sangam 14
....meeting of minds

HISTOGRAMS
PRE-12c AND NOW

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About me

- More than 11 years of experience in IT Industry
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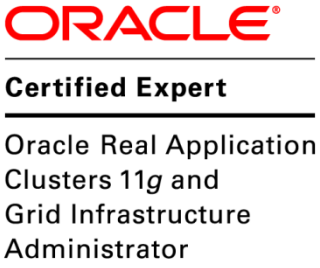
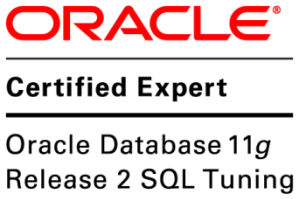


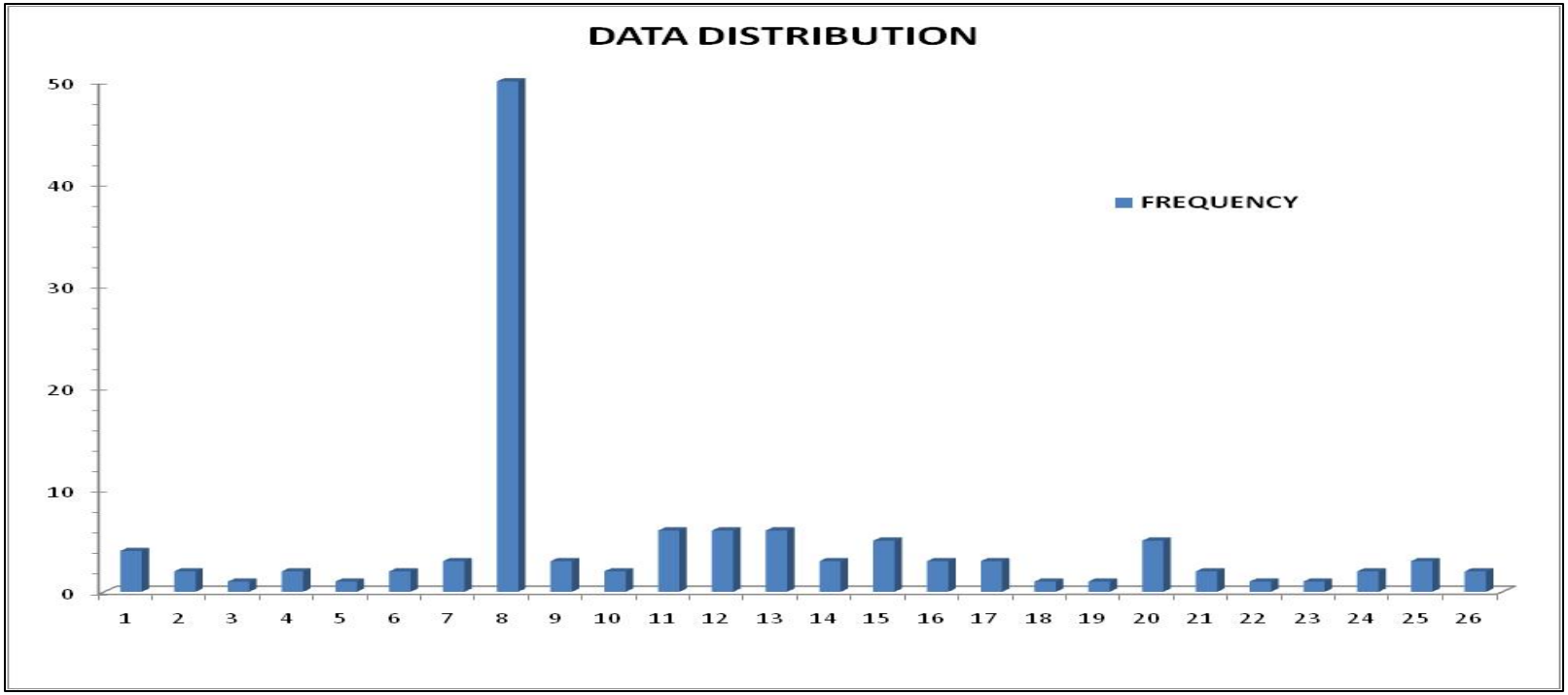


Agenda

- Need For Histograms
- Pre-12c Histograms
  - Frequency Histograms
  - Height Balanced Histograms
- Issues With Histograms In 11g
- Histograms in 12c
  - Top Frequency Histograms
  - Hybrid Histograms
  - Hybrid Histograms - Corollary
- Conclusion
- References
- Q & A

