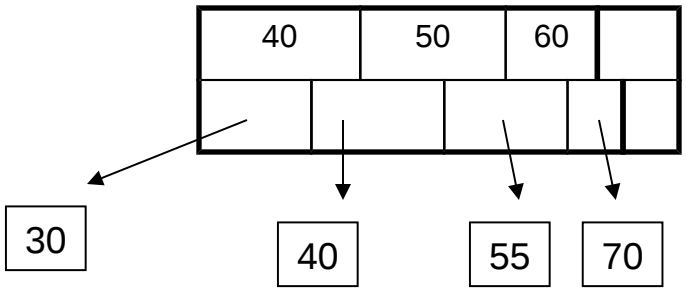
CSE 444: Database Internals

Section 3:

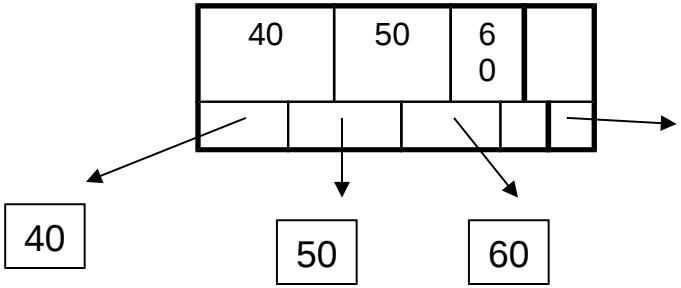
Indexing and Operator Algorithms

Insertions and Deletion in a B+ tree

- Note: the <, <= assumptions in this class:



Internal node:
• Left pointer from key = k: to keys < k
• Right pointer: to keys >= k



Leaf node:
• Left pointer from key = k: to the block containing data with value k in that attribute
• Last remaining pointer on right: To the next leaf on right

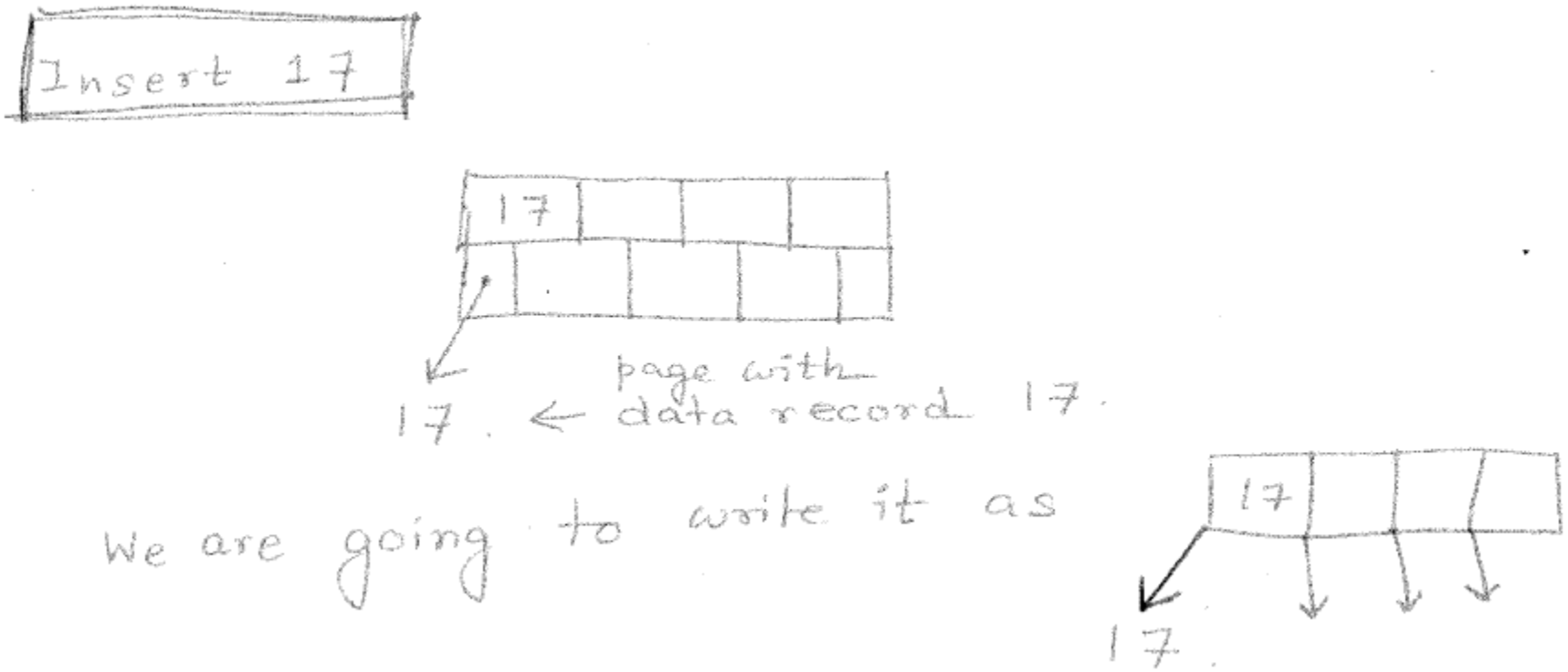
Insertions and Deletion in a B+ tree

- Note: when a leaf is split, the middle (d+1-th) key is copied to the new leaf on right (and also inserted in parent)
  - Since we assumed the right pointer from key = k points to keys >= k
- Note: when an internal node is split, we do not need to copy the middle (d+1-th) key to the right, only insert it in parent
  - Use the left pointer of the new right internal node.
  - See the example

Problem 1:
B+ tree insertion and deletion

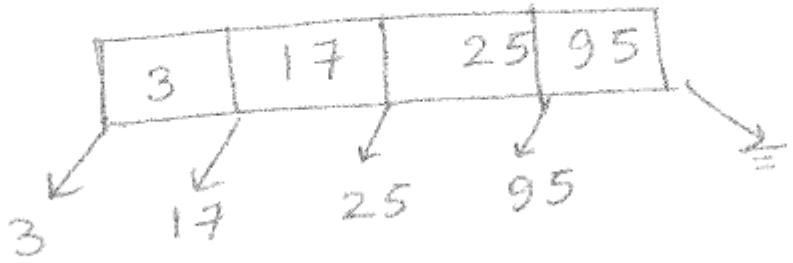
- Start with an empty B+ tree, d=2
- Insert 17, 3, 25, 95, 8, 57, 69
- Then insert 29, 91, 78, 80, 92, 99, 97

Problem 1:
B+ tree insertion and deletion



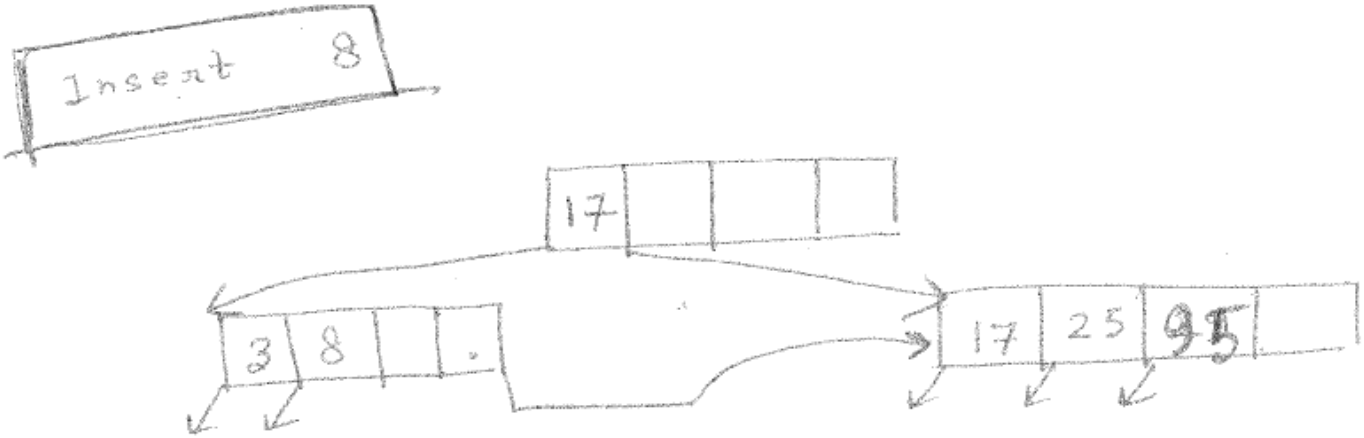
Problem 1:
B+ tree insertion and deletion

Insert 3, 25, 95



no next leaf on right.

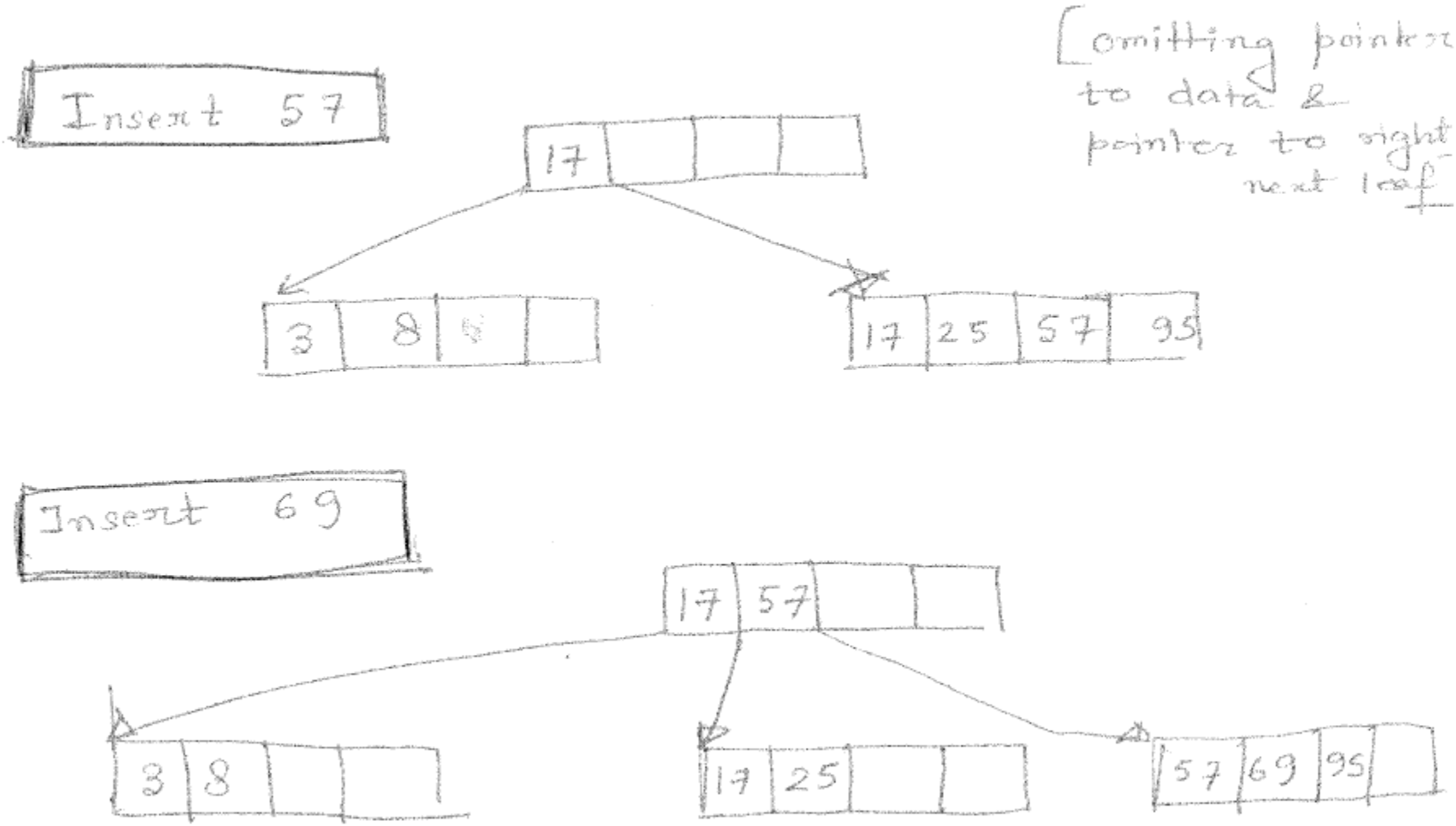
Problem 1:
B+ tree insertion and deletion



