JOIN          |       |
|   2 |   TABLE ACCESS FULL | DEPT  |
|   3 |   TABLE ACCESS FULL | EMP   |
-------------------------------------
Predicate Information
-------------------------------------
  1 - access("D"."DEPTNO"="E"."DEPTNO")
```

scan

EMPNO	ENAME	JOB	MGR	HIREDATE	SAL	COMM	DEPTNO
1	SMITH	CLERK	7902	17-DEC-80	800		2
2	ALLEN	SALESMAN	7698	20-FEB-81	1600	300	3
3	WARD	SALESMAN	7698	22-FEB-81	1250	500	4
4	JONES	MANAGER	7839	02-APR-81	2975		5
5	MARTIN	SALESMAN	7698	28-SEP-81	1250	1400	6
6	BLAKE	MANAGER	7839	01-MAY-81	2850		7
7	CLARK	MANAGER	7839	09-JUN-81	2450		8
8	SCOTT	ANALYST	7566	19-APR-87	3000		9
9	KING	PRESIDENT		17-NOV-81	5000		10
10	TURNER	SALESMAN	7698	08-SEP-81	1500	0	11
11	ADAMS	CLERK	7788	23-MAY-87	1100		12
12	JAMES	CLERK	7698	03-DEC-81	950		13
13	FORD	ANALYST	7566	03-DEC-81	3000		14
14	MILLER	CLERK	7782	23-JAN-82	1300		15

Apply hash function to EMP.DEPTNO to find in which bucket to probe for matching DEPT record
If match found: join and return row

Probe phase

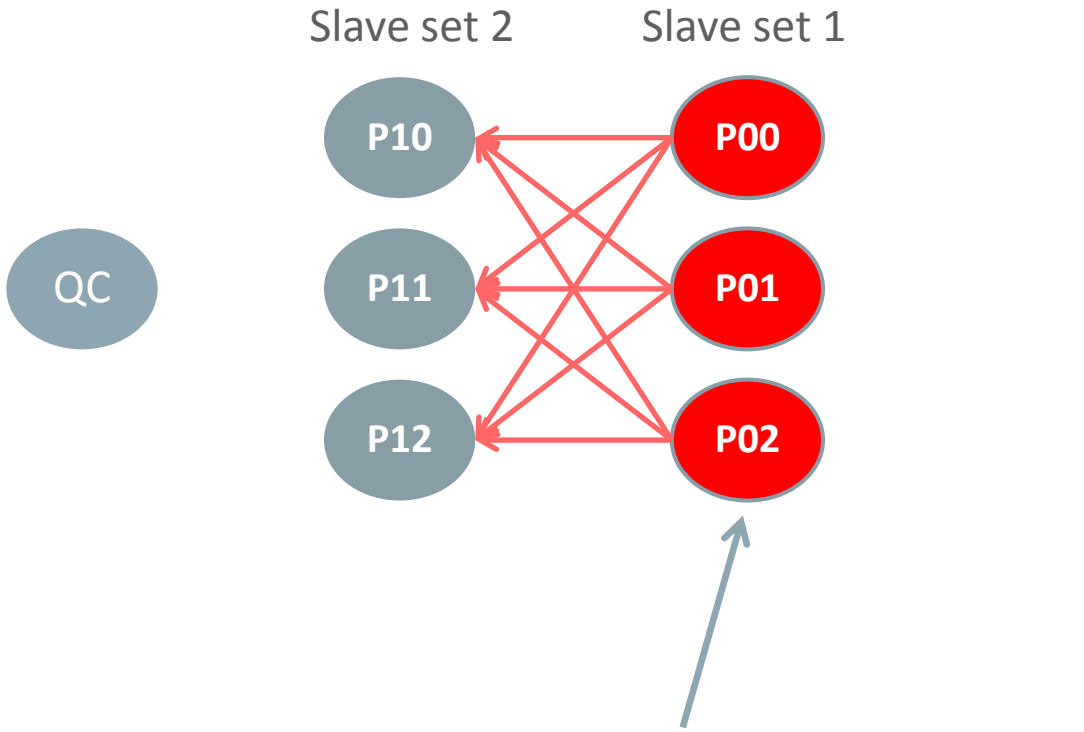
Hash joins parallel execution plan

```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL | DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL | EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```

Assuming DOP = 3

Build phase

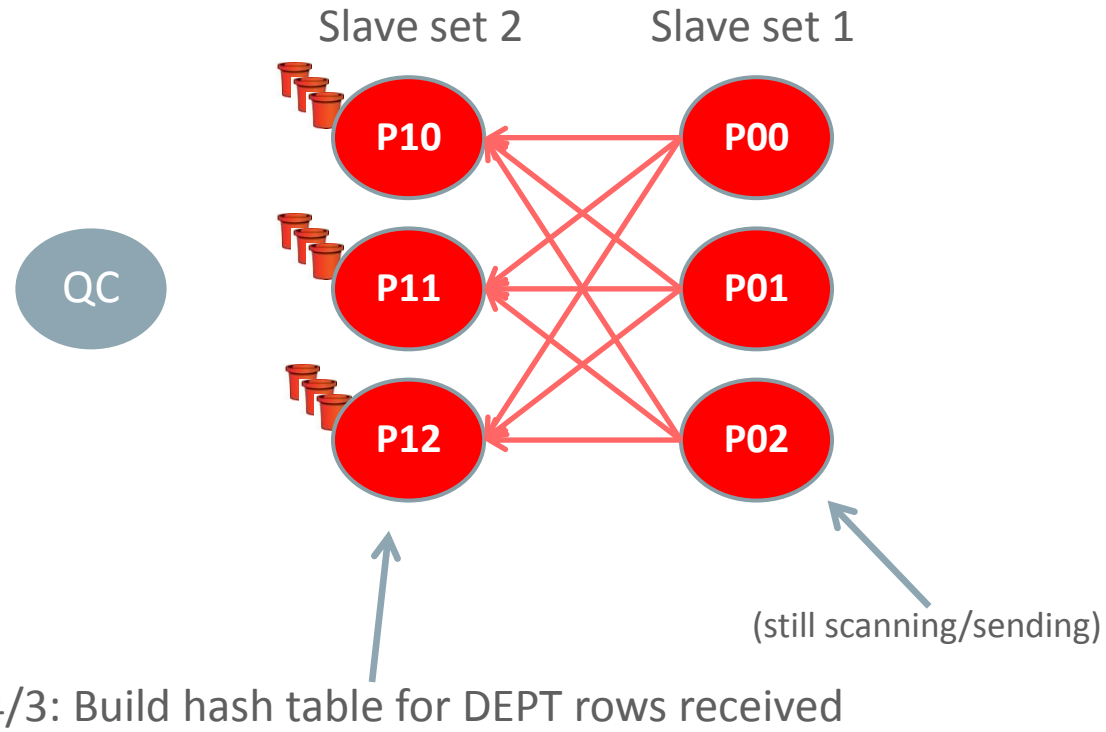
```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL | DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL | EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```



Hash PQ Distrib:
conceptually distributes rows based on
mod(hash(deptno),3)

Build phase