Need For Histograms

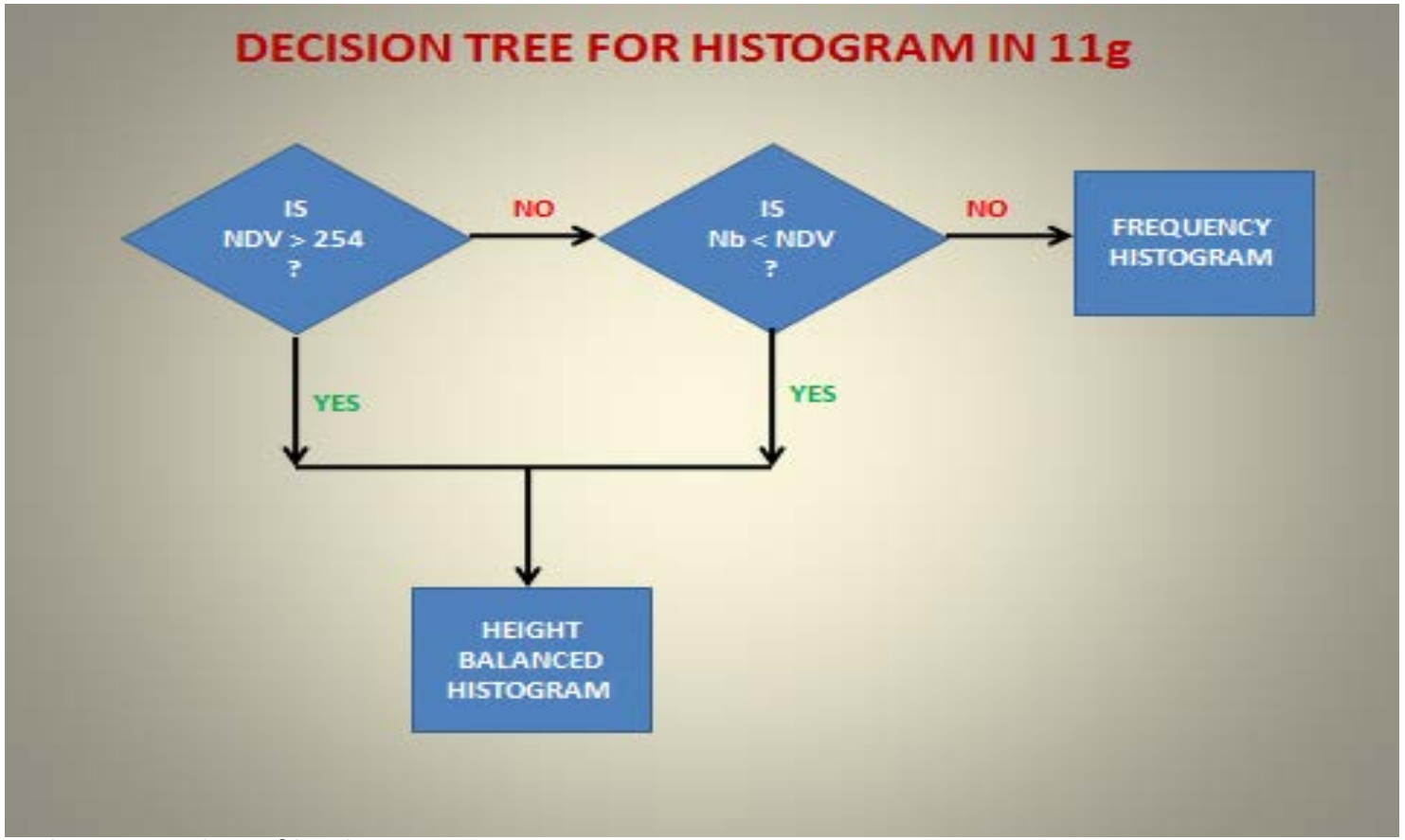
Skewed Data Distribution



- 26 distinct values in the column ID
- More than 40% rows have ID = 8
- Optimizer assumes uniform distribution and misestimates cardinality
- Results in a bad execution path

Pre-12c Histograms

- Frequency histograms
- Height balanced histograms



Nb – Number of buckets
NDV – No. of Distinct Values

Frequency Histogram

- NDV <= 254 and Nb >= NDV
- Records each different value and its exact cardinality.
- **One bucket contains exactly one value**.
- One value resides entirely in one bucket.
- Bucket size = cardinality of the value
- **Precise**

```
SQL>exec dbms_stats.gather_table_stats -
             (ownname => 'HR', -
                         tabname =>  'HIST', -
                         method_opt => 'FOR COLUMNS ID', -
                         cascade => true);

SQL>select table_name, column_name, histogram,num_distinct,num_buckets
    Where  table_name = 'HIST'
    And    column_name = 'ID';

   TABLE_NAME COLUMN_NAME     HISTOGRAM       NUM_DISTINCT NUM_BUCKETS
   ---------- --------------- --------------- ------------ -----------
   HIST       ID              FREQUENCY                 26          26
```

Nb – Number of buckets
NDV – No. of Distinct Values

Frequency Histogram

```
SQL>select ENDPOINT_VALUE, ENDPOINT_NUMBER
    from   dba_histograms
    where  table_name = 'HIST'
    and    column_name = 'ID';
```

ENDPOINT_VALUE	ENDPOINT_NUMBER
1	4
2	6
3	7
4	9
5	10
6	12
7	15
8	65
9	68
10	70
11	76
12	82
13	88
14	91
15	96
16	99
17	102
18	103
19	104
20	109
21	111
22	112
23	113
24	115
25	118
26	120