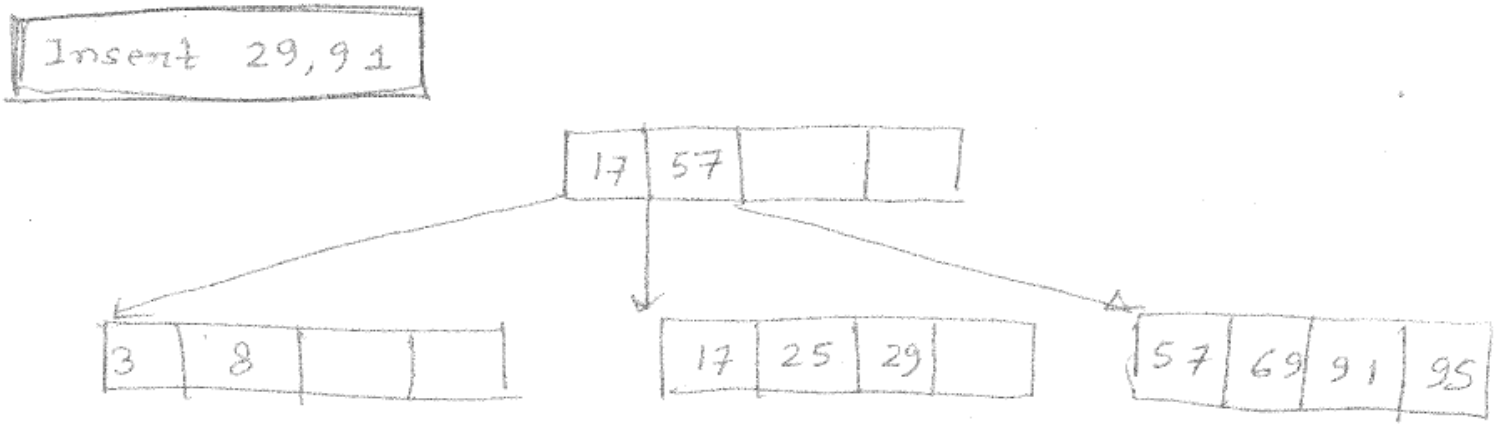
Note : A Leaf is being split
Copy middle key to right leaf

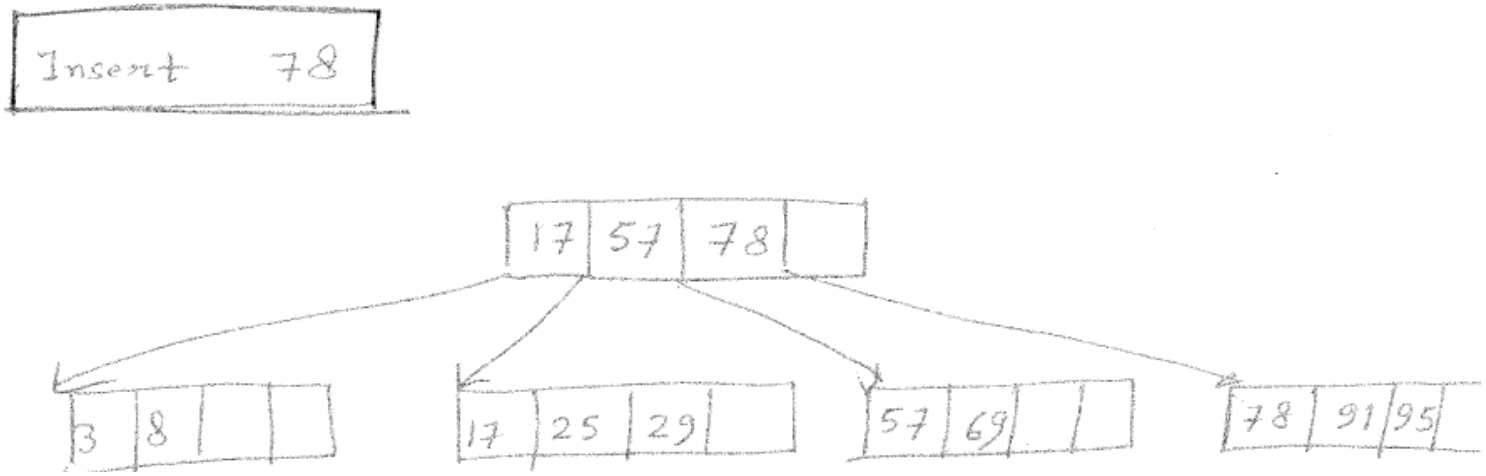
(later :- copying the key at the middle is not needed when an internal node is split).

Problem 1:
B+ tree insertion and deletion

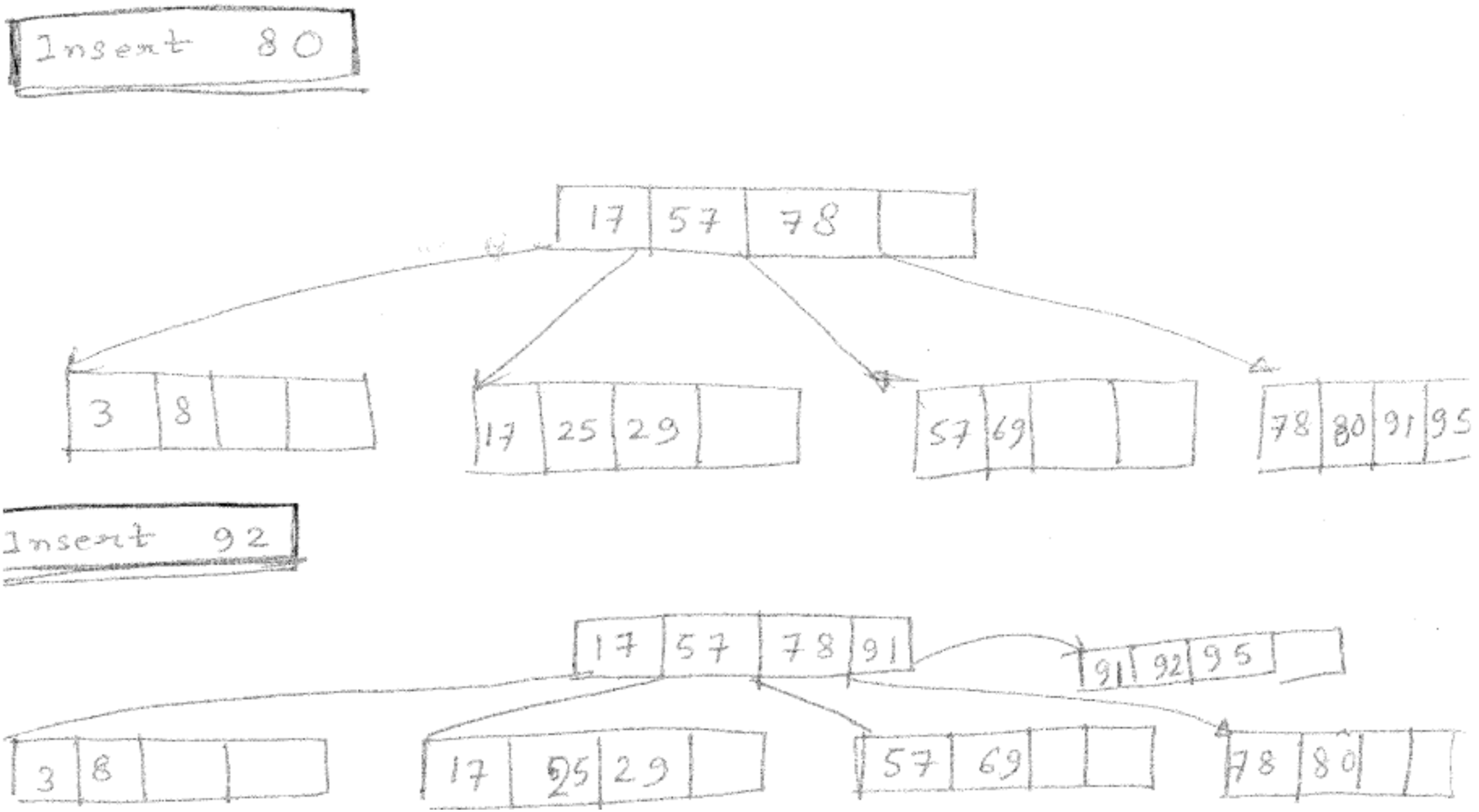


Problem 1:
B+ tree insertion and deletion

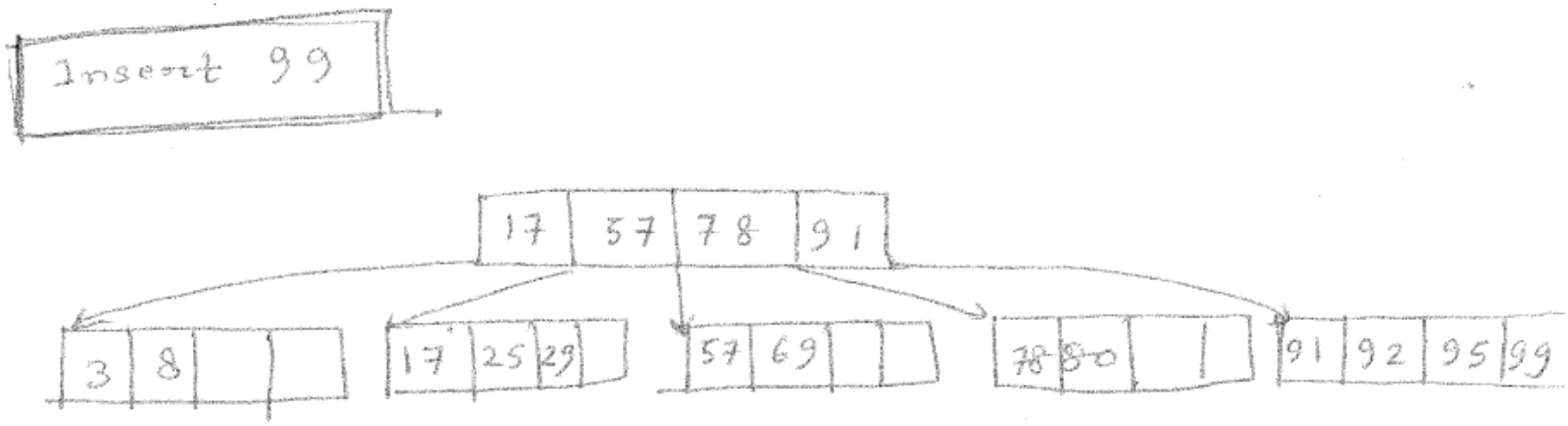




Problem 1:
B+ tree insertion and deletion



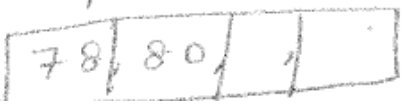
Problem 1:
B+ tree insertion and deletion