```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL| DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL| EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```



Line 4/3: Build hash table for DEPT rows received

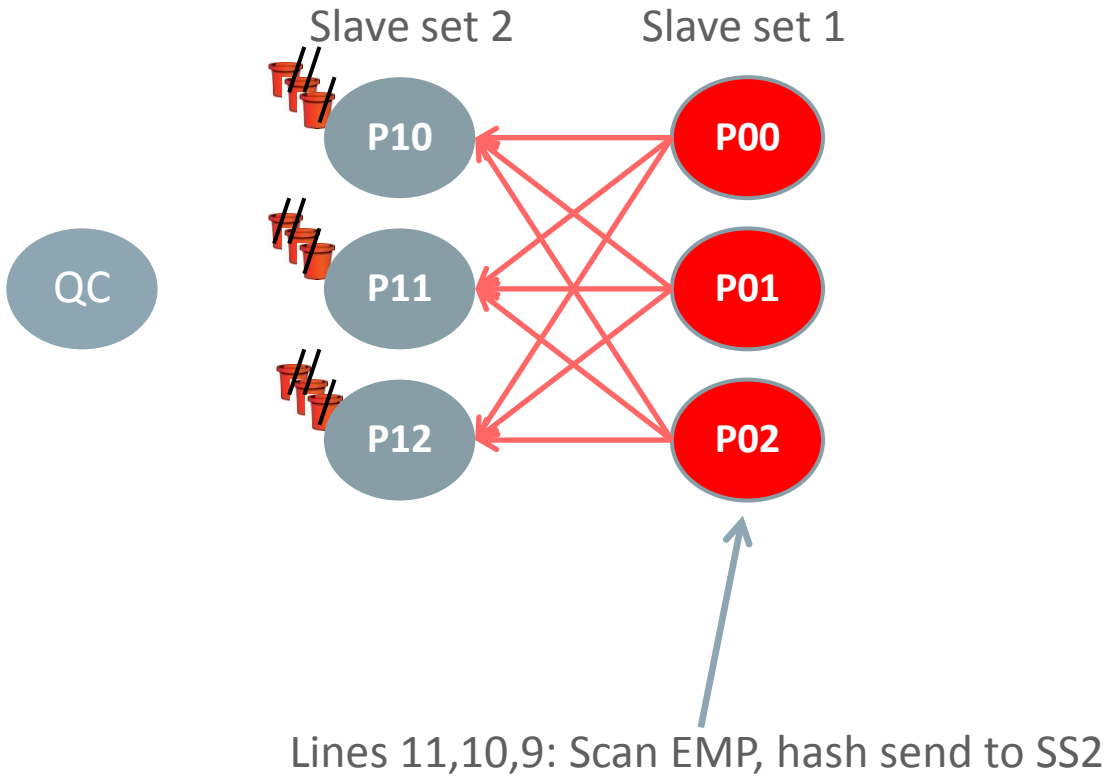
Hash joins parallel execution plan

```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL| DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL| EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```

Build phase ready

Probe phase

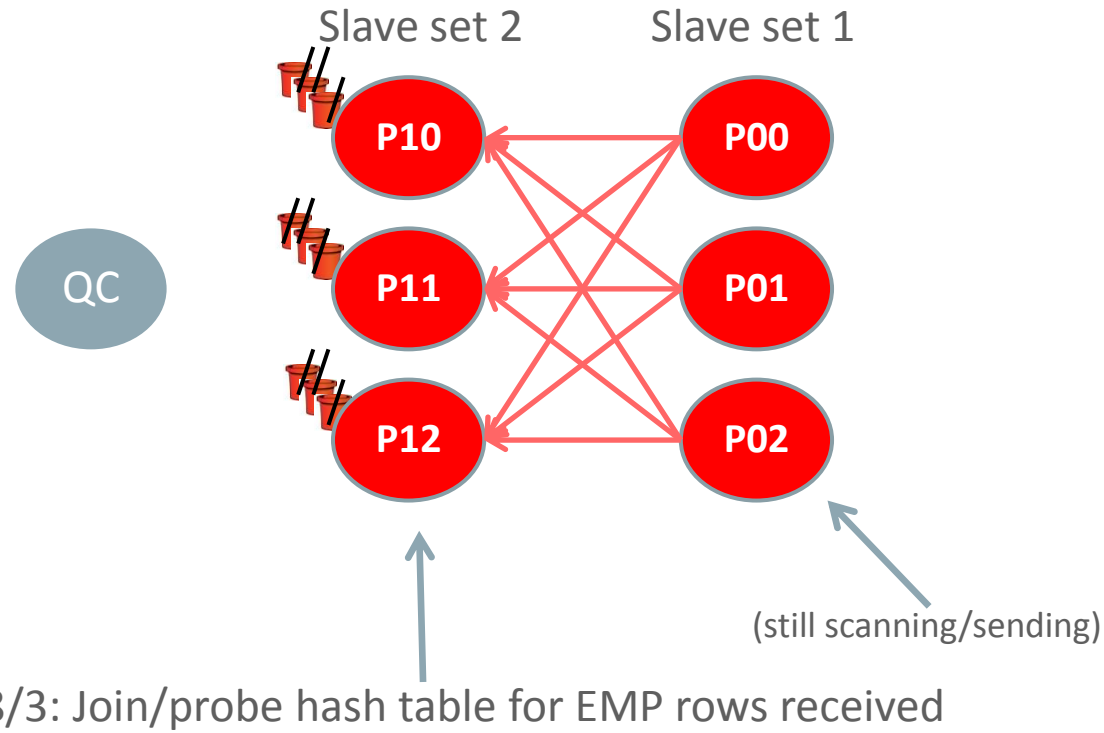
```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL | DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL | EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```