Table 2.2

ENDPOINT_VALUE - The value in a bucket.
ENDPOINT_NUMBER - Cumulative frequency

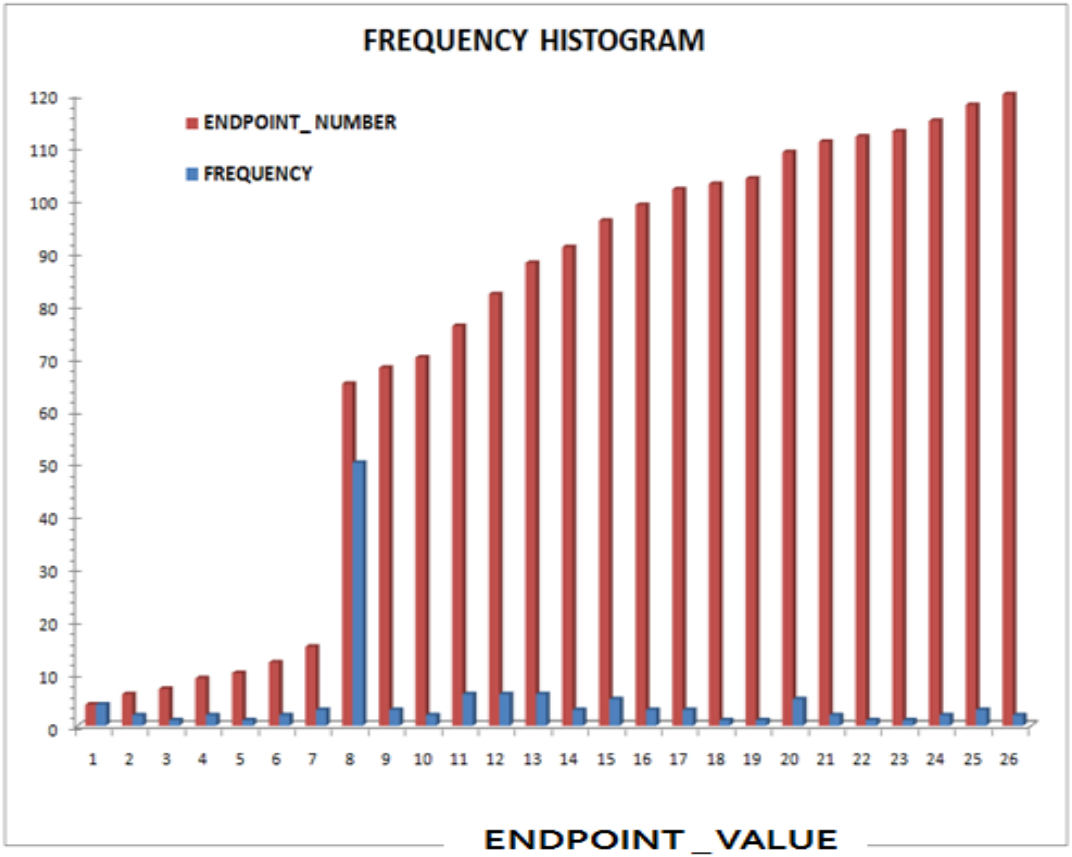


Fig 2.2

Frequency Histogram

- Optimizer uses frequency histogram to estimate cardinality accurately
- Uses FTS access path as desired even though column ID is indexed

```
SQL>explain plan for select * from hr.hist where id = 8;
    select * from table(dbms_xplan.display);

    PLAN_TABLE_OUTPUT
    ------------------------------------------------------------------------------
    Plan hash value: 538080257
    ------------------------------------------------------------------------------
    | Id  | Operation         | Name | Rows  | Bytes | Cost (%CPU)| Time     |
    ------------------------------------------------------------------------------
    |   0 | SELECT STATEMENT  |      |    50 | 50200 |     7   (0)| 00:00:01 |
    |*  1 |  TABLE ACCESS FULL| HIST |    50 | 50200 |     7   (0)| 00:00:01 |
    ------------------------------------------------------------------------------
```

Height-Balanced Histogram

- NDV > 254 or Nb < NDV
- Distributes the count of all rows evenly across all histogram buckets
- **All buckets have almost the same number of rows**
- **Less precise**
- No. of buckets = 20 (< NDV (=26))

```
DB11g>exec dbms_stats.gather_table_stats -
           (ownname => 'HR', -
                     tabname => 'HIST', -
                     method_opt => 'FOR COLUMNS ID size 20', -
                     cascade => true);

DB11g>select table_name,column_name,histogram,num_distinct,num_buckets
      from   dba_tab_col_statistics
      where  table_name = 'HIST' and column_name = 'ID';

TABLE_NAME COLUMN_NAME     HISTOGRAM       NUM_DISTINCT NUM_BUCKETS
---------- --------------- --------------- ------------ -----------
HIST       ID              HEIGHT BALANCED           26          20
```

