Before We Go Into Query Plan Costs… How do Updates Work? (Insert/Delete)

Example Using Delete

```
delete from R where a=1;
```

Query plan

Delete

|

Filter ($\sigma_{a=1}$)

|

SeqScan

|

R

In SimpleDB, the Delete Operator calls BufferPool.deleteTuple()

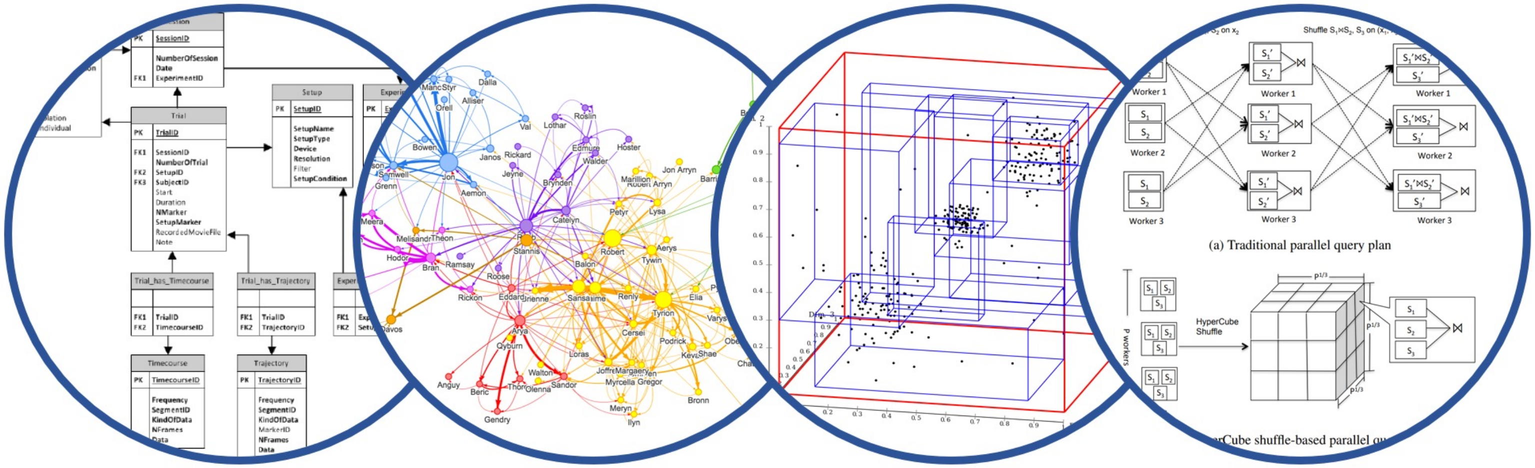
Why not call HeapFile.deleteTuple() directly?

Because there could also be indexes. Need some entity that will decide all the structures from where tuple needs to be deleted

BufferPool then calls HeapFile.deleteTuple()

Pushing Updates to Disk

- When inserting a tuple, HeapFile inserts it on a page but does not write the page to disk
- When deleting a tuple, HeapFile deletes tuple from a page but does not write the page to disk
- The buffer manager worries when to write pages to disk (and when to read them from disk)
- When need to add new page to file, HeapFile adds page to file on disk and then reads it through buffer manager



Database System Internals

Query Plan Costs

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

Query Optimizer

Three components:

- Cost estimation
  - Cardinality estimation T(R) each intermediate result
  - Cost = CPU + I/O + Network, all depend on T(R)
- Search space
  - Which plans do we consider?
- Search algorithm
  - How do we search the space?

Summary of External Join Algorithms

- Block Nested Loop: B(S) + B(R)*B(S)/(M-1)

- Index Join: B(R) + T(R)B(S)/V(S,a)
  (unclustered)

- Partitioned Hash: 3B(R)+3B(S);
  - min(B(R),B(S)) <= M^2

- Merge Join: 3B(R)+3B(S)
  - B(R)+B(S) <= M^2

Summary of Query Execution

- For each logical query plan
  - There exist many physical query plans
  - Each plan has a different cost
  - Cost depends on the data
- Additionally, for each query
  - There exist several logical plans
- Next lecture: query optimization
  - How to compute the cost of a complete plan?
  - How to pick a good query plan for a query?

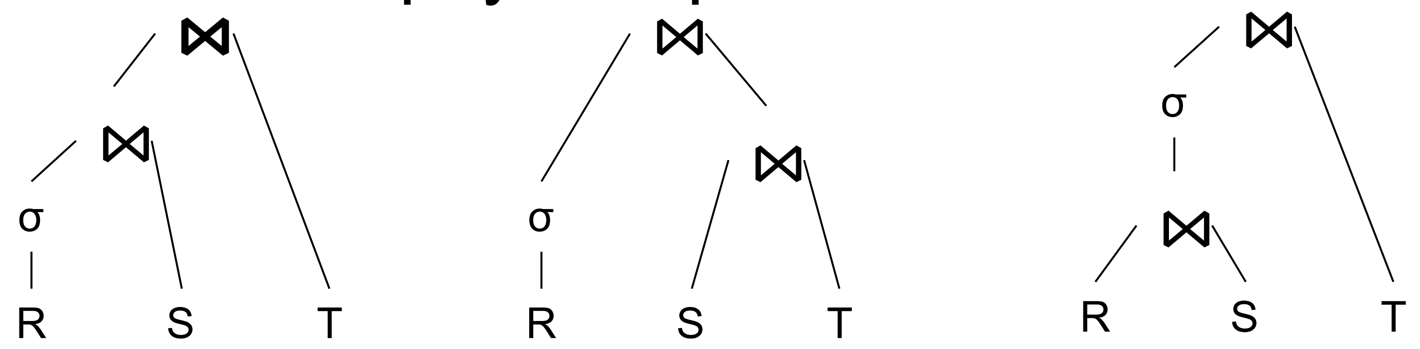
A Note About Skew

- Previously shown 2 pass join algorithms do not work for heavily skewed data

- For a sort-merge join, the maximum number of tuples with a particular join attribute should be the number of tuples per page:
  - This often isn't the case: would need multiple passes

Query Optimization Summary

Goal: find a physical plan that has minimal cost



What is the cost of a plan?