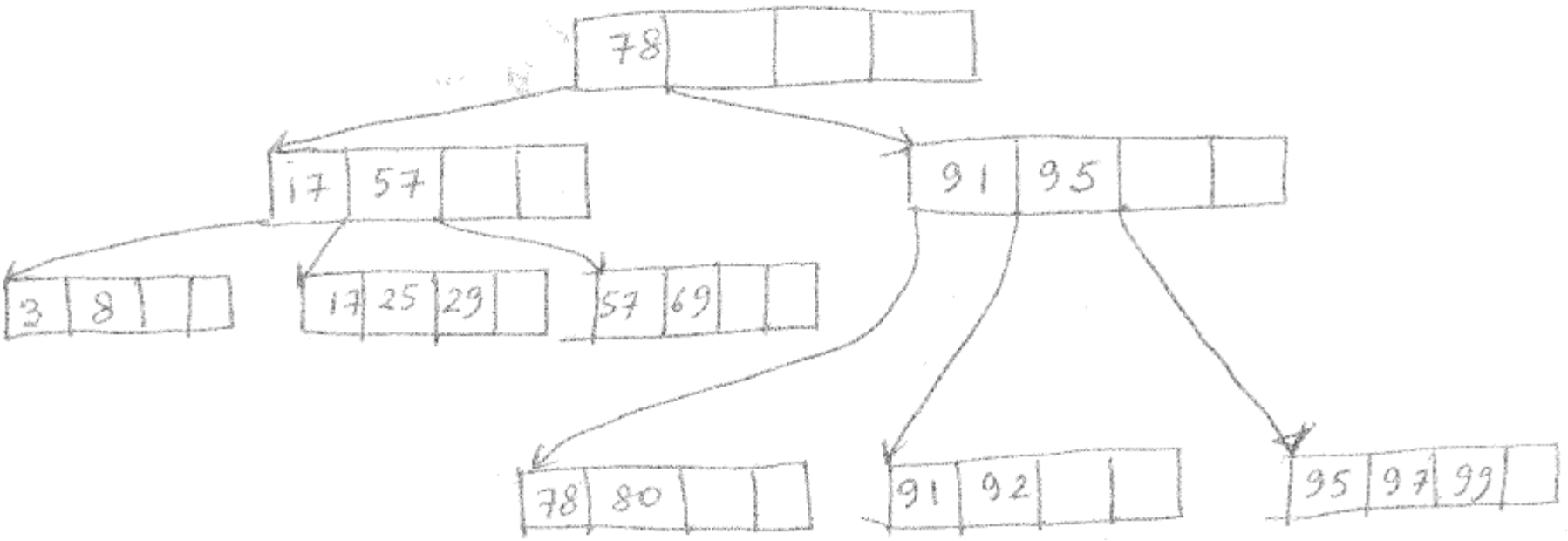
Need to split root, height increases !

Note :- 78 is not being copied to right new node. unlike leaves

why ? We have left pointer from 91 which can point to



Problem 1:
B+ tree insertion and deletion

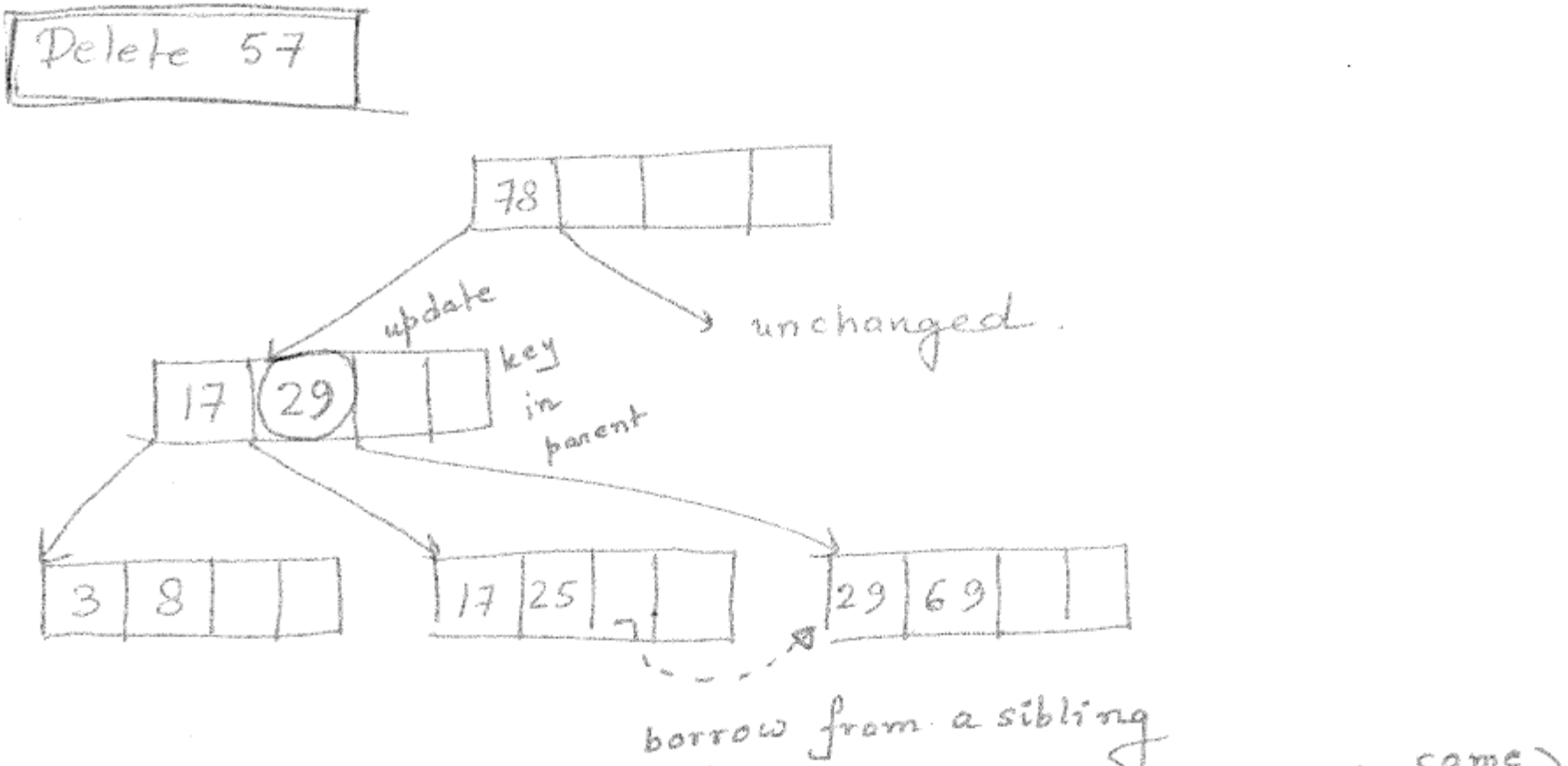


Problem 1:
B+ tree insertion and deletion

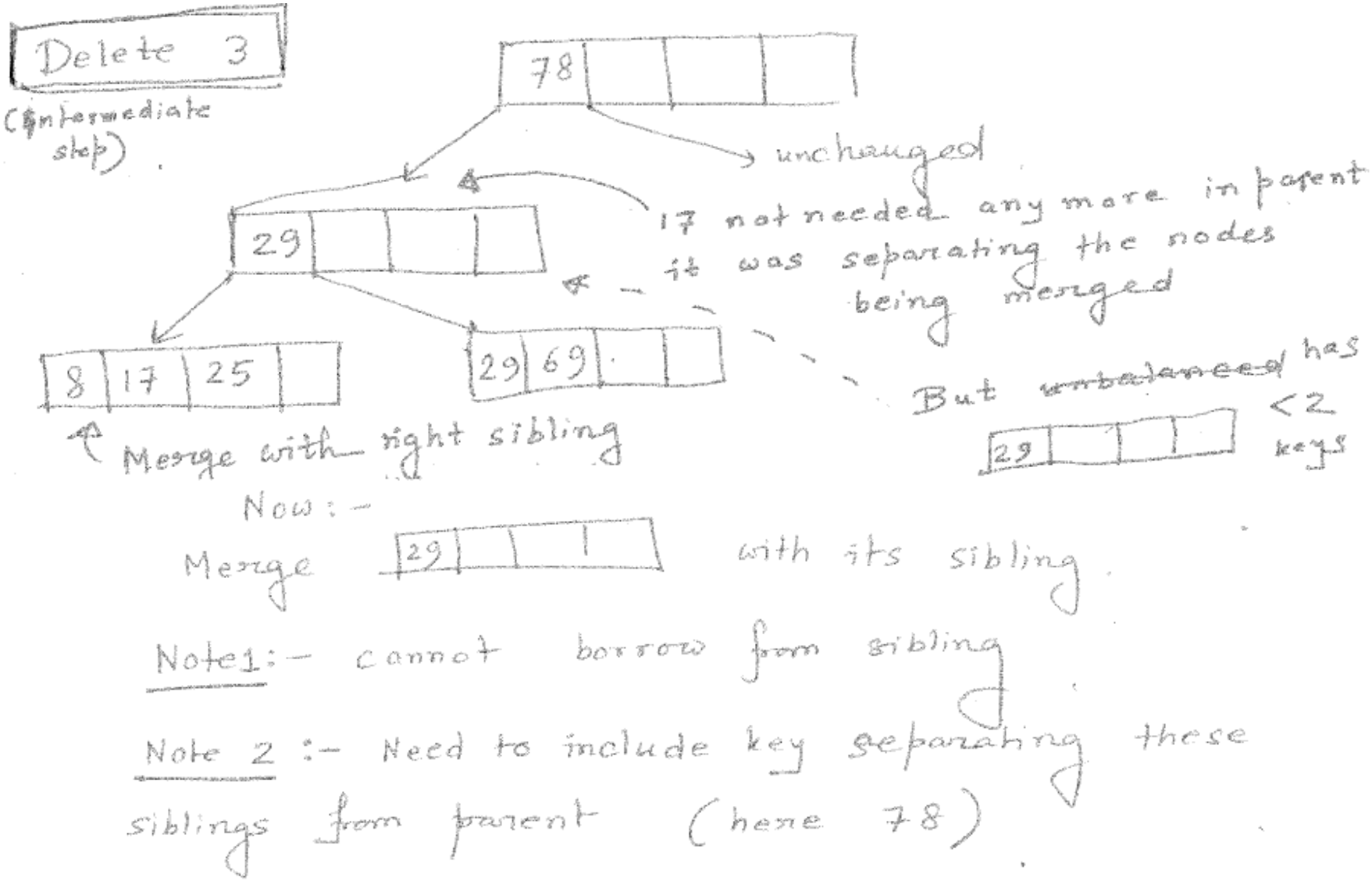
- Now delete all nodes in the following order:

57, 3, 99, 29, 17, 25, 95, 8, 78, 92, 69, 97, 91

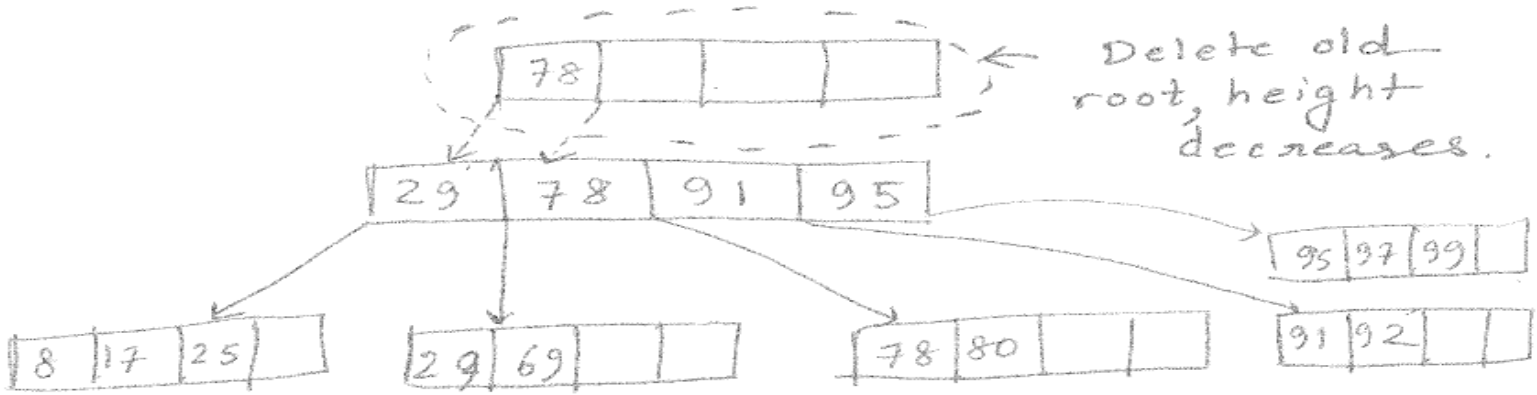
Problem 1:
B+ tree insertion and deletion



Problem 1:
B+ tree insertion and deletion



Problem 1:
B+ tree insertion and deletion



Note 3: We always have space to include the key separating the siblings.

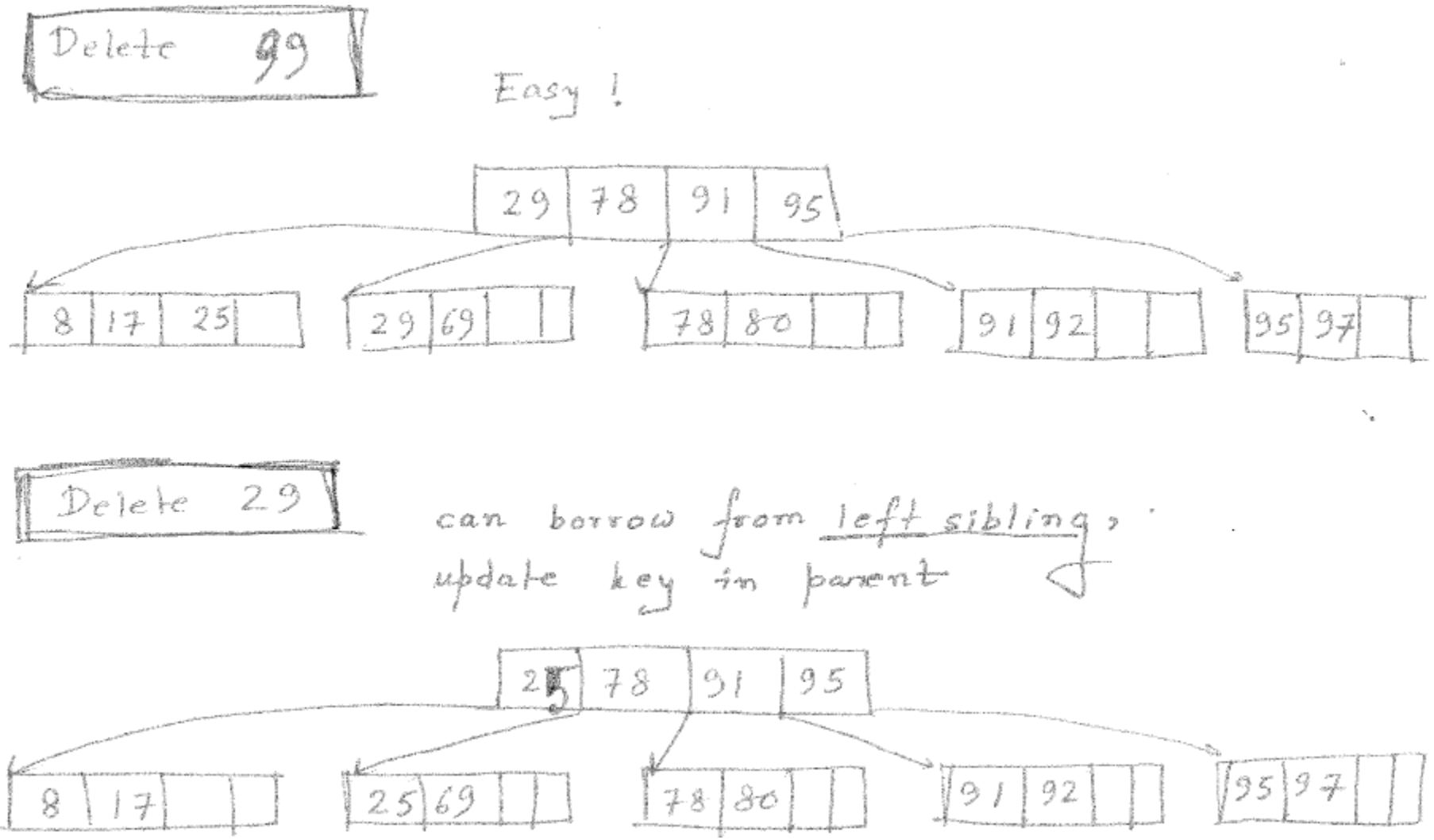
left sibling : $\leq d-1$ keys (that's why needed more keys)

right sibling : $\leq d$ keys (that's why we could not borrow from it)

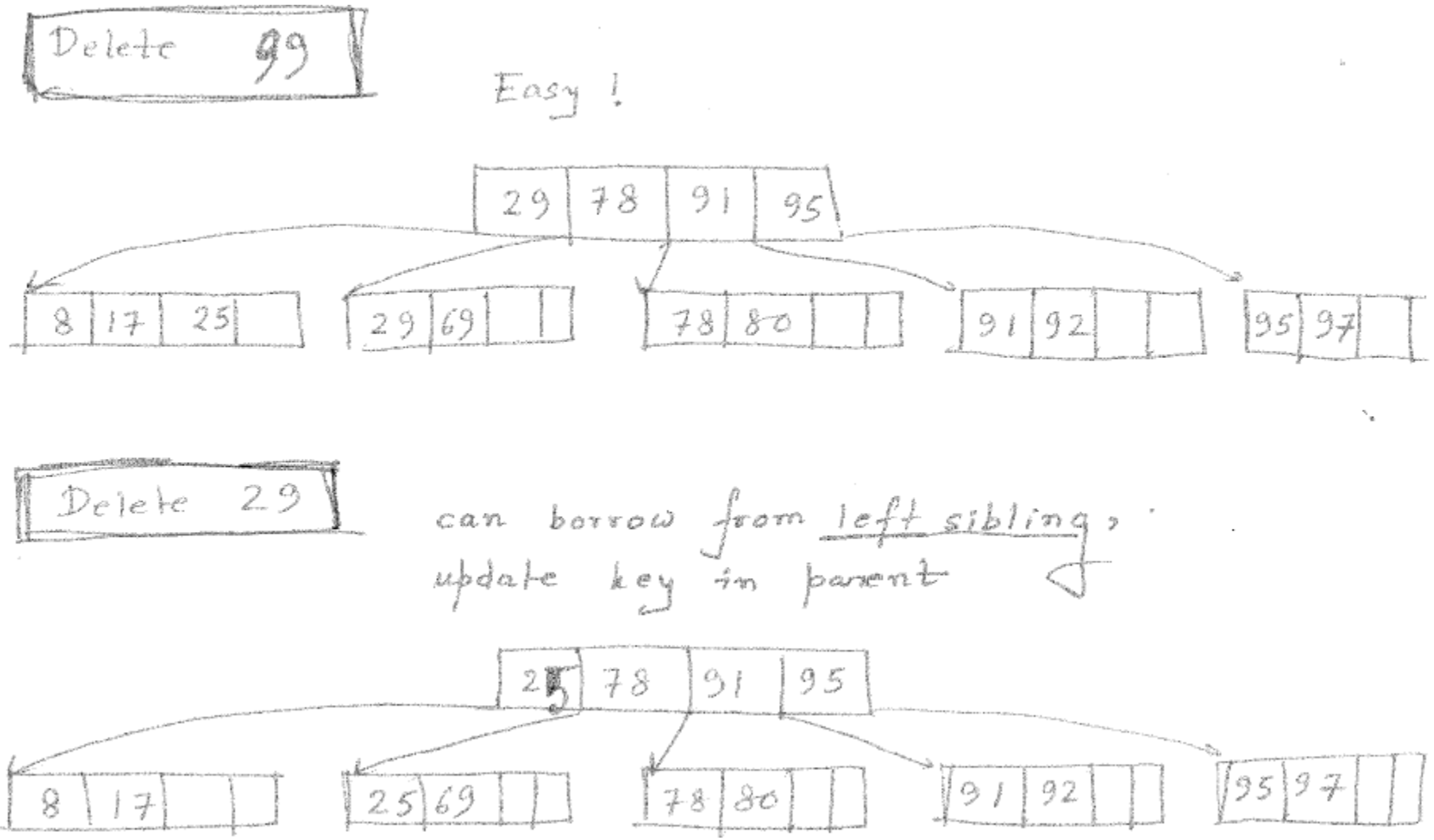
Total $\leq 2d-1$ keys.