Nb – Number of buckets
NDV – No. of Distinct Values

Height-Balanced Histogram

```
DB11g>select ENDPOINT_VALUE,ENDPOINT_NUMBER
             from dba_histograms
             where table_name = 'HIST'
             and column_name = 'ID';

   ENDPOINT_VALUE ENDPOINT_NUMBER
   -------------- --------------
                1              0
                2              1
                6              2
                8             10
                9             11
               11             12
               12             13
               13             14
               14             15
               15             16
               17             17
               20             18
               24             19
               26             20

14 rows selected.
```

Table 2.5

ENDPOINT_NUMBER	VALUES						ENDPOINT_VALUE
1	1	1	1	1	2	2	2
2	3	4	4	5	6	6	6
3	7	7	7	8	8	8	8
4	8	8	8	8	8	8	8
5	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8
7	8	8	8	8	8	8	8
8	8	8	8	8	8	8	8
9	8	8	8	8	8	8	8
10	8	8	8	8	8	8	8
11	8	8	8	8	8	9	9
12	9	9	10	10	11	11	11
13	11	11	11	11	12	12	12
14	12	12	12	12	13	13	13
15	13	13	13	13	14	14	14
16	14	15	15	15	15	15	15
17	16	16	16	17	17	17	17
18	18	19	20	20	20	20	20
19	20	21	21	22	23	24	24
20	24	25	25	25	26	26	26

HEIGHT- BALANCED HISTOGRAM

Fig 2.3

Bucket size = Total no. of rows / Nb = 120 / 20 = 6
ENDPOINT_NUMBER - unique identifier of a bucket
ENDPOINT_VALUE - largest value stored in a bucket

Height-Balanced Histogram

- One bucket can have multiple values.
- One value can span multiple buckets.
- Multiple buckets (3 – 10) with same ENDPOINT_VALUE (8) compressed into a single bucket with the highest endpoint number (bucket 10).
- A **popular value** (8) occurs as an endpoint value of multiple buckets.
- Any value that is not popular is a **non-popular value**.

Height-Balanced Histogram Popular values

- Cardinality of popular value = (Bucket size)*(no. of buckets with value as endpoint)
- ID = 8 is an end point of 8 buckets
- **Estimated cardinality = (6 * 8) = 48 (Actual = 50)**

```
DB11g> explain plan for select * from hr.hist where id =8;
       select * from table(dbms_xplan.display);

PLAN_TABLE_OUTPUT
------------------------------------------------------------------------------
Plan hash value: 538080257

-------------------------------------------------------------------------------
| Id  | Operation         | Name | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT  |      |    48 | 48192 |     7   (0)| 00:00:01 |
|*  1 |  TABLE ACCESS FULL| HIST |    48 | 48192 |     7   (0)| 00:00:01 |
-------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("ID"=8)
```

Height-Balanced Histogram
Non-Popular values (Endpoint)

- Cardinality of non-popular value = (number of rows in table) * density
- ID = 15 is an end point of one bucket
- **Estimated cardinality = 3 (Actual = 5)**

```
DB11g>explain plan for select * from hr.hist where id = 15;
      select * from table(dbms_xplan.display);
PLAN_TABLE_OUTPUT
------------------------------------------------------------------------------
Plan hash value: 4058847011
------------------------------------------------------------------------------
| Id  | Operation                    | Name     | Rows  | Bytes | Cost (%CPU)|Time
------------------------------------------------------------------------------
|   0 | SELECT STATEMENT             |          |  3 |  3012 |   2   (0)| 00:00:01
|   1 |  TABLE ACCESS BY INDEX ROWID| HIST     |  3 |  3012 |   2   (0)| 00:00:01
|*  2 |   INDEX RANGE SCAN           | HIST_IDX |  3 |       |   1   (0)| 00:00:01
------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("ID"=15)
```

Height-Balanced Histogram
Non-Popular values (Non-endpoint)

- Cardinality of non-popular value = (num of rows in table) * density
- ID = 3 is not an endpoint
- **Estimated cardinality = 3 (Actual = 1)**

```
DB11g>explain plan for select * from hr.hist where id = 3;
      select * from table(dbms_xplan.display);
PLAN_TABLE_OUTPUT
------------------------------------------------------------------------------
Plan hash value: 4058847011
------------------------------------------------------------------------------
| Id  | Operation                    | Name     | Rows  | Bytes |Cost (%CPU)| Time
------------------------------------------------------------------------------
|   0 | SELECT STATEMENT             |          | 3 |  3012 |    2   (0)| 00:00:01
|   1 |  TABLE ACCESS BY INDEX ROWID| HIST     | 3 |  3012 |    2   (0)| 00:00:01
|*  2 |   INDEX RANGE SCAN           | HIST_IDX | 3 |       |    1   (0)| 00:00:01
------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access"ID"=3)
```