For each operator, cost is function of CPU, IO, network bw

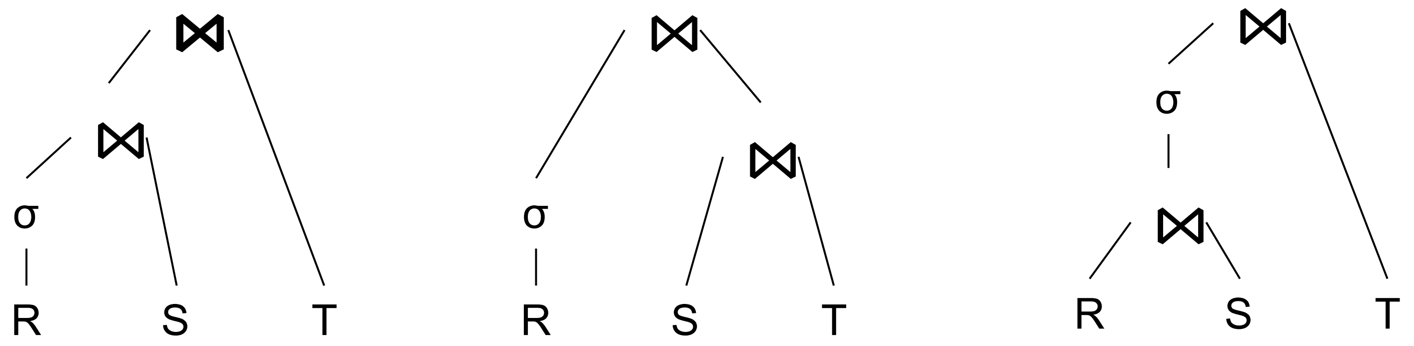
$$\text{Total\_Cost} = \text{CPUCost} + w_{IO}\,\text{IOCost} + w_{BW}\,\text{BWCost}$$

Cost of plan is total for all operators

In this class, we look only at IO

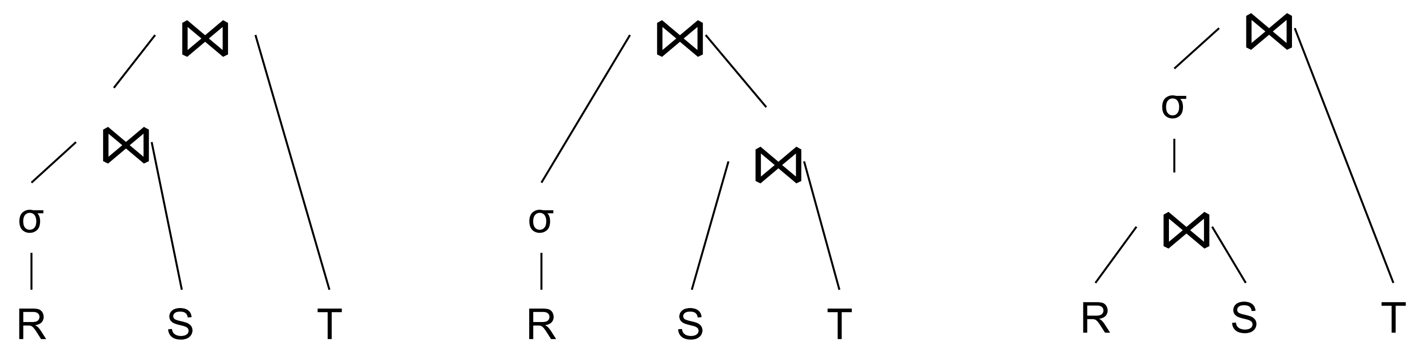
Query Optimization Summary

Goal: find a physical plan that has minimal cost



Query Optimization Summary

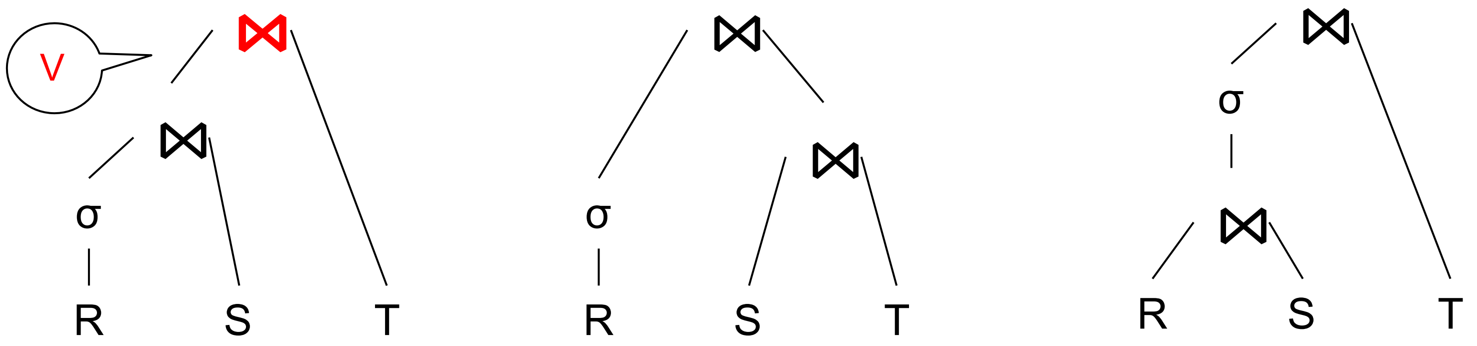
Goal: find a physical plan that has minimal cost