Same mod(hash(deptno),3) distribution used

Probe phase

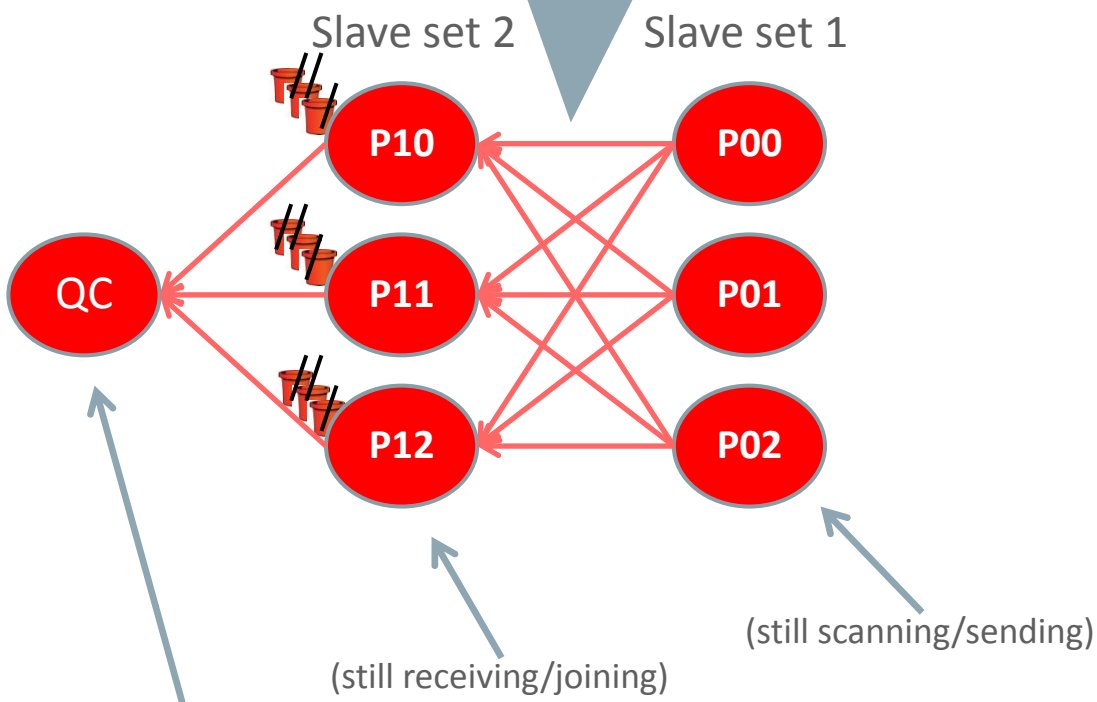
```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
| * 3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL| DEPT     |  Q1,00 | PCWP |            |
|   8 |    PX RECEIVE            |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL| EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```



Probe phase

```
-------------------------------------------------------------------------------
| Id  | Operation                | Name     |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |        |      |            |
|   1 |  PX COORDINATOR          |          |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10002 |  Q1,02 | P->S | QC (RAND)  |
|*  3 |    HASH JOIN             |          |  Q1,02 | PCWP |            |
|   4 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |  Q1,00 | P->P | HASH       |
|   6 |       PX BLOCK ITERATOR  |          |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL| DEPT     |  Q1,00 | PCWP |            |
|   8 |     PX RECEIVE           |          |  Q1,02 | PCWP |            |
|   9 |      PX SEND HASH        | :TQ10001 |  Q1,01 | P->P | HASH       |
|  10 |       PX BLOCK ITERATOR  |          |  Q1,01 | PCWC |            |
|  11 |        TABLE ACCESS FULL| EMP      |  Q1,01 | PCWP |            |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   3 - access("D"."DEPTNO"="E"."DEPTNO")
```

Point to be made:
Inter slave set traffic = expensive as 2nd table would be much larger



Lines 2/1: Receive resulting joined rows

Filter early

- What do we mean by “filter early”?
  - In the hierarchical execution plan tree
  - Eliminate rows as soon (early) as possible
  - Preventing their (expensive) flow through parent execution stages in plan

Filter early: join example

Remember this plan
BF's operate in same way

```
select d.dname,e.ename
from dept d, emp e
where d.deptno = e.deptno
  and d.deptno between 130 and 150
```