Drawbacks Of Pre-12c Histograms

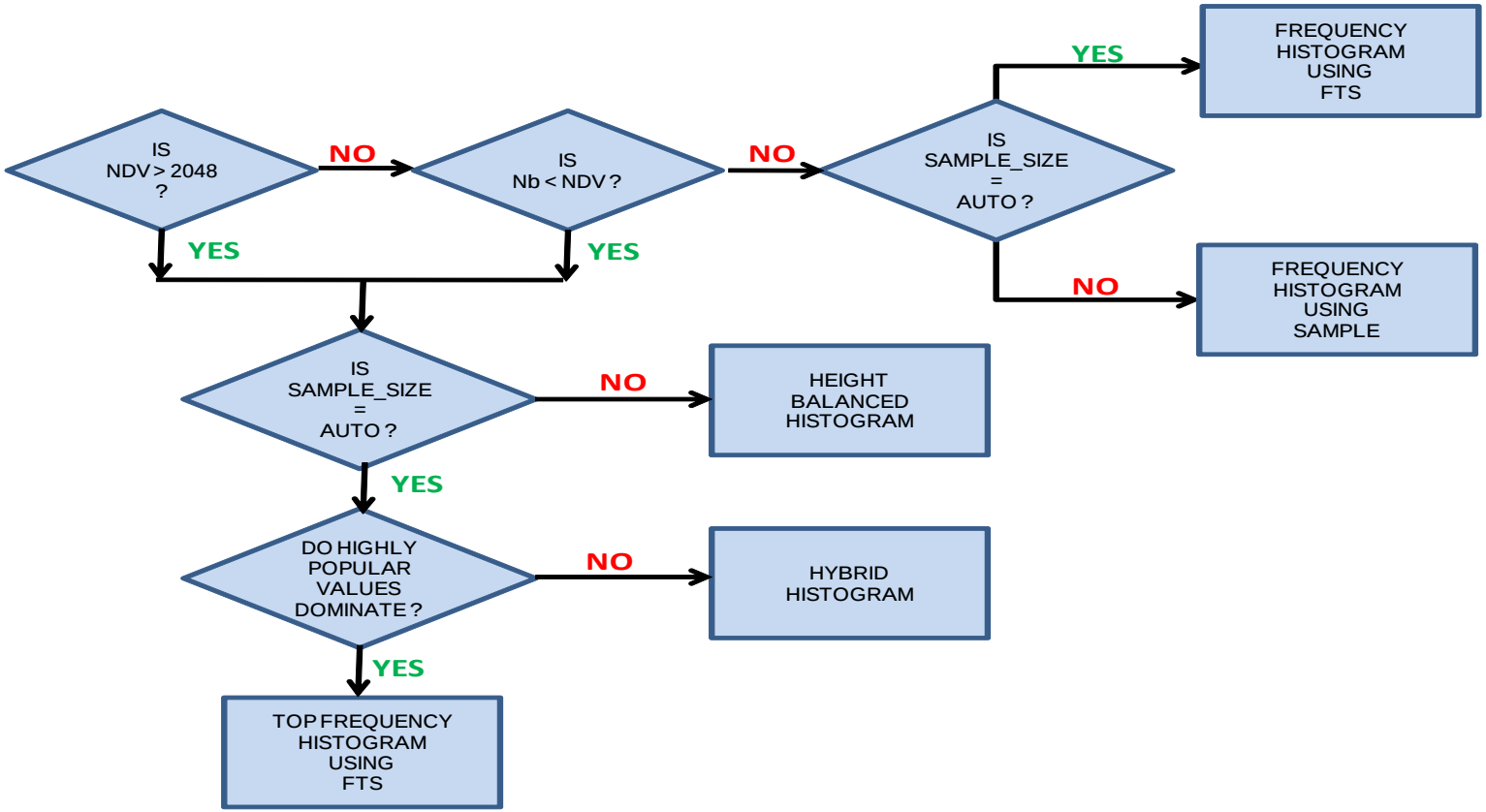
- **Frequency histograms**
  - Accurate but can be created only for NDV <= 254.

- **Height balanced histograms**
  - May misestimate cardinality for both popular and non-popular values.
  - Produces inaccurate estimates for values that are almost popular.
  - A value which is endpoint of one bucket and almost fills up another bucket value might be considered unpopular.
  - Could result in a sub-optimal execution plan being chosen.

NDV – No. of Distinct Values

Histograms in 12c

- Frequency histograms can be created for up to 2048 distinct values .
- Introduces two new types of histograms
  - Top-n-frequency histograms
  - Hybrid histograms



Top Frequency Histograms

- Useful when a small number of distinct values dominate the data set.
- Capture highly popular values by ignoring statistically insignificant unpopular values.

- **Prerequisites**
  - NDV > Nb
  - The percentage of rows occupied by the top Nb frequent values is equal to or greater than threshold p, where p is (**1-(1/Nb))*100**.
  - The **ESTIMATE_PERCENT** is set to **AUTO_SAMPLE_SIZE** in the DBMS_STATS statistics gathering procedure.