Know how to compute cost if know cardinalities

Query Optimization Summary

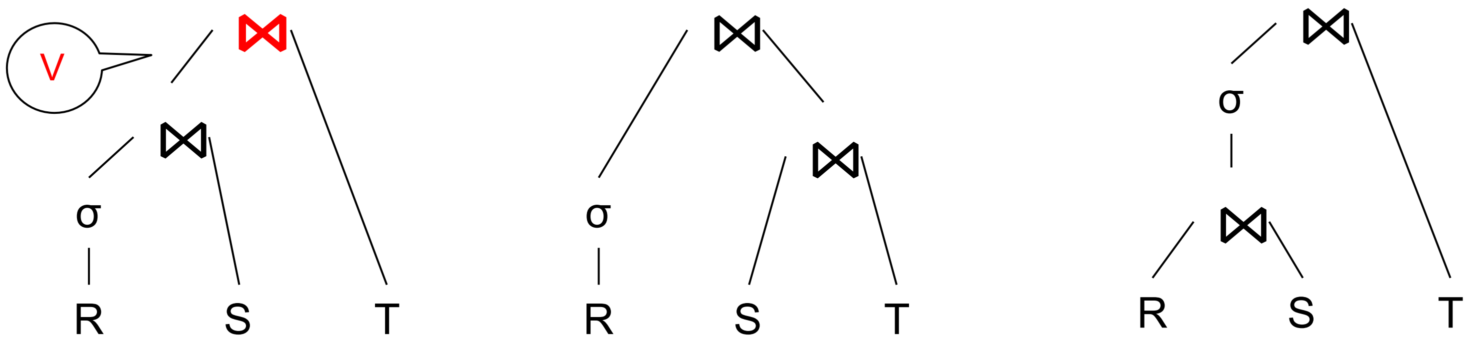
Goal: find a physical plan that has minimal cost



Know how to compute cost if know cardinalities

Query Optimization Summary

Goal: find a physical plan that has minimal cost

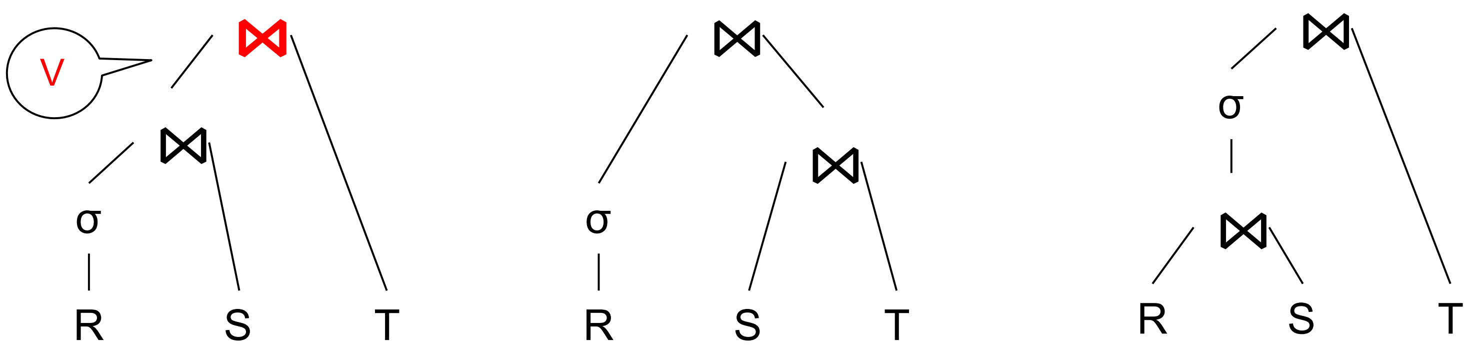


Know how to compute cost if know cardinalities

- Eg. Cost(V ⋈ T) = 3B(V) + 3B(T)
- B(V) = T(V) / PageSize
- T(V) = T(σ(R) ⋈ S)

Query Optimization Summary

Goal: find a physical plan that has minimal cost



Know how to compute cost if know cardinalities

- Eg. Cost(V ⋈ T) = 3B(V) + 3B(T)
- B(V) = T(V) / PageSize
- T(V) = T(σ(R) ⋈ S)

Cardinality estimation problem: e.g. estimate T(σ(R) ⋈ S)

Database Statistics

- Collect statistical summaries of stored data

- Estimate size (=cardinality) in a bottom-up fashion
  - This is the most difficult part, and still inadequate in today's query optimizers
- Estimate cost by using the estimated size
  - Hand-written formulas, similar to those we used for computing the cost of each physical operator

Database Statistics

- Number of tuples (cardinality) T(R)
- Indexes, number of keys in the index V(R,a)
- Number of physical pages B(R)
- Statistical information on attributes
  - Min value, Max value, V(R,a)
- Histograms

- Collection approach: periodic, using sampling

Size Estimation Problem

Q = SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Given T(R1), T(R2), …, T(Rn)
Estimate T(Q)

How can we do this ? Note: doesn't have to be exact.

Size Estimation Problem

Q = SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Remark: $T(Q) \leq T(R1) \times T(R2) \times \ldots \times T(Rn)$

Size Estimation Problem

Q = SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Remark: $T(Q) \leq T(R1) \times T(R2) \times \ldots \times T(Rn)$

Key idea: each condition reduces the size of $T(Q)$ by some factor, called selectivity factor

Selectivity Factor

- Each condition cond reduces the size by some factor called selectivity factor

- Assuming independence, multiply the selectivity factors

Example

R(A,B)
S(B,C)
T(C,D)

```
Q = SELECT *
      FROM R, S, T
      WHERE R.B=S.B and S.C=T.C and R.A<40
```

T(R) = 30k, T(S) = 200k, T(T) = 10k

Selectivity of R.B = S.B is 1/3
Selectivity of S.C = T.C is 1/10
Selectivity of R.A < 40 is ½

Q: What is the estimated size of the query output T(Q) ?

Example

R(A,B)
S(B,C)
T(C,D)

```
Q = SELECT *
    FROM R, S, T
    WHERE R.B=S.B and S.C=T.C and R.A<40
```

T(R) = 30k, T(S) = 200k, T(T) = 10k

Selectivity of R.B = S.B is 1/3
Selectivity of S.C = T.C is 1/10
Selectivity of R.A < 40 is ½

Q: What is the estimated size of the query output T(Q) ?