```
-----------------------------------------------------
| Id  | Operation                          | Name    |
-----------------------------------------------------
|   0 | SELECT STATEMENT                   |         |
|*  1 |  HASH JOIN                         |         |
|   2 |   TABLE ACCESS BY INDEX ROWID BATCHED| DEPT    |
|*  3 |    INDEX RANGE SCAN                | DEPT_PK |
|*  4 |   TABLE ACCESS FULL                | EMP     | <== Filter!
-----------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
  1 - access("D"."DEPTNO"="E"."DEPTNO")
  3 - access("D"."DEPTNO">=130 AND "D"."DEPTNO"<=150)
  4 - filter(("E"."DEPTNO">=130 AND "E"."DEPTNO"<=150))  <== Filter!
```

Bloom filter concept

Bloom filter concept

- Memory structure representing a *set of values* (say S)
  - "representing" ➔ member values are encoded in specific manner
- Memory structure can be used to answer:
  - Is a given value x, member of set S?
- Two possible answers
  - Definitely not
  - Possibly yes

Two operators on structure:
1) Add value x
2) Test membership

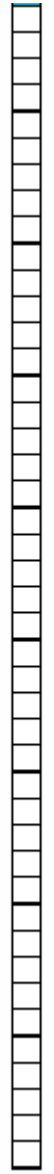
Conceived by Burton Howard Bloom in 1970

Bloom filter concept

- BF(m,k)
  - m = size of memory structure in bits → array of m bits
  - k = number of hash functions used to encode value (hf_1,…,hf_k)
    - Range of hash functions is: [0..m]

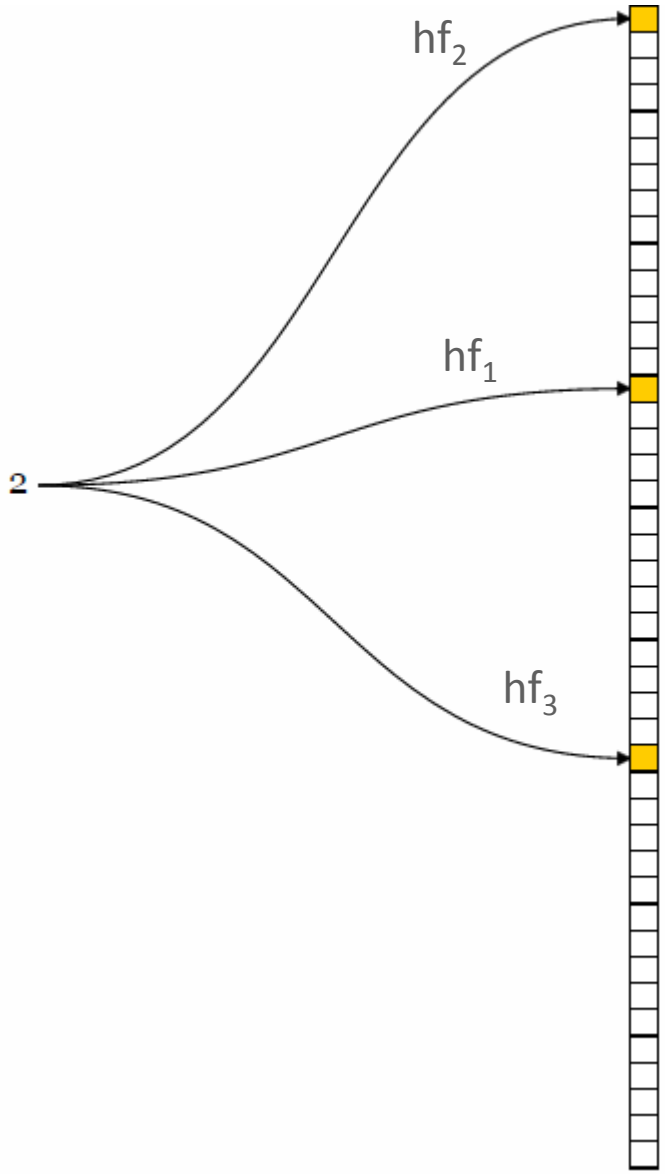
  Bit array initially filled with 0's

- Adding (encoding) a value x:
  - Apply each hash-function to value x → this produces k hash-values
  - Set bit in array at each hash-value's position

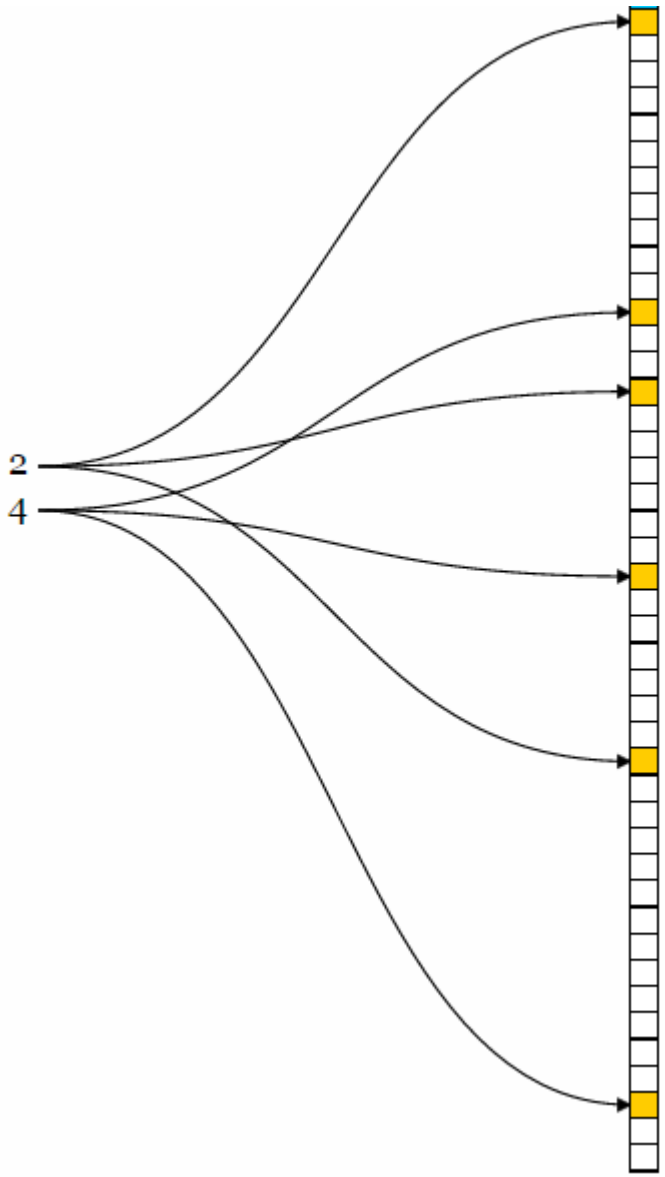


Bloom filter: adding value 2

Assuming 3 hash functions used

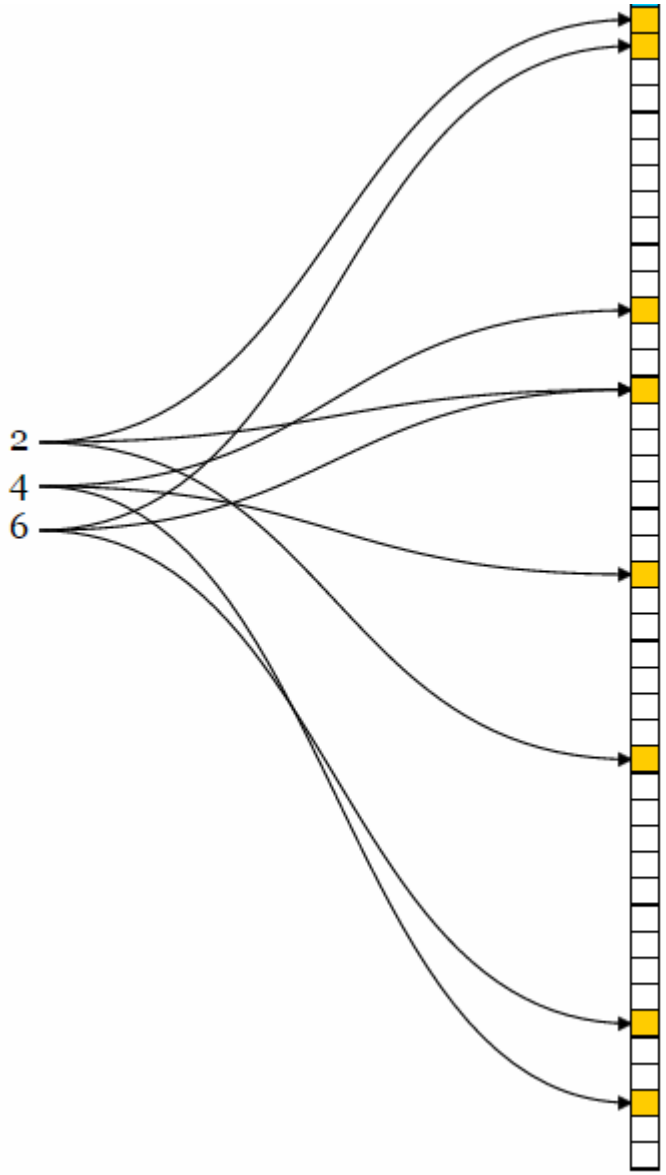


Bloom filter: adding value 4



Bloom filter: adding value 6

Note:
one of hashes of 6 is same as
one of hashes of 2

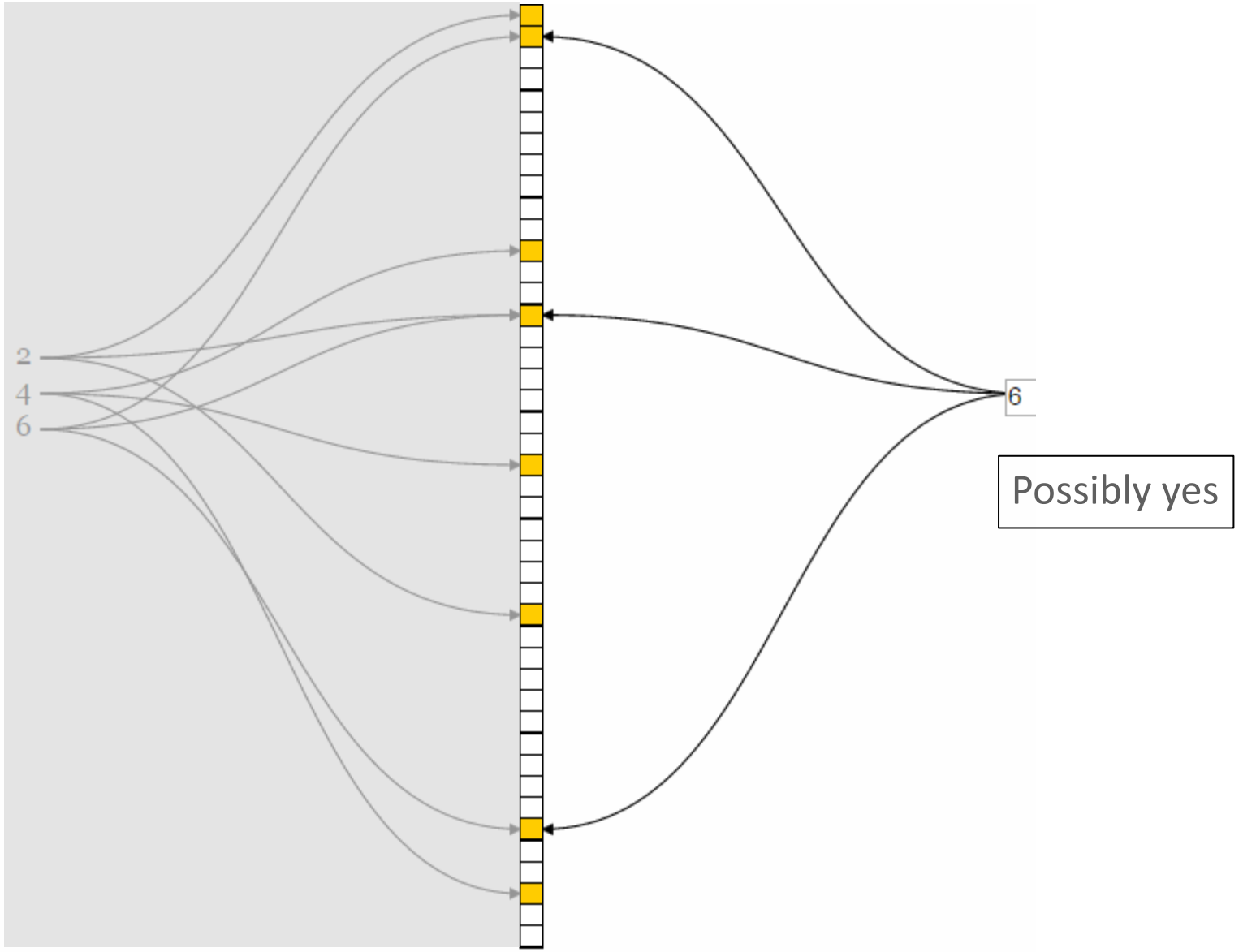


Bloom filter: testing for membership