- **Features**
  - One value per bucket
  - One value contained entirely in one bucket
  - Cardinality of the value = Bucket size
  - Variable bucket size
  - Precise for all the endpoints captured

Nb – Number of buckets
NDV – No. of Distinct Values

Top Frequency Histogram

- NDV (26) > Nb (20)
- Threshold p for 20 buckets = **(1 - (1/Nb))*100** = (1 - (1/20))*100 = 95.0
- Top 20 most popular values occupy more than 95% of rows
- **ESTIMATE_PERCENT** = **AUTO_SAMPLE_SIZE** (default)
- Precisely captures cardinality of values occurring top Nb (20) times.
- 6 (= NDV –Nb) Values occurring least no. of times are not captured.

```
DB12c>exec dbms_stats.gather_table_stats -
      (ownname => 'HR', tabname => 'HIST', method_opt => 'FOR COLUMNS ID size
20', cascade => true);
        select table_name, column_name,histogram,num_distinct, num_buckets
        from   dba_tab_col_statistics
        where  table_name = 'HIST' and column_name = 'ID';

TABLE_NAME COLUMN_NAME     HISTOGRAM       NUM_DISTINCT NUM_BUCKETS
---------- --------------- --------------- ------------ -----------
HIST       ID              TOP-FREQUENCY             26          20
```

Nb – Number of buckets
NDV – No. of Distinct Values

Top Frequency Histogram

```
DB12c>set pagesize 100
      select ENDPOINT_VALUE, ENDPOINT_NUMBER
      from dba_histograms
      where table_name = 'HIST'
      and column_name = 'ID';
ENDPOINT_VALUE ENDPOINT_NUMBER
-------------- ---------------
             1               4
             2               6
             4               8
             6              10
             7              13
             8              63
             9              66
            10              68
            11              74
            12              80
            13              86
            14              89
            15              94
            16              97
            17             100
            20             105
            21             107
            24             109
            25             112
            26             114
20 rows selected
```

Table 3.3

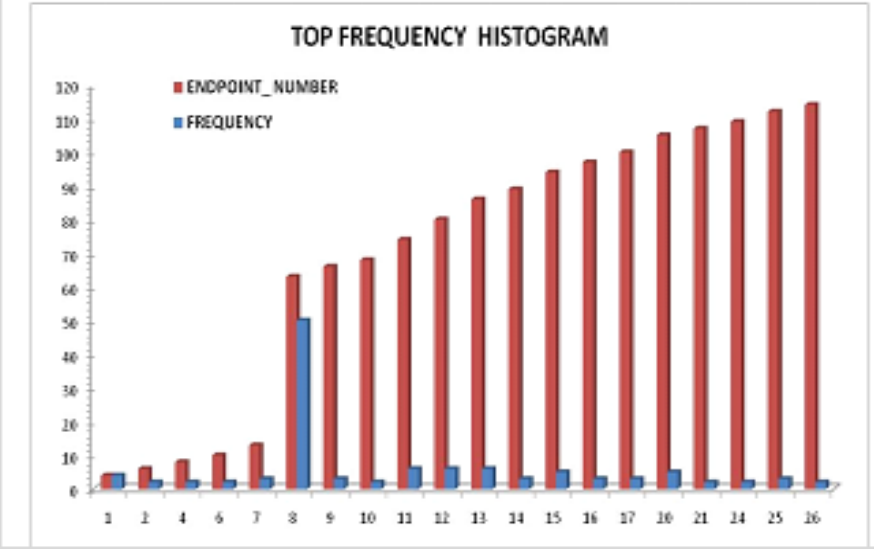


Fig 3.2

ENDPOINT_VALUE - Key value (ID)
ENDPOINT_NUMBER – Cumulative Frequency

Top Frequency Histogram
Non-Popular values (Endpoint)

- Top Frequency histogram makes **accurate cardinality estimate** for unpopular value ID = 15
  - is one of the top 20 most frequently occurring values
  - Is an endpoint
  - Occurs 5 times

```
DB12c>explain plan for select * from hr.hist where id = 15;
      select * from table(dbms_xplan.display);
PLAN_TABLE_OUTPUT
------------------------------------------------------------------------------
Plan hash value: 3950962134
------------------------------------------------------------------------------
| Id  | Operation                           | Name  | Rows|Bytes|Cost(%CPU)|Time|
------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                    |       |  5 |5020 | 2 (0)| 00:00:01
|   1 |  TABLE ACCESS BY INDEX ROWID BATCHED| HIST  |  5 |5020 | 2 (0)| 00:00:01
|*  2 |   INDEX RANGE SCAN                  |HIST_IDX|  5 |     | 1 (0)| 00:00:01
------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("ID"=15)
```

Top Frequency Histogram
Non-Popular values (Non-endpoint)

- Top Frequency histogram makes **accurate cardinality estimate** for unpopular value ID = 3
  - is not one of the top 20 most frequently occurring values
  - Is not an endpoint
  - Occurs once

```
DB12c>explain plan for select * from hr.hist where id = 3;
             select * from table(dbms_xplan.display);
PLAN_TABLE_OUTPUT
------------------------------------------------------------------------------
Plan hash value: 3950962134
------------------------------------------------------------------------------
| Id  | Operation                           | Name    |Rows| Bytes|Cost(%CPU)|Time
------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                    |         | 1 |1004 | 2  (0)| 00:00:01
|   1 |  TABLE ACCESS BY INDEX ROWID BATCHED|HIST     | 1 |1004 | 2  (0)| 00:00:01
|*  2 |   INDEX RANGE SCAN                  |HIST_IDX| 1 |     | 1  (0)| 00:00:01
------------------------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("ID"=3)
```

Top Frequency Histograms Conclusion

- The occurrences of popular values are accurately captured at the expense of not capturing the data for least occurring values.
- Accurately estimates cardinality of top Nb popular values.
- Does not capture (NDV – Nb) values occurring least no. of times.
- Useful for cases when data set is dominate by a small no. of values.