A: T(Q) = 30k * 200k * 10k * 1/3 * 1/10 * ½ = 10^{12}

Selectivity Factors for Conditions

- A = c /* $\sigma_{A=c}(R)$ */
  - Selectivity = 1/V(R,A)

Selectivity Factors for Conditions

- A = c /* $\sigma_{A=c}(R)$ */
  - Selectivity = 1/V(R,A)
- A < c /* $\sigma_{A<c}(R)$ */
  - Selectivity = (c - Low(R, A))/(High(R,A) - Low(R,A))

Selectivity Factors for Conditions

- A = c   /* $\sigma_{A=c}(R)$ */
  - Selectivity = 1/V(R,A)
- A < c   /* $\sigma_{A<c}(R)$ */
  - Selectivity = (c - Low(R, A))/(High(R,A) - Low(R,A))
- A = B   /* $R \bowtie_{A=B} S$ */
  - Selectivity = 1 / max(V(R,A),V(S,B))
  - (will explain next)

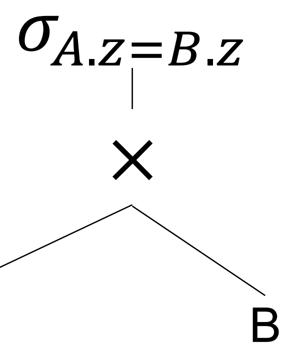
Assumptions

- *Containment of values*: if V(R,A) <= V(S,B), then all values R.A occur in S.B
  - Note: this indeed holds when A is a foreign key in R, and B is a key in S

- *Preservation of values*: for any other attribute C, $V(R \bowtie_{A=B} S, C) = V(R, C)$ (or V(S, C))
  - Note: we don't need this to estimate the size of the join, but we need it in estimating the next operator

Cardinality Estimation: JOIN

```
SELECT *
FROM A, B
WHERE A.z = B.z
```



1. T(A) * T(B) tuples in Cartesian product
2. Suppose z0 exists in the join
3. How many times does z0 occur?
   - Like the selection condition $\sigma_{A.z=z0\ AND\ B.z=z0}$

Selectivity Factor
1/V(A, z) * 1/V(B, z)

4. How many distinct z0s exist in the join?
   - ≥ 0 [if no overlap]
   - ≤ min{V(A, z), V(B, z)} [if full overlap]
   - For this class, ASSUME full overlap
     - As if one is a subset of the other (containment assumption)
5. Multiply by estimate # of distinct z0s

$$\frac{T(A) * T(B)}{V(A,z) * V(B,z)} * \min\{V(A,z), V(B,z)\} = \frac{T(A) * T(B)}{\max\{V(A,z),\ V(B,z)\}}$$

Complete Example

Supplier(sno, sname, scity, sstate)
Supply(sno, pno, quantity)

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sno = y.sno
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```

Suppy.sno references Supplier.sno

- Some statistics
  - T(Supplier) = 1000 records
  - T(Supply) = 10,000 records
  - B(Supplier) = 100 pages
  - B(Supply) = 100 pages
  - V(Supplier,scity) = 20, V(Suppliers,state) = 10
  - V(Supply,pno) = 2,500
  - Both relations are clustered
- M = 11

Physical Query Plan 1

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier,scity) = 20
V(Supplier,state) = 10
V(Supply,pno) = 2,500

M = 11
Suppy.sno references Supplier.sno

(On the fly) π_{sname}

(On the fly) $\sigma_{scity=\text{'Seattle'} \wedge sstate=\text{'WA'} \wedge pno=2}$

(Nested loop memory optimized) $\bowtie_{sno = sno}$

Supplier (File scan)

Supply (File scan)

Selection and project on-the-fly
-> No additional cost.

Total cost of plan is thus cost of join:
= B(Supplier)+B(Supplier)*B(Supply)
= 100 + 100 * 100 / (11-1)
= 1,100 I/Os