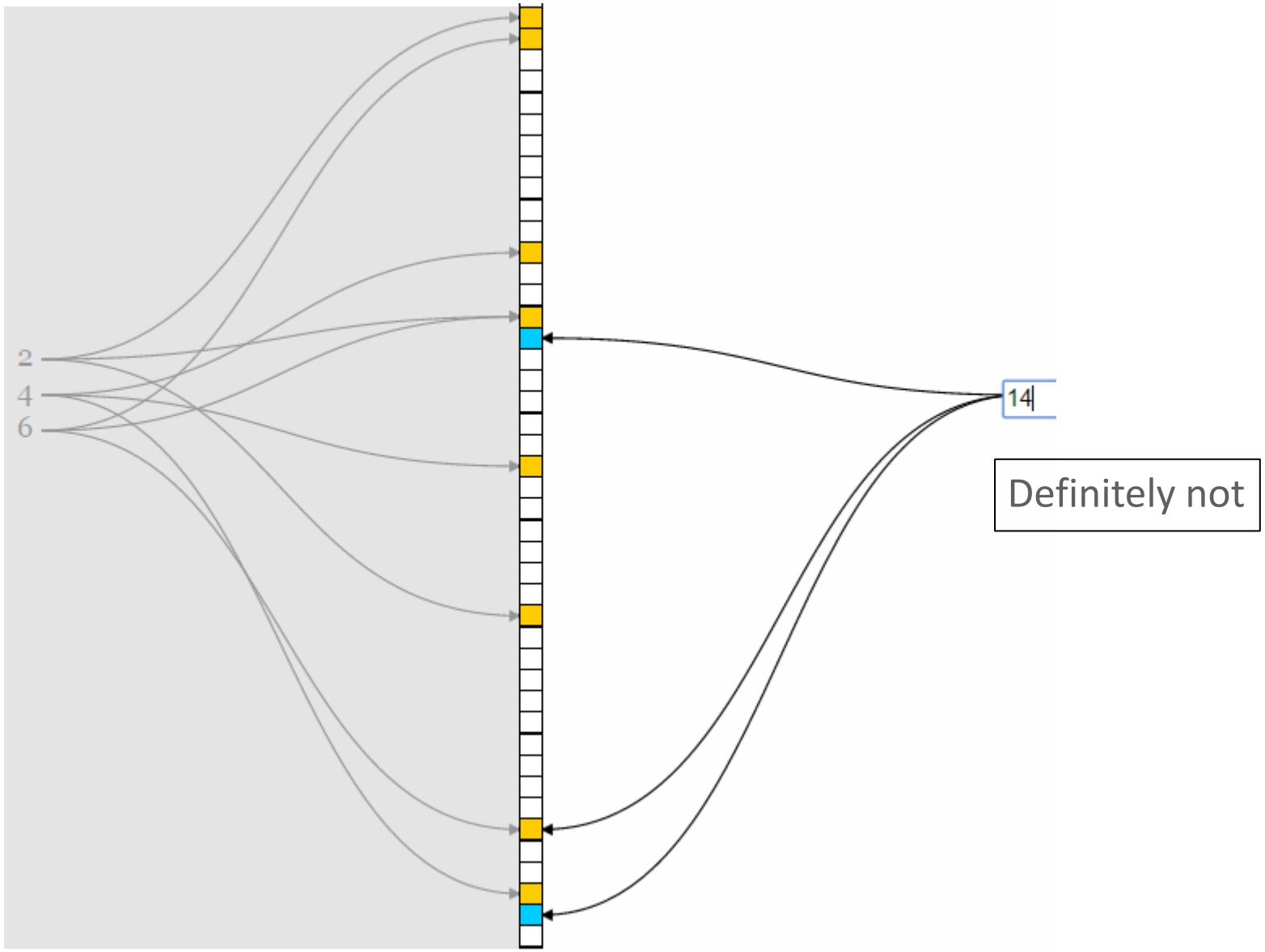
- Once bloom filter is populated with complete set, we can test for membership of any given value
  - By just applying hash-functions to given value
  - And checking if all hashed positions in bit-array are filled with 1
- If any not filled ➔ then *definitely not* a member of the set
- If all filled ➔ then *possibly* (!) member of the set

- Two possible answers
  - Definitely not
  - Possibly yes

Testing value 6



Testing value 14



False positives possible

- Likelihood increases when bit-array is sized too small

- Demo: https://www.jasondavies.com/bloomfilter/

Bloom filter sizing

- CBO uses estimated NDV to size Bloom filter
  - Number of Distinct Values

- Demo: http://hur.st/bloomfilter?n=1000000&p=0.01

Why use Bloom filters?

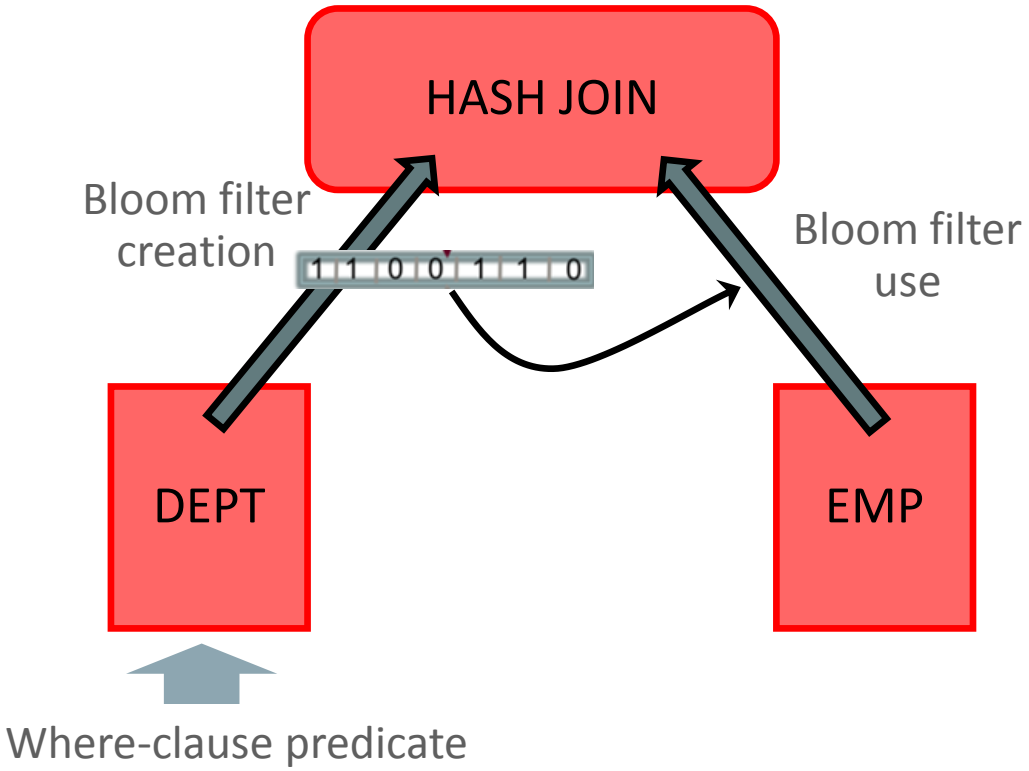
1. Memory structure is small
   - Around 9-10 bits per (distinct) element required for a 1% false positive probability
2. Add and test operators are fast
   - Cheap hash + fast set/test bit-operations

➔ Bloom filters are cheap to create, use and dispose of, on-the-fly

How can Bloom filter help filter early in hash joins?

- BF use-cases in hash-join are of the form:
  - In BUILD stage of execution plan: BF CREATE
    - All join-column values of build-table added to BF
    - BF filter = bit signature of join condition
  - Then during PROBE stage of execution plan: BF USE
    - Every join-column value of probe-table tested against BF
    - BF filter used to filter ‘definitely not member’ cases

Early filtering



- Bloom filter encodes subset of DEPT PK join-values
- Used during scan of EMP FK join-values
- Bloom filter prevents flow of EMP rows to Hash-Join operator for which there would not be matching DEPT row

Bloom filter examples

- Parallel join filter
- Serial subquery filter
- Multiple BF’s (rightdeep tree)
- Bloom pruning filter

Parallel join filter