Nb – Number of buckets
NDV – No. of Distinct Values

Hybrid Histograms

- Combines characteristics of both height-based histograms and frequency histograms.
- **Correctly estimates the frequency of endpoints**
  - stores the ENDPOINT_REPEAT_ COUNT - number of times the endpoint value is repeated.
- **Captures more endpoints**
  - stores all occurrences of every value in the same bucket - makes available buckets to store more endpoints.
- **Pre-requisites**
  - Nb < NDV
  - The criteria for top frequency histograms do not apply i.e.

    Percentage of rows occupied by the top Nb most popular values is less than p

    where **p = (1-(1/Nb))*100**.
  - The sampling percentage is **AUTO_SAMPLE_SIZE**.

Nb – Number of buckets

NDV – No. of Distinct Values

Hybrid Histogram

- On deleting 20 rows with ID = 8 from table HR.HIST , it qualifies for hybrid histogram creation.
- Nb (20) < NDV (26)
- Threshold p for 20 buckets = p = (1 - (1/nb))*100 = (1 - (1/20))*100 = 95.0
- Top 20 most popular ID's occupy less than 95% of total rows.

```
DB12c>exec dbms_stats.gather_table_stats -
             (ownname => 'HR',tabname => 'HIST', -
              method_opt => 'FOR COLUMNS ID size 20', -
              cascade => true);

DB12c>select table_name,column_name, histogram,num_distinct,num_buckets
      from  dba_tab_col_statistics
      where table_name = 'HIST' and column_name = 'ID';

TABLE_NAME COLUMN_NAME     HISTOGRAM       NUM_DISTINCT NUM_BUCKETS
---------- --------------- --------------- ------------ -----------
HIST       ID              HYBRID                    26          20
```

Nb – Number of buckets
NDV – No. of Distinct Values

Hybrid Histogram

```
DB12c>select ENDPOINT_VALUE, ENDPOINT_NUMBER,
             ENDPOINT_REPEAT_COUNT RPT_CNT
       from dba_histograms
       where table_name = 'HIST'
       and   column_name = 'ID';

ENDPOINT_VALUE ENDPOINT_NUMBER    RPT_CNT
-------------- --------------- ----------
             1               4          4
             3               7          1
             5              10          1
             7              15          3
             8              45         30
            10              50          2
            11              56          6
            12              62          6
            13              68          6
            14              71          3
            15              76          5
            16              79          3
            17              82          3
            19              84          1
            20              89          5
            21              91          2
            22              92          1
            23              93          1
            24              95          2
            26             100          2

20 rows selected.
```

ENDPOINT_VALUE : The largest value in a bucket

ENDPOINT_NUMBER : Cumulative frequency

ENDPOINT_REPEAT_COUNT: No. of times the endpoint value occurs

BUCKET NUMBER	VALUES	ENDPOINT _VALUE
1	1 1 1 1	1
2	2 2 3	3
3	4 4 5	5
4	6 6 7 7 7	7
5	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	8
6	9 9 9 10 10	10
7	11 11 11 11 11 11	11
8	12 12 12 12 12 12	12
9	13 13 13 13 13 13	13
10	14 14 14	14
11	15 15 15 15 15	15
12	16 16 16	16
13	17 17 17	17
14	18 19	19
15	20 20 20 20 20	20
16	21 21	21
17	22	22
18	23	23
19	24 24	24
20	25 25 25 26 26	26

HYBRID HISTOGRAM

Hybrid Histograms Conclusion

- Hybrid histograms have features of both frequency and height balanced histograms
- **Features similar to frequency histograms**
  - All occurrences of a value are placed in one bucket
  - ENDPOINT_NUMBER stores cumulative frequency
  - Variable bucket size
- **Features similar to Height Balanced histograms**
  - One bucket can have multiple values.
- Captures more endpoints
- Now we have a better estimate of the data distribution of “non-popular” values.
- Hybrid histograms are an improvement over height balanced histograms when top frequency histograms cannot be used

Hybrid Histograms : Corollary

- If no more than two values are stored in one bucket, frequency of all the values captured in buckets can be accurately estimated.