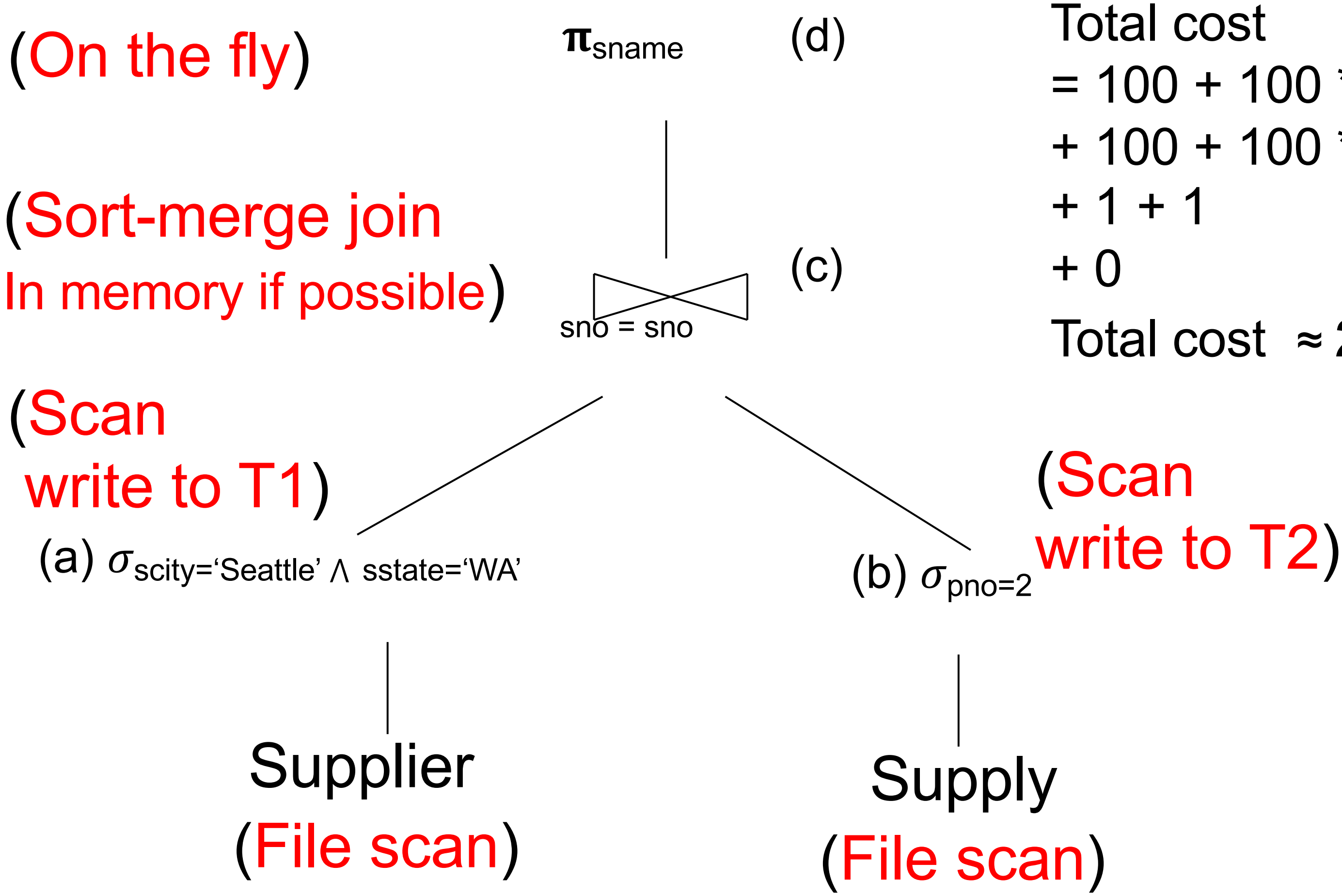
Physical Query Plan 2

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier,scity) = 20
V(Supplier,state) = 10
V(Supply,pno) = 2,500

M = 11
Suppy.sno references Supplier.sno



Total cost
= 100 + 100 * 1/20 * 1/10 (a)
+ 100 + 100 * 1/2500 (b)
+ 1 + 1 (c)
+ 0 (d)
Total cost ≈ **204 I/Os**

Plan 2 with Different Numbers

V(Supplier,scity) = 20   V(Supplier,state) = 10   V(Supply,pno) = 2,500

M = 11

Suppy.sno references Supplier.sno

What if we had:
10K pages of Supplier
10K pages of Supply

(d) π_{sname}

(c) ⋈ sno = sno
(Sort-merge join
In memory if possible)

(a) $\sigma_{scity=\text{'Seattle'} \wedge sstate=\text{'WA'}}$
(Scan
write to T1)

(b) $\sigma_{pno=2}$
(Scan write to T2)

Supplier
(File scan)

Supply
(File scan)

Total cost
= 10000 + 50 (a)
+ 10000 + 4 (b)
+ 3*50 + 4 (c)
+ 0 (d)
Total cost ≈ 20,208 I/Os

Need to do a two-pass sort algorithm for Supplier since 50 blocks > M

Physical Query Plan 3

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier,scity) = 20
V(Supplier,state) = 10
V(Supply,pno) = 2,500

M = 11

Suppy.sno references Supplier.sno

(On the fly) (d)

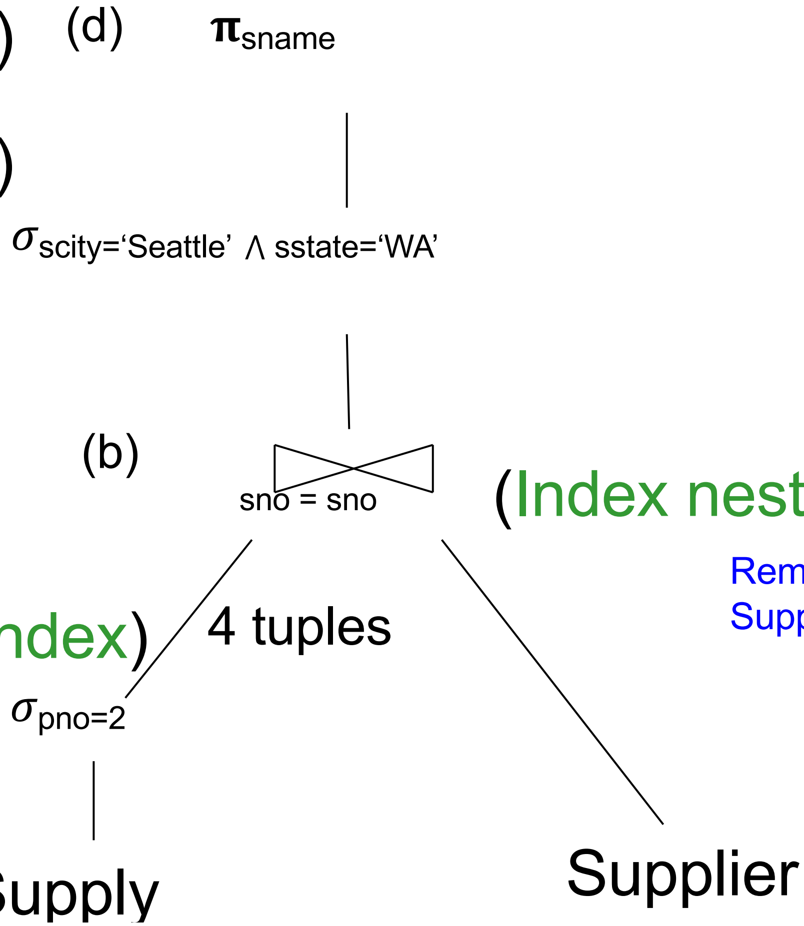
(On the fly) (c)

(b)

(Index nested loop)

Remember: Suppy.sno references Supplier.sno

(Use hash index) (a)