```
select d.dname,e.ename
from dept d, emp e
where d.deptno = e.deptno
    and d.loc = 'UTRECHT'
```

Filter on non-join column (LOC) used to 'early filter' EMP rows

False positives caught in line 3

What is saved?

1. Less rows distributed SS1 → SS2 during probe phase
2. Bit vs byte-string operations

```
-----------------------------------------------
| Id  | Operation                     | Name    |
-----------------------------------------------
|   0 | SELECT STATEMENT              |         |
|   1 |  PX COORDINATOR               |         |
|   2 |   PX SEND QC (RANDOM)         | :TQ10002|
|*  3 |    HASH JOIN                  |         |
|   4 |     JOIN FILTER CREATE        | :BF0000 |
|   5 |      PX RECEIVE               |         |
|   6 |       PX SEND HASH            | :TQ10000|
|   7 |        PX BLOCK ITERATOR      |         |
|*  8 |         TABLE ACCESS FULL     | DEPT    |
|   9 |     PX RECEIVE                |         |
|  10 |      PX SEND HASH             | :TQ10001|
|  11 |       JOIN FILTER USE         | :BF0000 |
|  12 |        PX BLOCK ITERATOR      |         |
|* 13 |         TABLE ACCESS FULL     | EMP     |
-----------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
  3 - access("D"."DEPTNO"="E"."DEPTNO")
  8 - filter("D"."LOC"='UTRECHT')
 13 - filter(SYS_OP_BLOOM_FILTER(:BF0000,"E"."DEPTNO"))
```

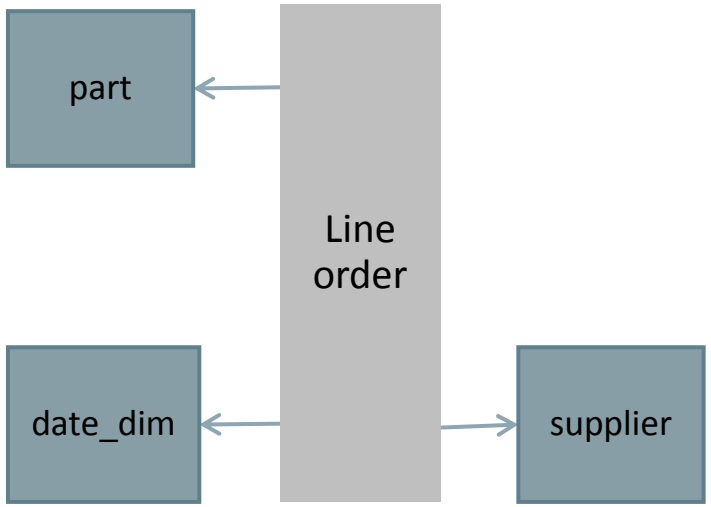
Serial subquery filter