Total no. of entries in the bucket = BUCKET_SIZE
= Difference of 2 consecutive ENDPOINT_NUMBER's

Frequency of endpoint = ENDPOINT_REPEAT_COUNT

If BUCKET_SIZE = ENDPOINT_REPEAT_COUNT (e.g. Bucket no. 5)
Bucket filled with ENDPOINT_VALUE (8)
Frequency of endpoint = ENDPOINT_REPEAT_COUNT (30)

else (e.g. Bucket no. 4)
Bucket has two entries : endpoint (7) and non-endpoint (6)
Frequency of endpoint (7) = ENDPOINT_REPEAT_COUNT (3)
Frequency of non endpoint (6)= (BUCKET_SIZE - ENDPOINT_REPEAT_COUNT)
= (5 – 3) = 2

Hybrid Histograms : Corollary

- Frequency of values up to twice the number of buckets should be estimated accurately using hybrid histogram.
- Create a histogram with No. of buckets = NDV/2 = 26/2 = 13

```
DB12c>exec dbms_stats.gather_table_stats -
     (ownname => 'HR', tabname => 'HIST',method_opt => 'FOR COLUMNS ID
size 13', cascade => true);

DB12c> select table_name, column_name, histogram, num_distinct,
              num_buckets
       from dba_tab_col_statistics
       where table_name = 'HIST' and column_name = 'ID';

TABLE_NAME COLUMN_NAME     HISTOGRAM       NUM_DISTINCT NUM_BUCKETS
---------- --------------- --------------- ------------ -----------
HIST       ID              HYBRID                    26          13
```

Nb – Number of buckets
NDV – No. of Distinct Values

Hybrid Histograms: Corollary

```
DB12c>select ENDPOINT_VALUE
             ENDPOINT,
             ENDPOINT_NUMBER
             ENDPOINT_NO,
           endpoint_repeat_count
             rpt_cnt
      from   dba_histograms
      where  table_name = 'HIST'
      and    column_name = 'ID';

ENDPOINT ENDPOINT_NO RPT_CNT
-------- ----------- -------
       1           4       4
       5          10       1
       8          45      30
      11          56       6
      12          62       6
      13          68       6
      15          76       5
      17          82       3
      20          89       5
      22          92       1
      23          93       1
      24          95       2
      26         100       2
13 rows selected.
```

ENDPOINT_VALUE : Largest value in a bucket
ENDPOINT_NUMBER : Cumulative frequency
ENDPOINT_REPEAT_COUNT :Frequency of endpoint

BUCKET NUMBER	VALUES	ENDPOINT _VALUE
1	1 1 1 1	1
2	2 2 3 4 4 5	5
3	6 6 7 7 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	8
4	9 9 9 10 10 11 11 11 11 11 11	11
5	12 12 12 12 12 12	12
6	13 13 13 13 13 13	13
7	14 14 14 15 15 15 15 15	15
8	16 16 16 17 17 17	17
9	18 19 20 20 20 20 20	20
10	21 21 22	22
11	23	23
12	24 24	24
13	25 25 25 26 26	26

ACTUAL HYBRID HISTOGRAM (Nb = NDV/2)

BUCKET NUMBER	VALUES	ENDPOINT _VALUE
1	1 1 1 1 2 2	2
2	3 4 4	4
3	5 6 6	6
4	7 7 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	8
5	9 9 9 10 10	10
6	11 11 11 11 11 11 12 12 12 12 12 12	12
7	13 13 13 13 13 13 14 14 14	14
8	15 15 15 15 15 16 16 16	16
9	17 17 17 18	18
10	19 20 20 20 20 20	20
11	21 21 22	22
12	23 24 24	24
13	25 25 25 26 26	26

HYPOTHETICAL HYBRID HISTOGRAM (Nb = NDV/2)

Hybrid Histograms : Corollary

- Actual histogram
  - some of the buckets have more than two values
  - cardinality of some of the non endpoint values cannot be accurately determined.
- Hypothetical histogram
  - All the buckets have two values each.
  - cardinality of all (2*Nb) values can be accurately determined.
- Further enhancement?
  - Nb >= NDV / 2
    - Hybrid histogram with no more than two values per bucket
    - Accurately estimates frequency of all the distinct values
  - Nb < NDV / 2
    - Top Frequency Hybrid histogram with no more than two values per bucket
    - Captures (2*Nb) most popular values
    - Accurately estimates frequency of all the captured values

Nb – Number of buckets

NDV – No. of Distinct Values

Conclusion

- In 12c, frequency histogram can be created for NDV <= 2048 .
- Top Frequency and Hybrid histograms are designed to overcome flaws of Height-Balanced histograms.
- Top frequency and Hybrid histograms are created only if ESTIMATE_PERCENT = AUTO_SAMPLE_SIZE .
- Top frequency histogram accurately estimates the frequencies for only top occurring values if a small number of values dominate the data set.
- Hybrid histogram has features of both frequency and height balanced histograms
- Hybrid histogram captures more endpoints and estimates their frequency accurately.

Nb – Number of buckets

NDV – No. of Distinct Values

References

- http://docs.oracle.com/database/121/TGSQL/tgsql_histo.htm#TGSQL366
- http://jimczuprynski.files.wordpress.com/2014/04/czuprynski-select-q2-2014.pdf
- http://jonathanlewis.wordpress.com/2013/09/01/histograms/


Q&A

Thank You!

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