So there we have room to include the key from parent (here 78)

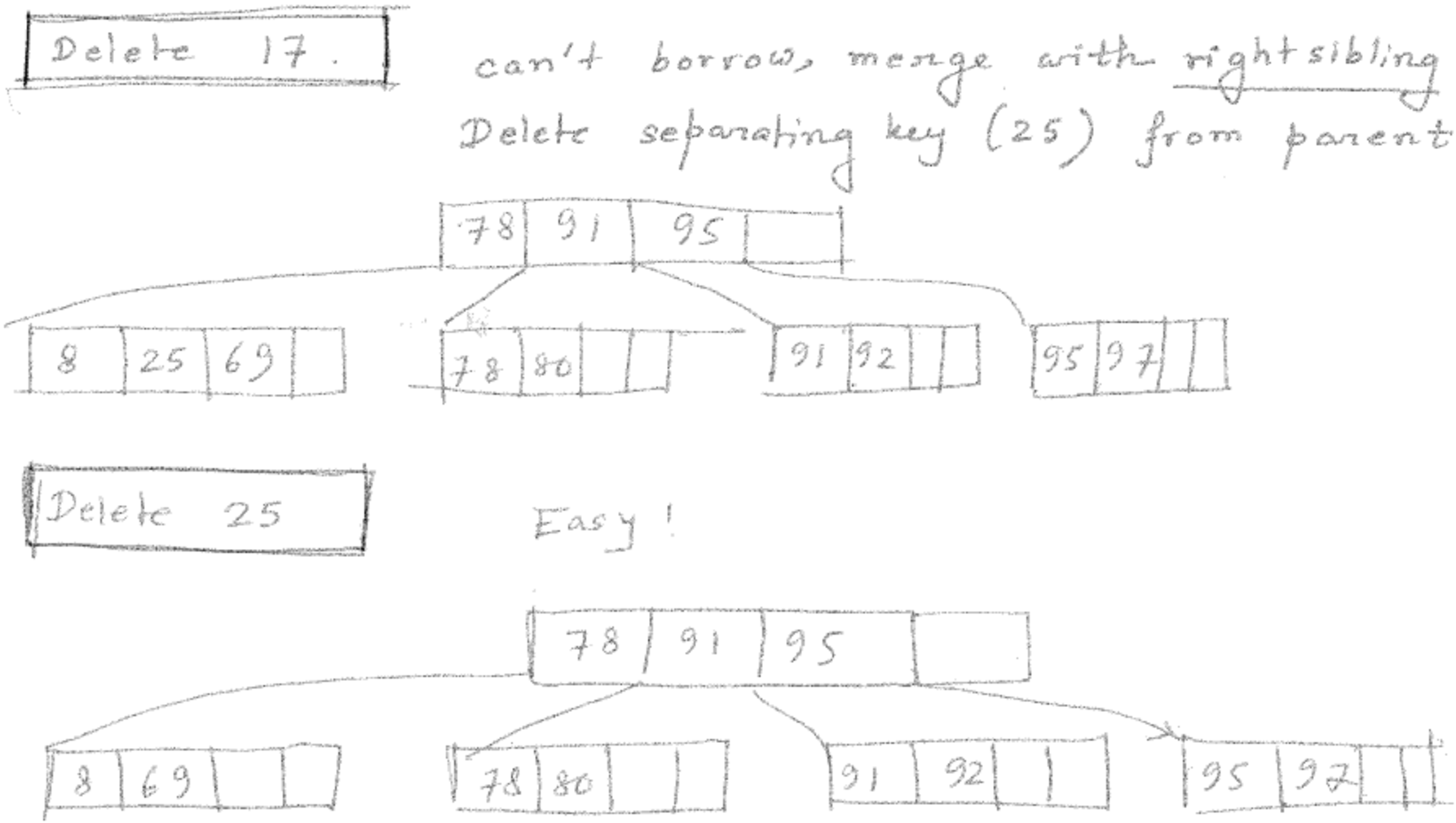
Problem 1:
B+ tree insertion and deletion



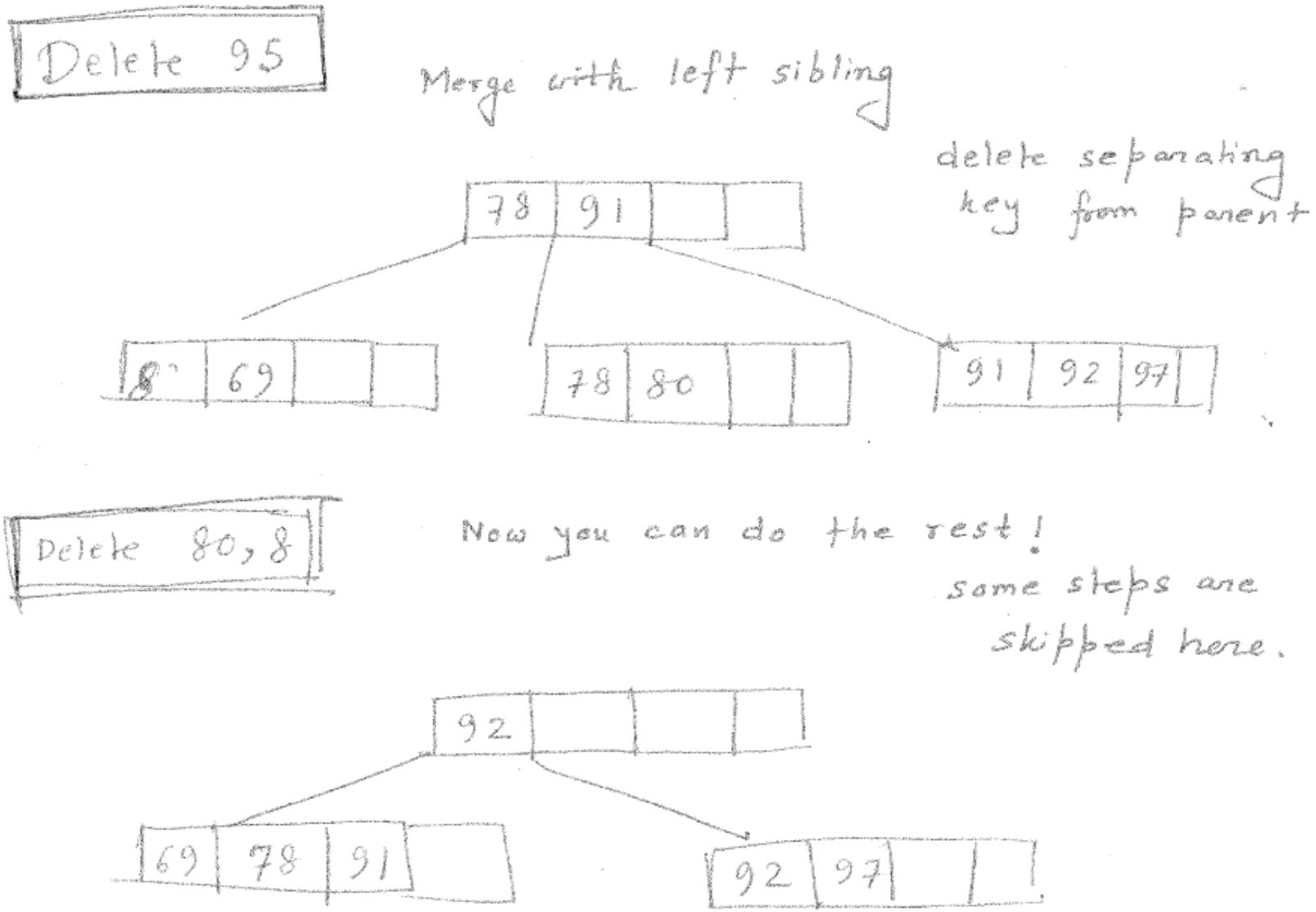
Problem 1:
B+ tree insertion and deletion



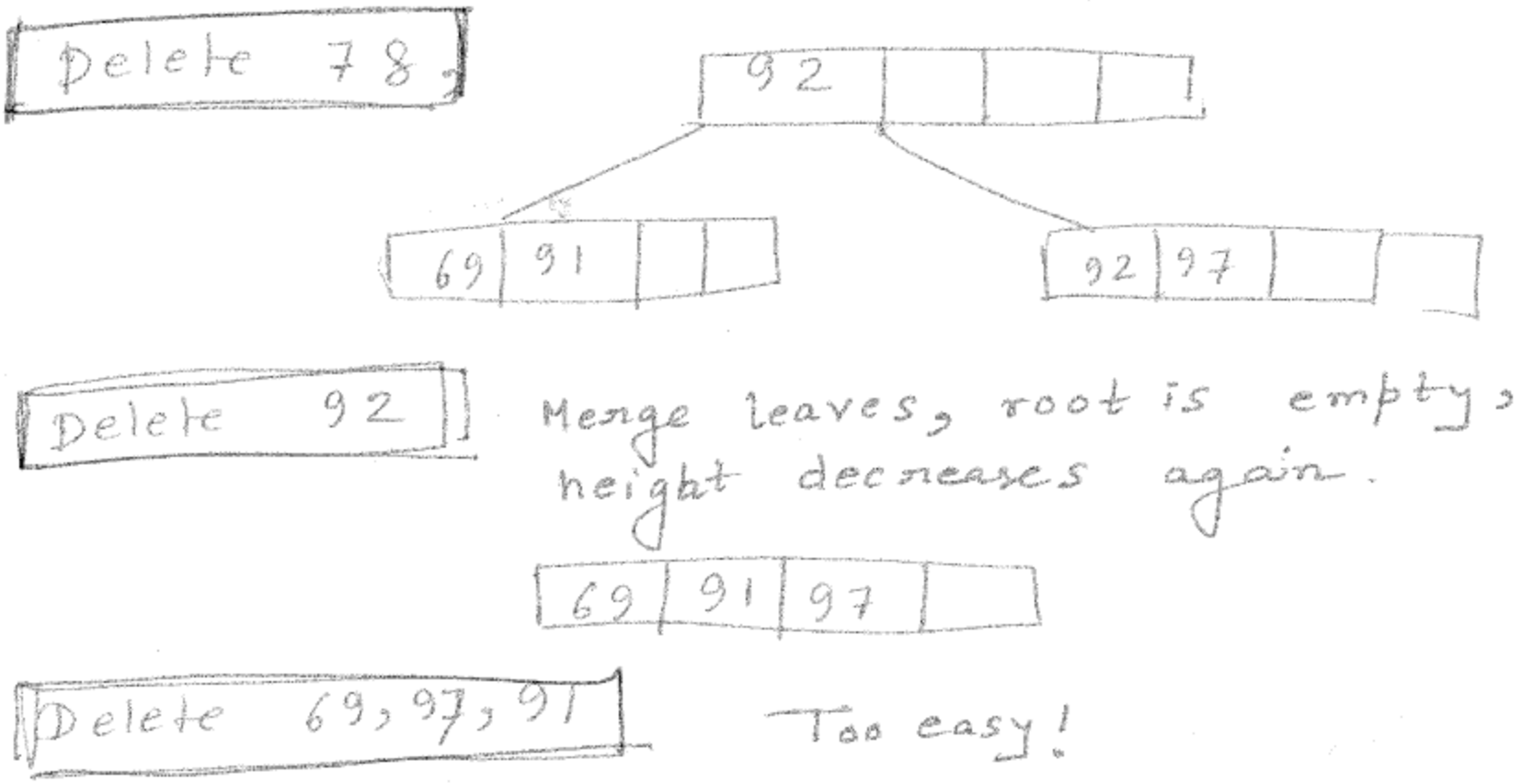
Problem 1:
B+ tree insertion and deletion



Problem 1:
B+ tree insertion and deletion



Problem 1:
B+ tree insertion and deletion



Notations

- B(R) = # of blocks (i.e. pages) for relation R
- T(R) = # of tuples in relation R
- V(R, a) = # of distinct values of attribute a
- Memory M

Problem 2
Algorithms for Group By and Aggregate Operators

For homework 2:

Understand what is going on, do not blindly apply formula!