```
select d.dname,e.disnm
 from dept d
     ,(select deptno
             ,count(distinct ename)
                                as disnm
         from emp
    group by deptno) e
where d.loc='UTRECHT'
    and d.deptno = e.deptno
```

BF push through GroupBy

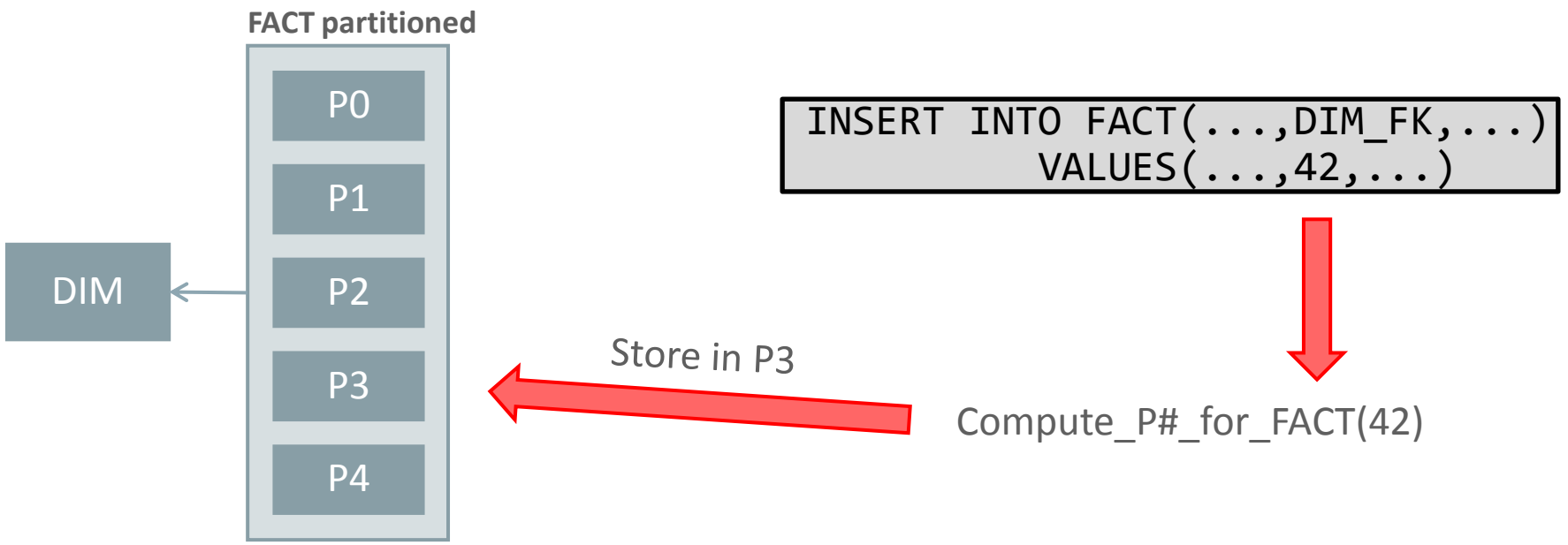
```
-----------------------------------------------------------------------
| Id  | Operation                | Name       | Starts | A-Rows |
-----------------------------------------------------------------------
|   0 | SELECT STATEMENT         |            |      1 |     11 |
|   1 |  HASH GROUP BY           |            |      1 |     11 |
|*  2 |   HASH JOIN              |            |      1 |     44 |
|   3 |    JOIN FILTER CREATE    | :BF0000    |      1 |     11 |
|*  4 |     TABLE ACCESS FULL    | DEPT       |      1 |     11 |
|   5 |    VIEW                  | VM_NWVW_1  |      1 |     44 |
|   6 |     HASH GROUP BY        |            |      1 |     44 |
|   7 |      JOIN FILTER USE     | :BF0000    |      1 |     44 |
|*  8 |       TABLE ACCESS FULL  | EMP        |      1 |     44 |
-----------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
  2 - access("D"."DEPTNO"="$vm_col_2")
  4 - filter("D"."LOC"='UTRECHT')
  8 - filter(SYS_OP_BLOOM_FILTER(:BF0000,"DEPTNO"))
```

Multiple Bloom filters



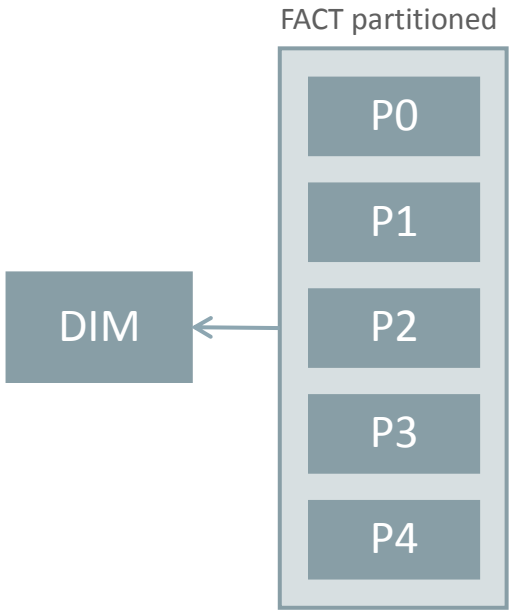