(Hash index on pno) Assume: clustered

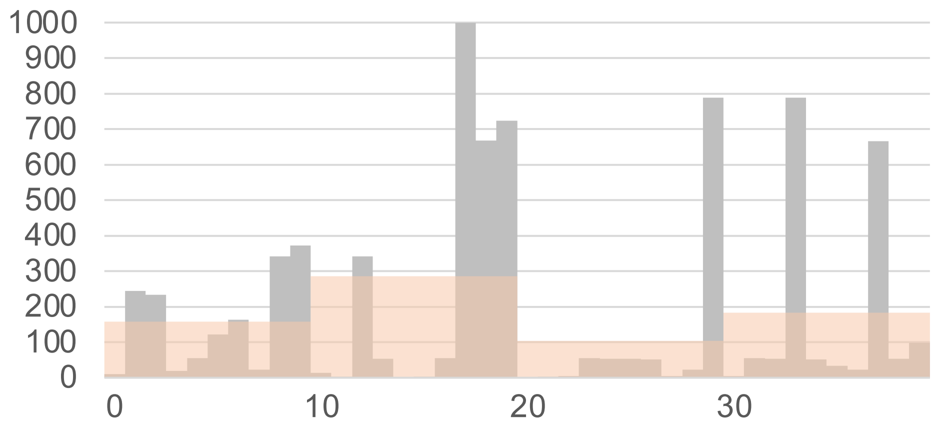
(Hash index on sno) Clustering does not matter

Total cost
= 1 (a)
+ 4 (b)
+ 0 (c)
+ 0 (d)

Total cost ≈ **5 I/Os**

Histograms

- Statistics on data maintained by the RDBMS
- Makes size estimation much more accurate (hence, cost estimations are more accurate)



Histograms

Employee(<u>ssn</u>, name, age)

T(Employee) = 25000, V(Empolyee, age) = 50
min(age) = 19, max(age) = 68

$\sigma_{age=48}$(Empolyee) = ? $\sigma_{age>28 \text{ and } age<35}$(Empolyee) = ?

Histograms

Employee(ssn, name, age)

T(Employee) = 25000, V(Empolyee, age) = 50
min(age) = 19, max(age) = 68

$\sigma_{age=48}$(Empolyee) = ? $\sigma_{age>28 \text{ and } age<35}$(Empolyee) = ?

Uniform Estimate = 25000 / 50 = 500

Uniform Estimate = 25000 * 6 / 50 = 3000

Histograms

Employee(<u>ssn</u>, name, age)

T(Employee) = 25000, V(Empolyee, age) = 50
min(age) = 19, max(age) = 68

$\sigma_{age=48}$(Empolyee) = ? $\sigma_{age>28 \text{ and } age<35}$(Empolyee) = ?

Age:	0-20	20-29	30-39	40-49	50-59	> 60
Tuples	200	800	5000	12000	6500	500

Histograms

Employee(ssn, name, age)

T(Employee) = 25000, V(Empolyee, age) = 50
min(age) = 19, max(age) = 68

$\sigma_{age=48}$(Empolyee) = ? $\sigma_{age>28 \text{ and } age<35}$(Empolyee) = ?

Age:	0..20	20..29	30-39	40-49	50-59	> 60
Tuples	200	800	5000	12000	6500	500

Histogram Estimate = 1200

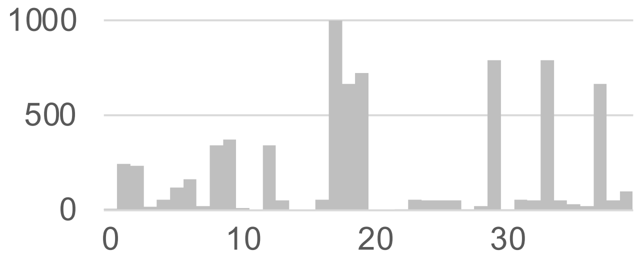
Histogram Estimate = 1*80 + 5*500 = 2580

Types of Histograms

- How should we determine the bucket boundaries in a histogram?