Try to choose outer relation carefully to reduce cost/fit data

in memory

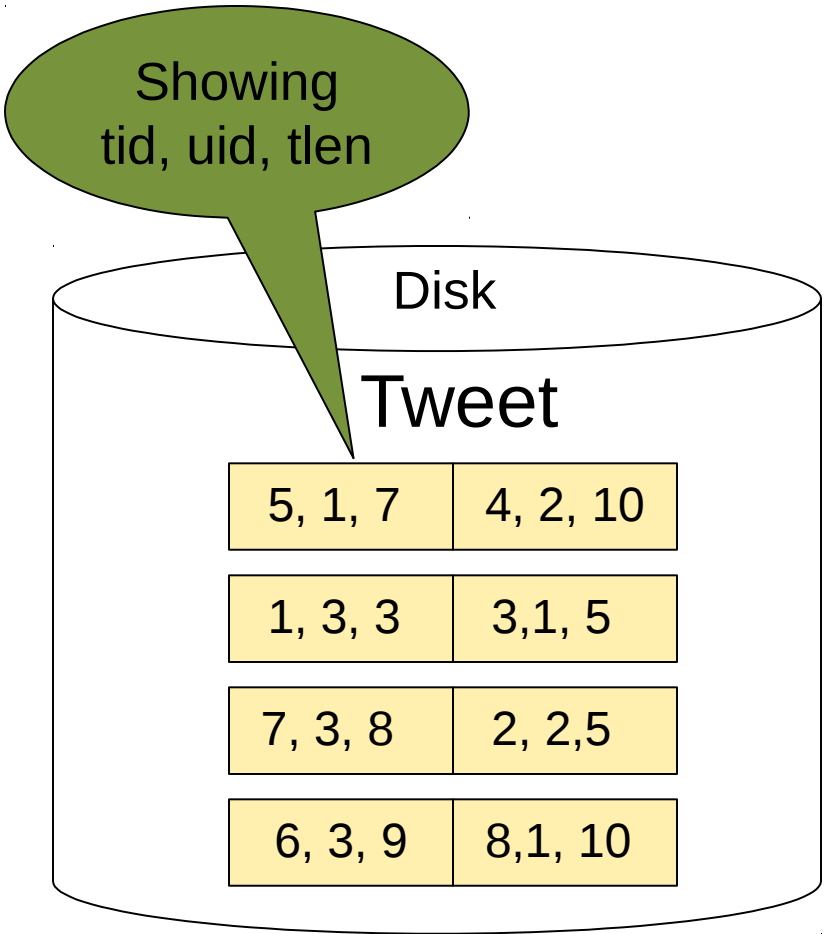
- Modified Tweet Example:

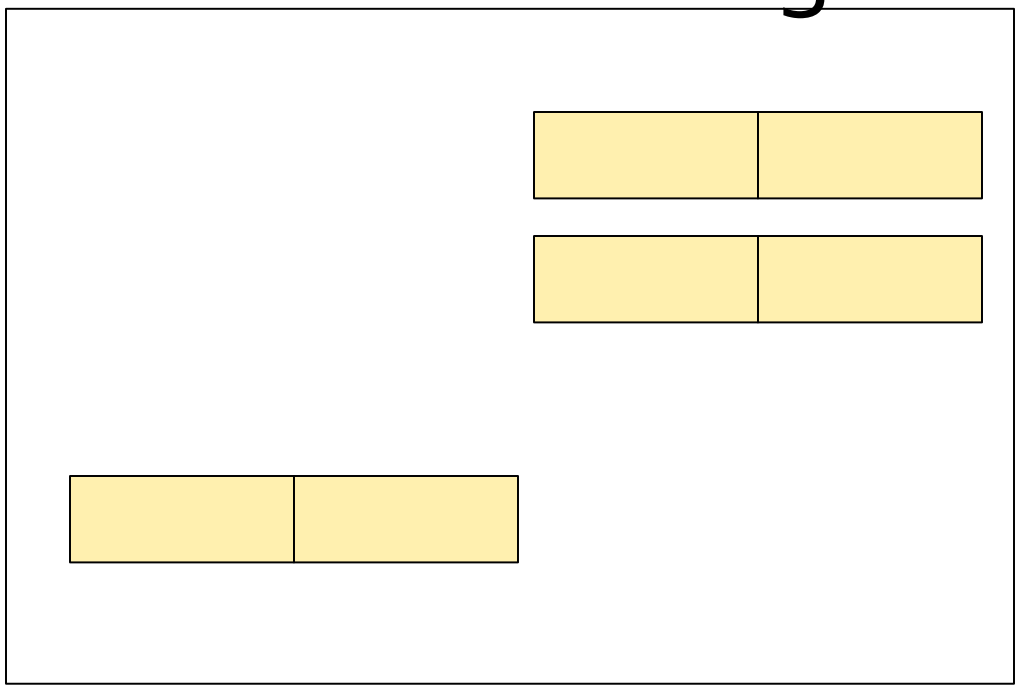
Tweet(tid, uid, tlen) tlen = tweet length

```
SELECT uid, MIN(tlen)
FROM Tweet
GROUP BY uid
```

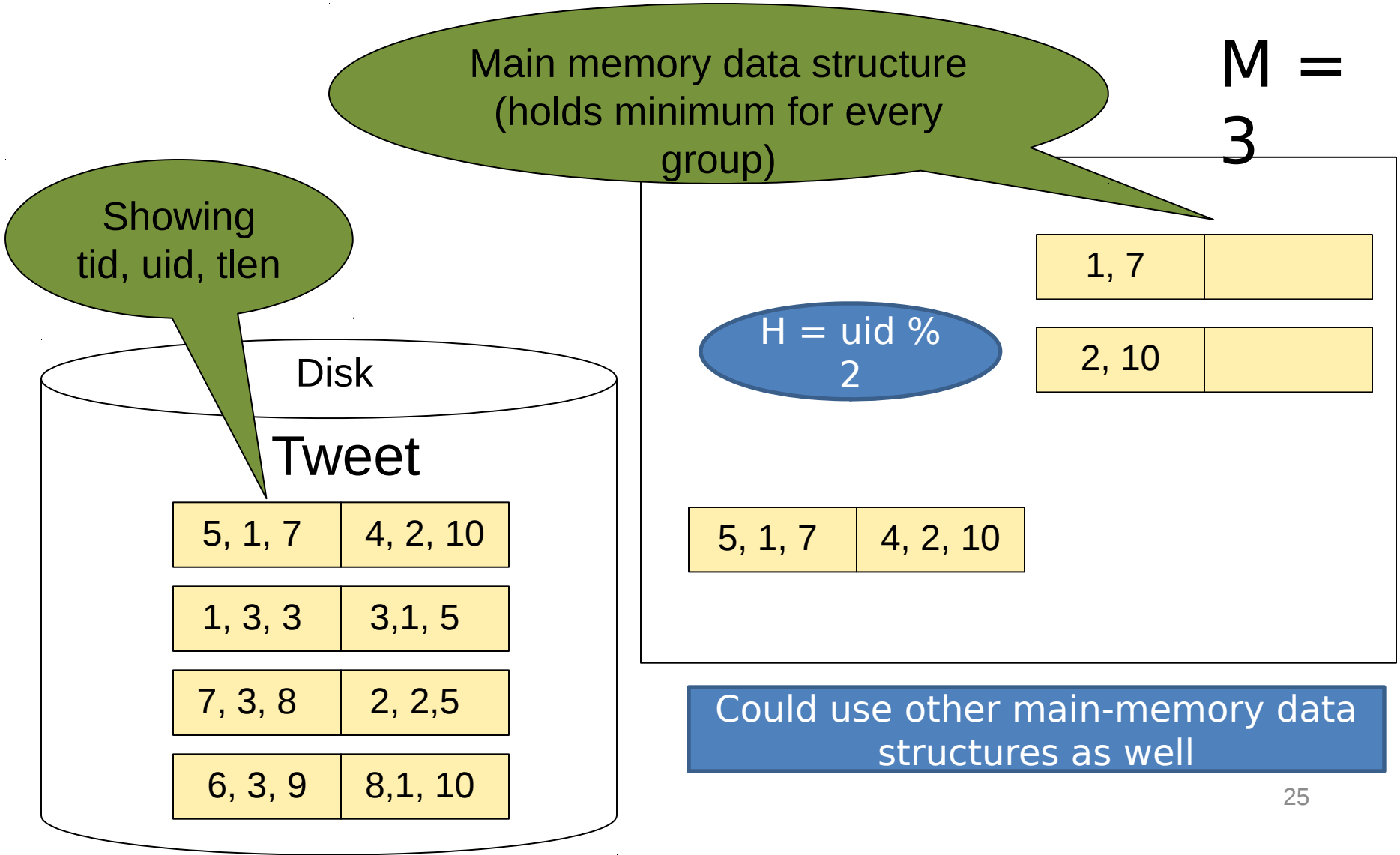
Problem 2a:
One pass, hash-based grouping

M = 3

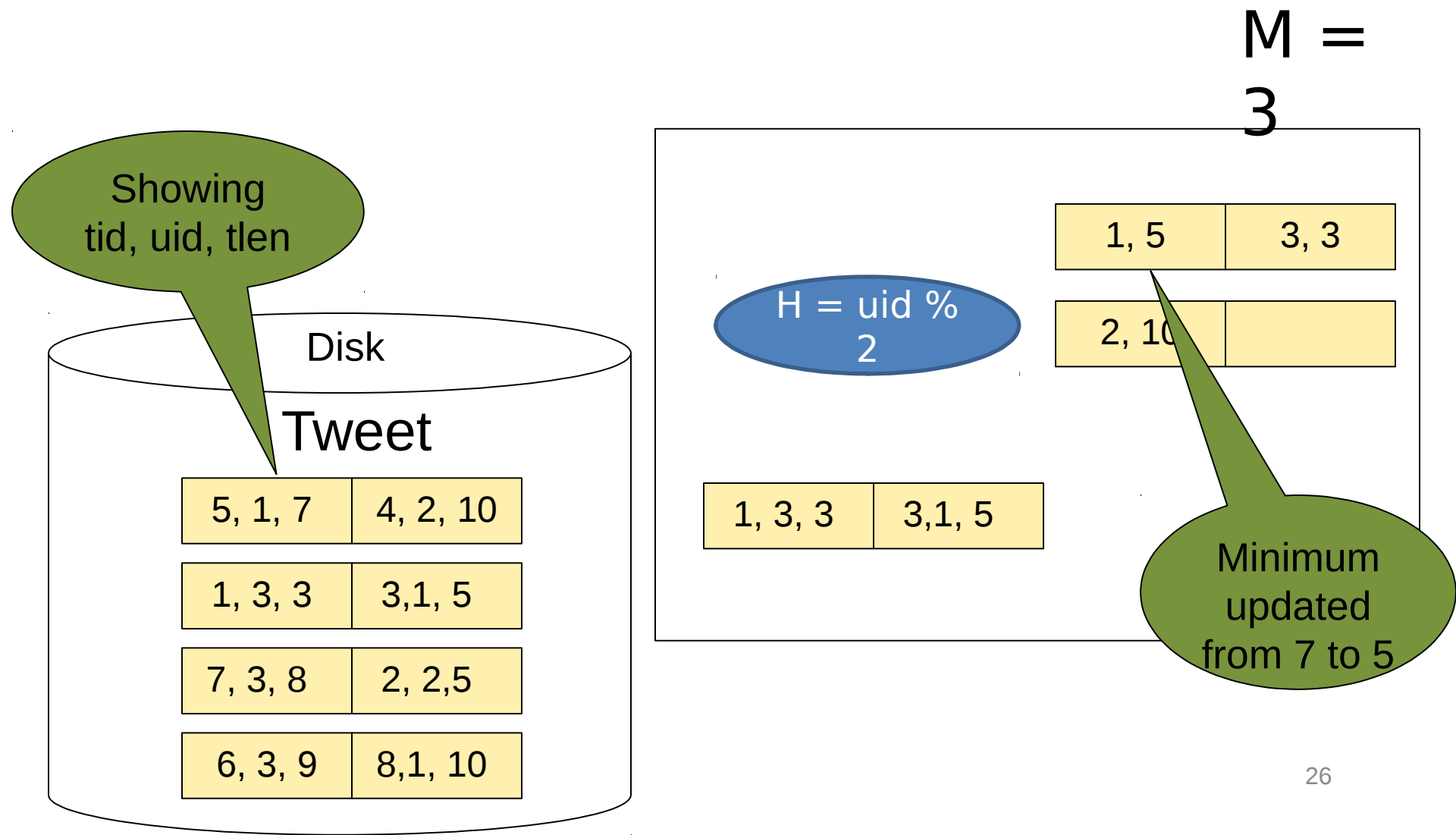




Problem 2a: One pass, hash-based grouping



One pass, hash-based grouping



Discussion: Problem 2a

Cost:

- Clustered?