```
-------------------------------------------------------------------------------
| Id  | Operation                          | Name        | Rows  | Bytes |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                   |             |    63 |  7371 |
|   1 |  PX COORDINATOR                    |             |       |       |
|   2 |   PX SEND QC (ORDER)               | :TQ10003    |    63 |  7371 |
|   3 |    SORT GROUP BY                   |             |    63 |  7371 |
|   4 |     PX RECEIVE                     |             |    63 |  7371 |
|   5 |      PX SEND RANGE                 | :TQ10002    |    63 |  7371 |
|   6 |       HASH GROUP BY                |             |    63 |  7371 |
|*  7 |        HASH JOIN                   |             |   430 | 50310 |
|   8 |         JOIN FILTER CREATE         | :BF0000     |  4013 |  133K|
|   9 |          PX RECEIVE                |             |  4013 |  133K|
|  10 |           PX SEND BROADCAST        | :TQ10000    |  4013 |  133K|
|  11 |            PX BLOCK ITERATOR       |             |  4013 |  133K|
|* 12 |             TABLE ACCESS INMEMORY FULL | SUPPLIER |  4013 |  133K|
|* 13 |         HASH JOIN                  |             | 10589 |  858K|
|  14 |          JOIN FILTER CREATE        | :BF0001     |    31 |  1023 |
|* 15 |           TABLE ACCESS INMEMORY FULL | DATE_DIM  |    31 |  1023 |
|* 16 |          HASH JOIN                 |             |  845K|    40M|
|  17 |           JOIN FILTER CREATE       | :BF0002     |  2332 | 65296 |
|  18 |            PX RECEIVE              |             |  2332 | 65296 |
|  19 |             PX SEND BROADCAST      | :TQ10001    |  2332 | 65296 |
|  20 |              PX BLOCK ITERATOR     |             |  2332 | 65296 |
|* 21 |               TABLE ACCESS INMEMORY FULL| PART   |  2332 | 65296 |
|  22 |           JOIN FILTER USE          | :BF0000     |  300M|  6294M|
|  23 |            JOIN FILTER USE         | :BF0001     |  300M|  6294M|
|  24 |             JOIN FILTER USE        | :BF0002     |  300M|  6294M|
|  25 |              PX BLOCK ITERATOR     |             |  300M|  6294M|
|* 26 |               TABLE ACCESS INMEMORY FULL| LINEORDER |  300M|  6294M|
-------------------------------------------------------------------------------
```

Bloom pruning filter (11g)



Bloom pruning filter (11g)

- Shows up as "*Partition* join filter create"
  - When joining DIM to FACT and join-column is input for partitioning scheme of FACT
  - Build phase:
    - FACT's partition function is applied to DIM PK values to find P#'s of FACT that would hold such values
    - These P#'s are added to Bloom filter
  - Probe phase:
    - Bloom filter is used when scanning FACT
    - Only partitions whose P#'s are in Bloom filter will be scanned



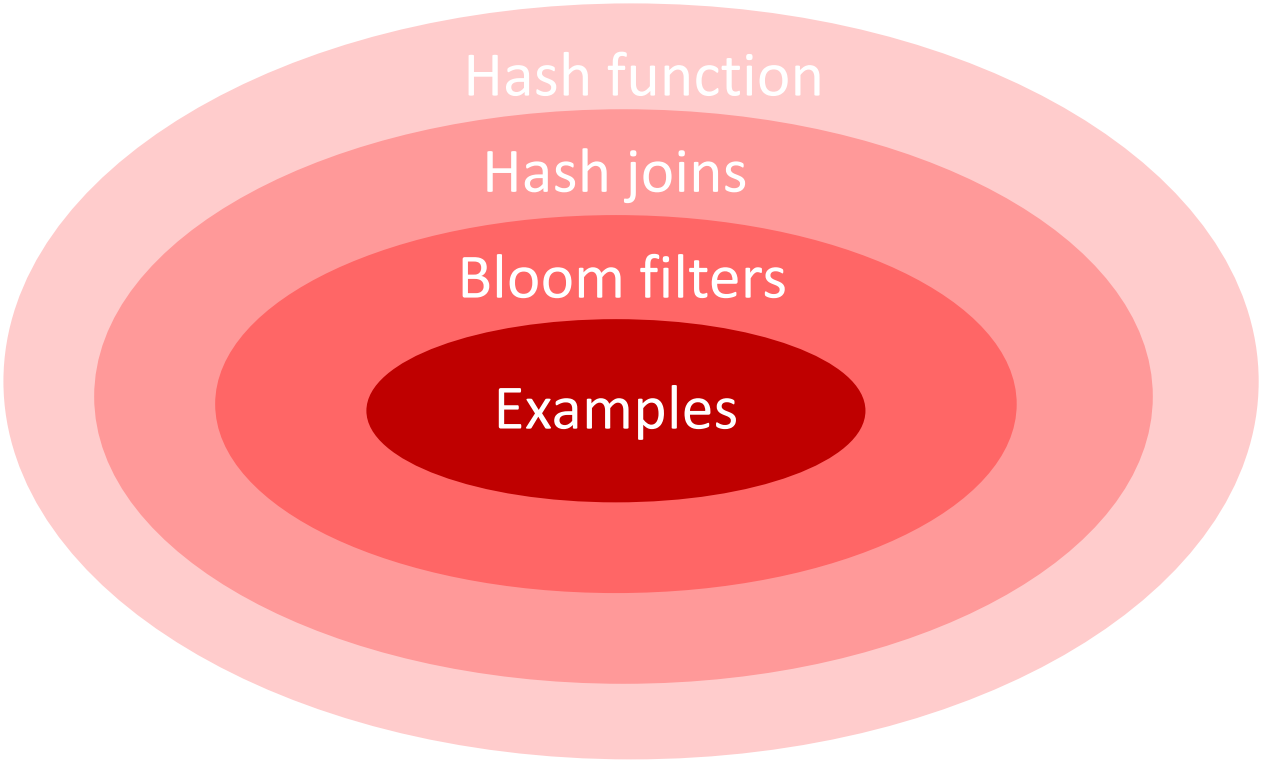
Bloom pruning filter

```
-------------------------------------------------------------------------
| Id  | Operation                          | Name         | Pstart| Pstop |
-------------------------------------------------------------------------
|   0 | SELECT STATEMENT                   |              |       |       |
|   1 |  SORT AGGREGATE                    |              |       |       |
|   2 |   PX COORDINATOR                   |              |       |       |
|   3 |    PX SEND QC (RANDOM)             | :TQ10001     |       |       |
|   4 |     SORT AGGREGATE                 |              |       |       |
|*  5 |      HASH JOIN                     |              |       |       |
|   6 |       BUFFER SORT                  |              |       |       |
|   7 |        PART JOIN FILTER CREATE     | :BF0000      |       |       |
|   8 |         PX RECEIVE                 |              |       |       |
|   9 |          PX SEND BROADCAST         | :TQ10000     |       |       |
|* 10 |           TABLE ACCESS FULL        | DATE_DIM     |       |       |
|  11 |       PX BLOCK ITERATOR            |              |:BF0000|:BF0000|
|* 12 |        TABLE ACCESS FULL           | STORE_SALES  |:BF0000|:BF0000|
-------------------------------------------------------------------------
```

Final remarks

- Bloom filter are pushed down to storage cells and DBIM scans
- SQL Monitor report has details on Bloom filter
  - V$sql_join_filter
- Hints px_join_filter() / no_px_join_filter()
- alter session set events 'trace[RDBMS.Bloom_filter] …'
- Event 10128 Bloom pruning filter

Questions?



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