Types of Histograms

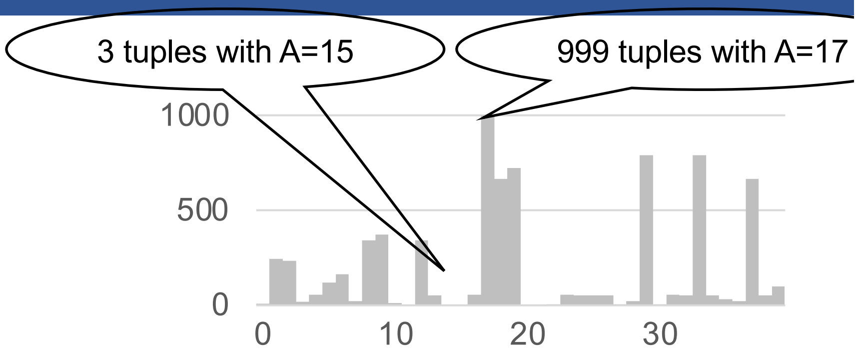
- Eqwidth



- Eqdepth

- V-optimal: minimize error

Types of Histograms



- Eqwidth

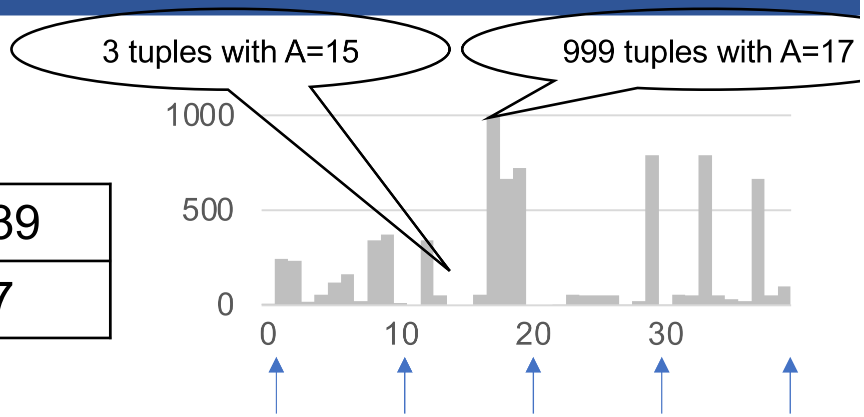
- Eqdepth

- V-optimal: minimize error

Types of Histograms

- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827



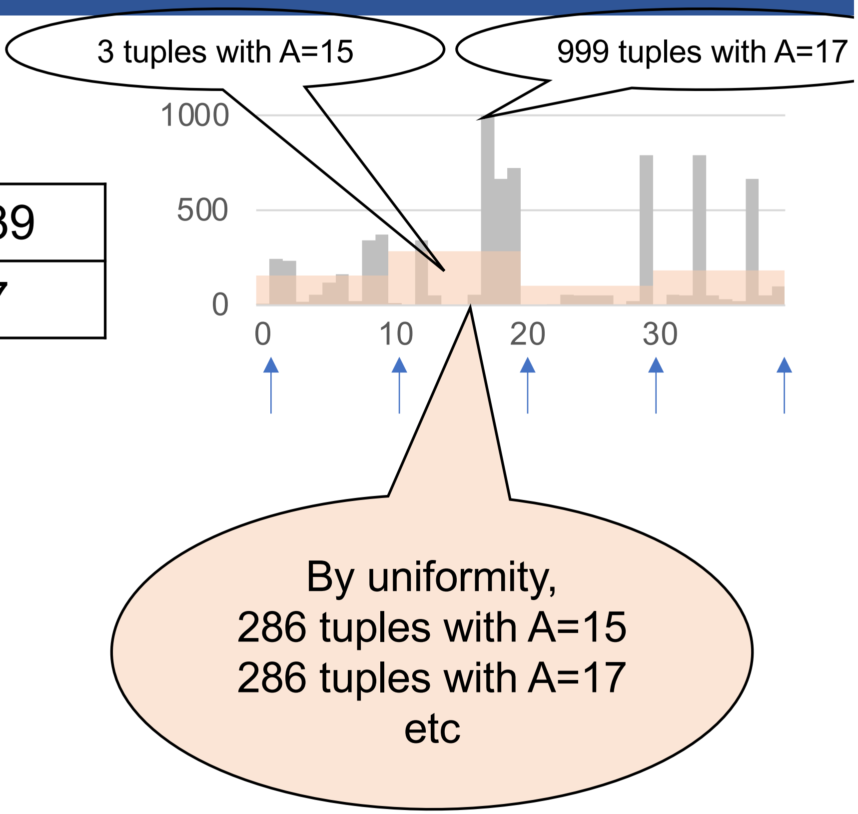
- Eqdepth

- V-optimal: minimize error

Types of Histograms

- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827



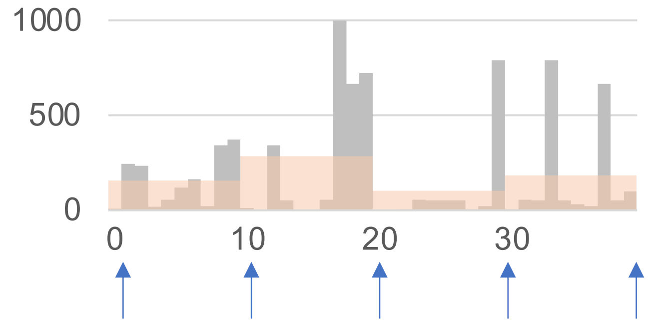
- Eqdepth

- V-optimal: minimize error

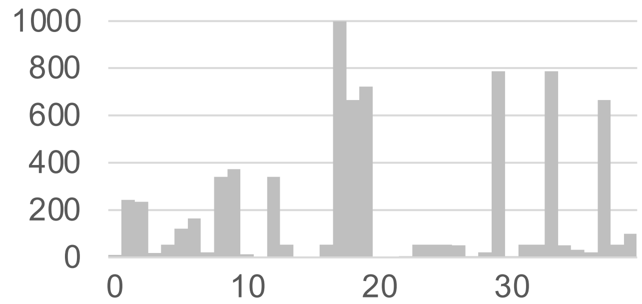
Types of Histograms

- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827



- Eqdepth

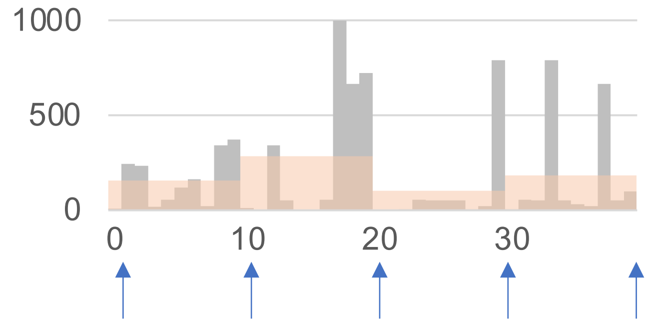


- V-optimal: minimize error

Types of Histograms

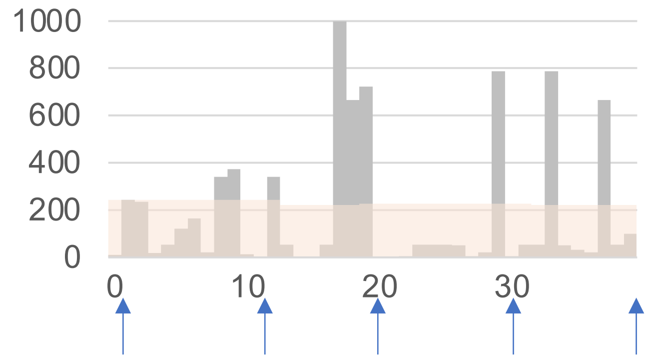
- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827



- Eqdepth

Attr =	0..12	13..18	19..31	32..39
#tuples	1943	1779	1822	1767

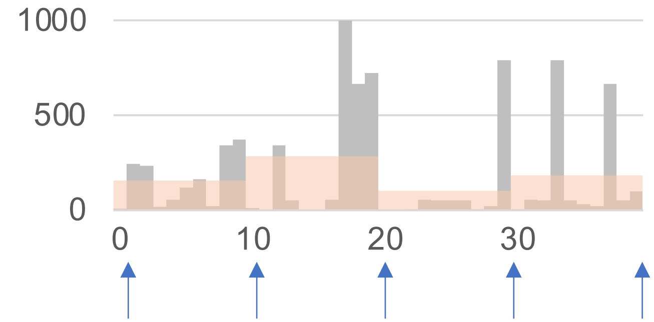


- V-optimal: minimize error

Types of Histograms

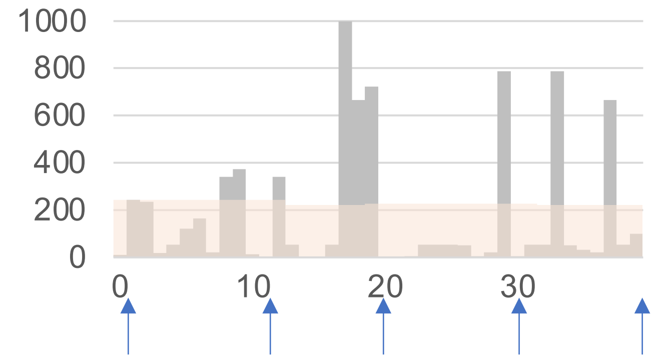
- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827

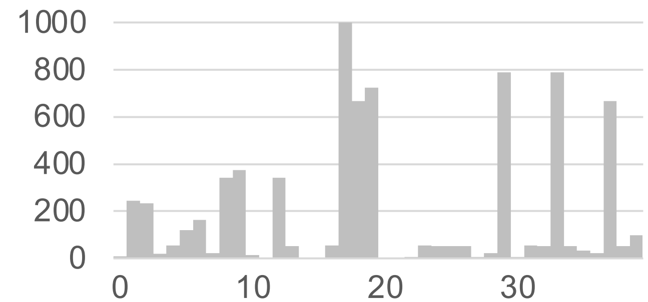


- Eqdepth

Attr =	0..12	13..18	19..31	32..39
#tuples	1943	1779	1822	1767



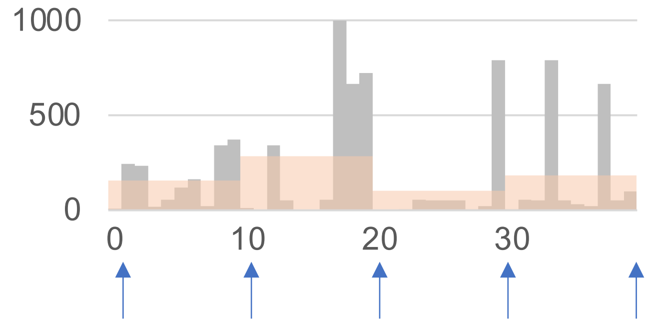
- V-optimal: minimize error



Types of Histograms

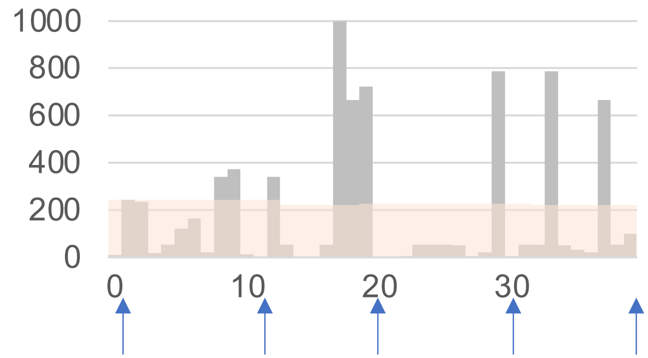
- Eqwidth

Attr =	0..9	10..19	20..29	30..39
#tuples	1585	2860	1039	1827



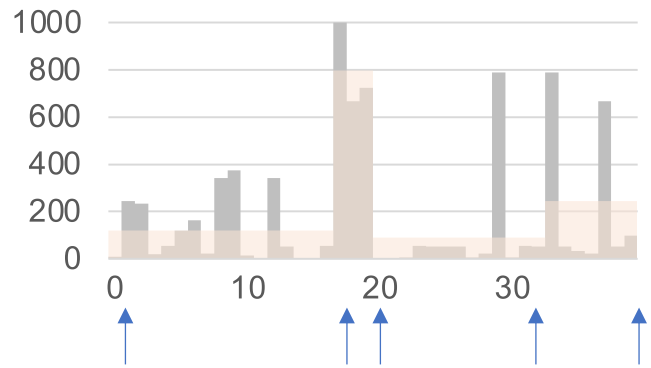
- Eqdepth

Attr =	0..12	13..18	19..31	32..39
#tuples	1943	1779	1822	1767



- V-optimal: minimize error

Attr =	0..16	17..19	20..34	35..39
#tuples	2056	2389	1152	1714



Minimizes $\sum_a |\text{true-\#tuples}(a) - \text{estimate-\#tuples}(a)|^2$

Difficult Questions on Histograms

- Small number of buckets
  - Hundreds, or thousands, but not more
  - WHY?

- *Not* updated during database update, but recomputed periodically
  - WHY?

- Multidimensional histograms rarely used
  - WHY?

Difficult Questions on Histograms

- Small number of buckets
  - Hundreds, or thousands, but not more
  - WHY? All histograms are kept in main memory during query optimization; plus need fast access

- *Not* updated during database update, but recomputed periodically
  - WHY?

- Multidimensional histograms rarely used
  - WHY?

Difficult Questions on Histograms

- Small number of buckets
  - Hundreds, or thousands, but not more
  - WHY? All histograms are kept in main memory during query optimization; plus need fast access
- *Not* updated during database update, but recomputed periodically
  - WHY? Histogram update creates a write conflict; would dramatically slow down transaction throughput
- Multidimensional histograms rarely used
  - WHY?

Difficult Questions on Histograms

- Small number of buckets
  - Hundreds, or thousands, but not more
  - WHY? All histograms are kept in main memory during query optimization; plus need fast access

- *Not* updated during database update, but recomputed periodically
  - WHY? Histogram update creates a write conflict; would dramatically slow down transaction throughput

- Multidimensional histograms rarely used
  - WHY? Too many possible multidimensional histograms, unclear which ones to choose and how to use