  - B(R): assuming M – 1 pages can hold all groups – tuples for groups can be shorter or larger than original tuples

- Unclustered?

  - Also B(R)

Which method does the grouping:

open(), next(), or close()?

- Cannot return anything until the entire data is read. Open() needs to do grouping

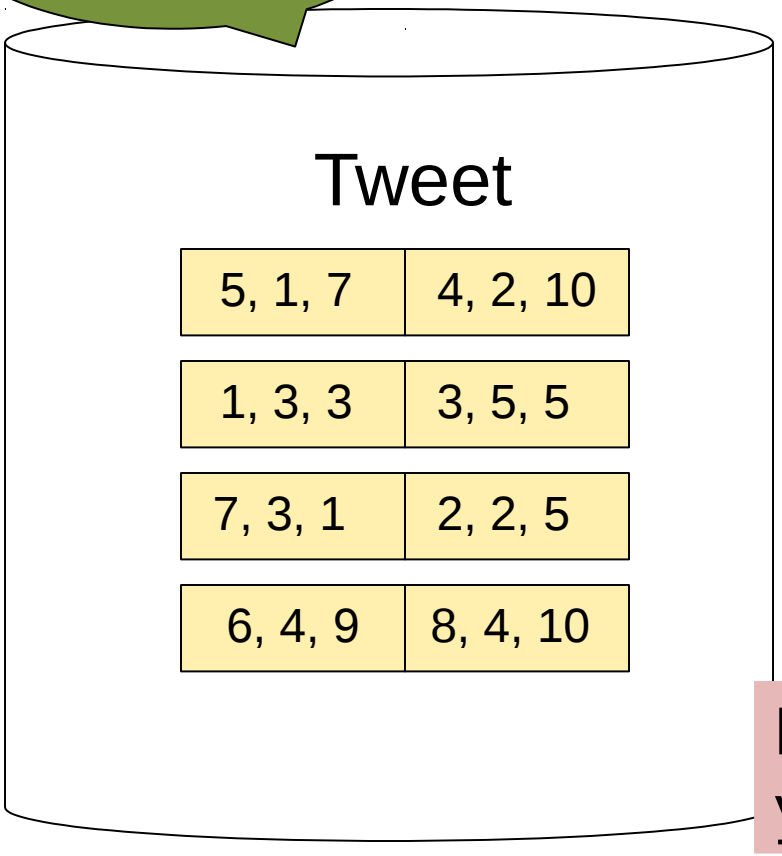
What to do for AVG(tlen)?

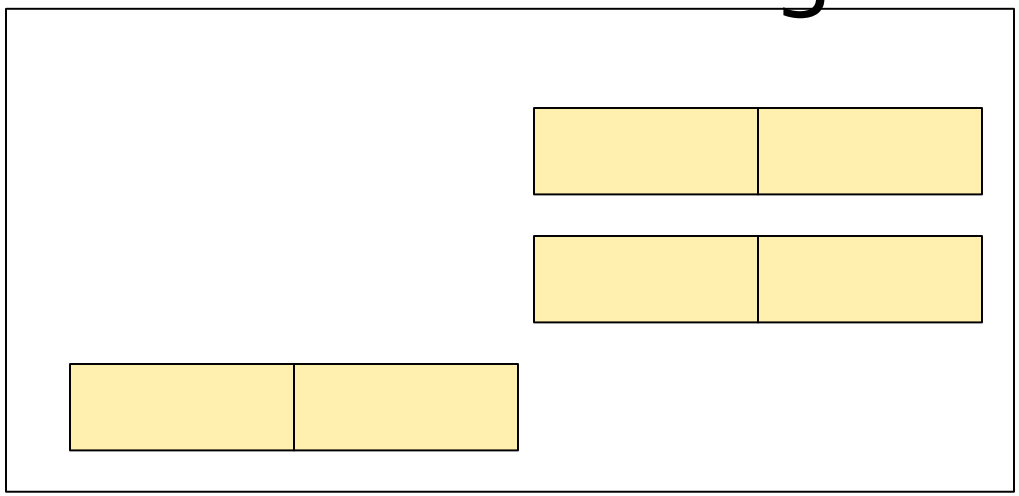
- Keep both SUM(tlen) and COUNT(*) for each group in memory

Problem 2b: Two pass, hash-based grouping

Showing tid, uid, tlen

M = 3





Hint: Two-pass hash-based join in yesterday's lecture!

Problem 2b: Two pass, hash-based grouping

Showing tid, uid, tlen

No Aggregation is performed in the first pass

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

H = uid % 2

5, 1, 7	4, 2, 10

5, 1, 7	
4, 2, 10	

Problem 2b: Two pass, hash-based grouping

Showing tid, uid, tlen

No Aggregation is performed in the first pass

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

H = uid % 2

1, 3, 3	3, 5, 5

5, 1, 7	1, 3, 3
4, 2, 10	

Flush !

Problem 2b: Two pass, hash-based grouping

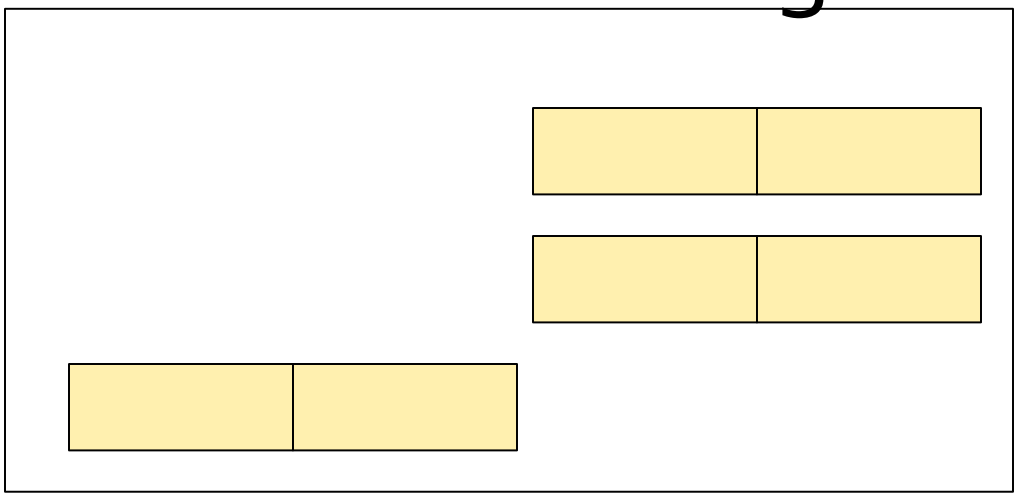
Showing tid, uid, tlen

Final buffer and disk after pass1

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10



5, 1, 7	1, 3, 3	3, 5, 5	7, 3, 1
4, 2, 10	2, 2, 5	6, 4, 9	8, 4, 10

Problem 2b: Two pass, hash-based grouping

Showing tid, uid, tlen

Second pass: compute aggregate in each bucket
Need to keep only one record per group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

1, 7	3, 3

5, 1, 7	1, 3, 3

5, 1, 7	1, 3, 3	3, 5, 5	7, 3, 1
4, 2, 10	2, 2, 5	6, 4, 9	8, 4, 10

Problem 2b: Two pass, hash-based grouping

Showing tid, uid, tlen

Second pass: compute aggregate in each bucket
Need to keep only one record per group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

Update min

1, 7	3, 3
5, 5	

3, 5, 5	7, 3, 1

5, 1, 7	1, 3, 3	3, 5, 5	7, 3, 1
4, 2, 10	2, 2, 5	6, 4, 9	8, 4, 10

Discussion: Problem 2b

Cost?

- 3B(R)

Assumptions?

- Need to hold all distinct values in the same bucket in M-1
- Assuming uniformity, B(R) <= M^2 is safe to assume
- But note that can handle much bigger relations R if the groups are large and #groups is small.

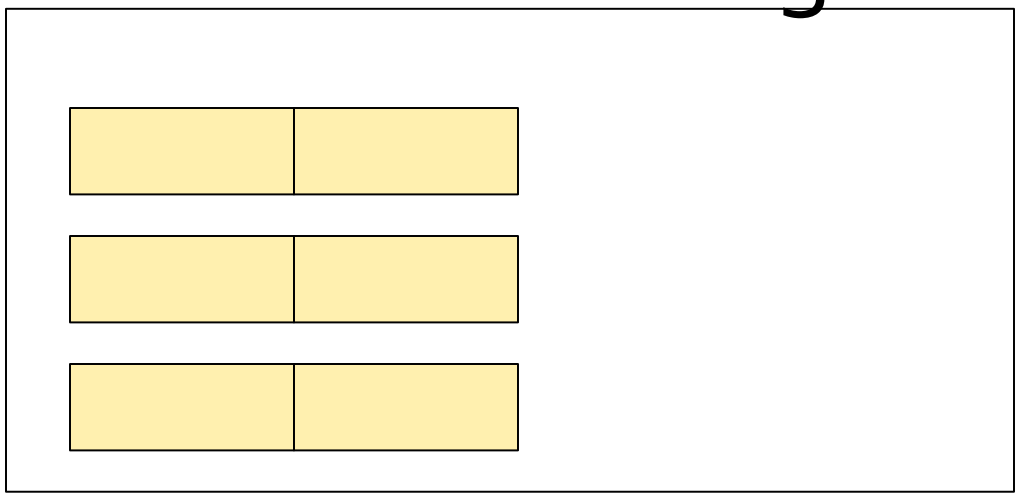
Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3 ,5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10



Hint: Two-pass sort-merged join in yesterday's lecture!

Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 1: Divide R into M partitions
sort each partition in memory
(on group by attr = uid)
Write to disk

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

5, 1, 7	4, 2, 10
2, 2, 5	1, 3, 3
7, 3, 1	3, 5, 5

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5

Problem 2c:
Two pass, sort-merge-based grouping

Showing
tid, uid, tlen

Step 1: Divide R into M partitions
sort each partition in memory
(on group by attr = uid)
Write to disk

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

6, 4, 9	8, 4, 10

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5

6, 4, 9	8, 4, 10

Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 2:
- Load first blocks from all runs
- Find minimum of each key by "Combine" approach in merge-sort
- Repeatedly find the lest value of the sort key: next group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

5, 1, 7	4, 2, 10
6, 4, 9	8, 4, 10

(uid, min(tlen))
(1, 7)

Not showing the outputs in output buffer

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5
6, 4, 9	8, 4, 10				

Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 2: Find minimum of each key by "Combine" approach in merge-sort

Repeatedly find the least value of the sort key: next group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

5, 1, 7	4, 2, 10
6, 4, 9	8, 4, 10

(uid, min(tlen))
(1, 7)
(2, 10)

Not showing the outputs in output buffer

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3,5, 5

6, 4, 9	8, 4, 10

Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 2: Find minimum of each key by "Combine" approach in merge-sort

Repeatedly find the least value of the sort key: next group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

5, 1, 7	4, 2, 10
6, 4, 9	8, 4, 10

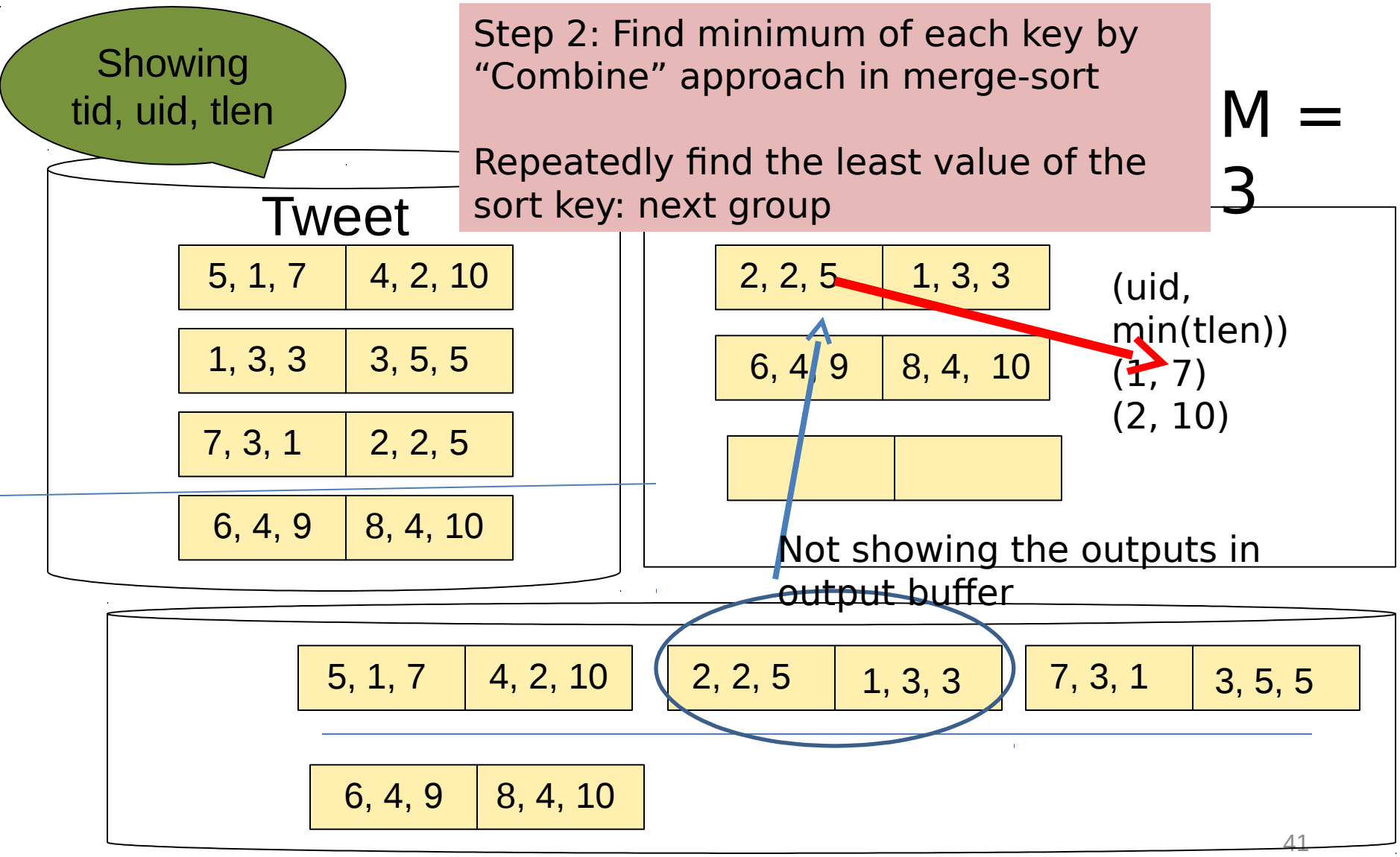
(uid, min(tlen))
(1, 7)
(2, 10)

Not showing the outputs in output buffer

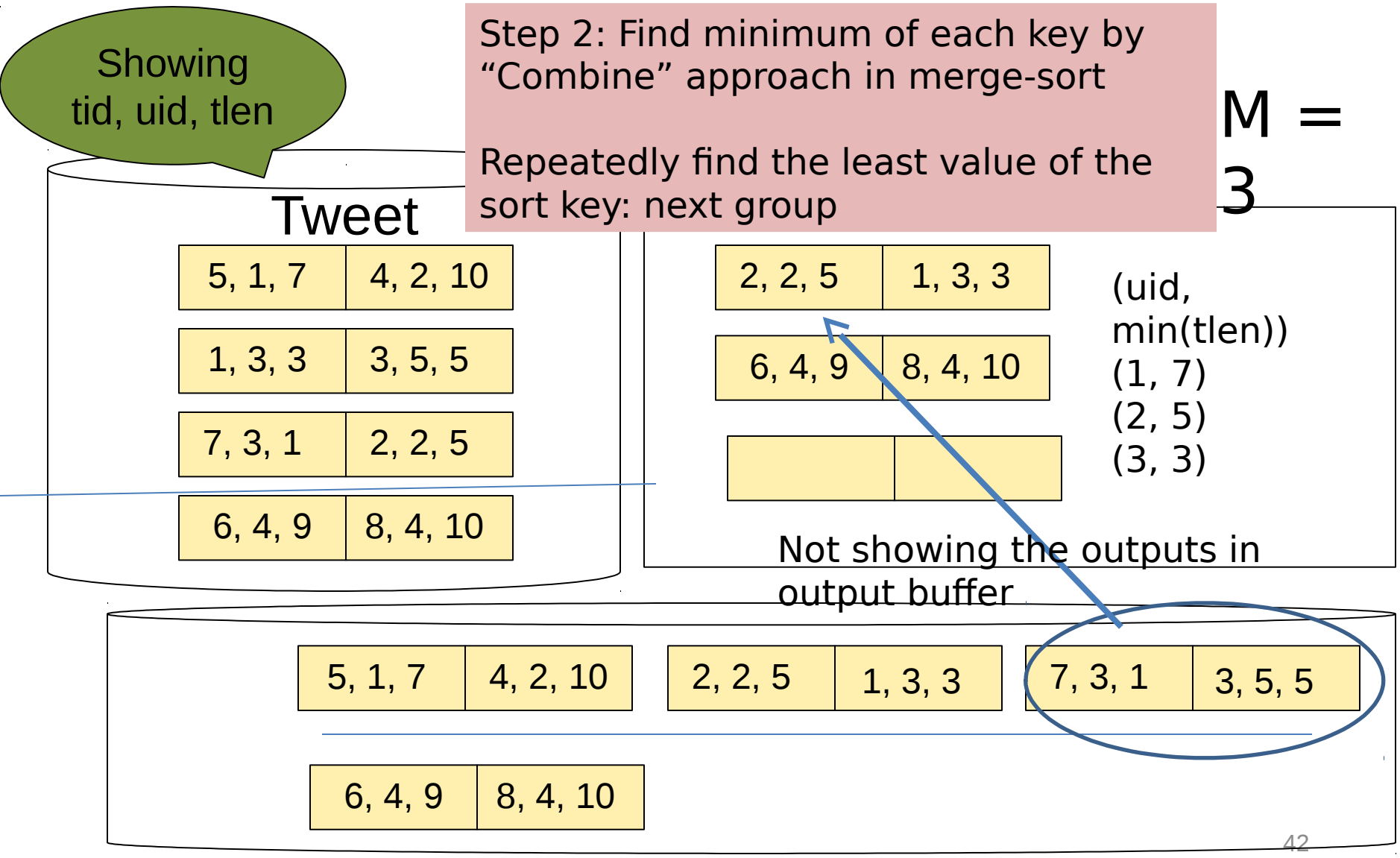
5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5

6, 4, 9	8, 4, 10

Problem 2c: Two pass, sort-merge-based grouping



Problem 2c: Two pass, sort-merge-based grouping



Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 2: Find minimum of each key by "Combine" approach in merge-sort

Repeatedly find the least value of the sort key: next group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

7, 3, 1	3, 5, 5
6, 4, 9	8, 4, 10

(uid, min(tlen))
(1, 7)
(2, 5)
(3, 3)

Not showing the outputs in output buffer

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5
6, 4, 9	8, 4, 10				

Problem 2c: Two pass, sort-merge-based grouping

Showing tid, uid, tlen

Step 2: Find minimum of each key by "Combine" approach in merge-sort

Repeatedly find the lest value of the sort key: next group

M = 3

Tweet

5, 1, 7	4, 2, 10
1, 3, 3	3, 5, 5
7, 3, 1	2, 2, 5
6, 4, 9	8, 4, 10

7, 3, 1	3, 5, 5
6, 4, 9	8, 4, 10

(uid, min(tlen))
(1, 7)
(2, 5)
(3, 1)
(4, 9)
(5, 5)

Not showing the outputs in output buffer

5, 1, 7	4, 2, 10	2, 2, 5	1, 3, 3	7, 3, 1	3, 5, 5
6, 4, 9	8, 4, 10				

Discussion: Problem 2c

Cost?

- 3B(R)

Assumptions?

- Need to hold one block from each run in M pages
- $B(R) <= M^2$

Merge-sort based single pass algorithm?

- Not good here: same IO cost, more CPU cost

One pass vs. Two pass

- One pass:
  - smaller disk I/O cost
    - e.g. B(R) for one-pass hash-based aggregation
  - Handles smaller relations
    - e.g. B(R) <= M
- Two/Multi pass:
  - Larger disk I/O cost
    - e.g. 3B(R) for two-pass hash-based aggregation
  - Can handle larger relations
    - e.g. B(R) <= M^2

Review

- Two-pass Hash-based Join
  - Cost: 3B(R) + 3B(S)
  - Assumption: Min(B(R), B(S)) <= M^2
- Two-pass Sort-merge-based Join
  - Implementation 1:
    - Cost: 5B(R) + 5B(S)
      - For R, S: sort runs/sublists (2 I/O, read + write)
      - Merge sublists to have entire R, S sorted individually (2 I/O, read + write)
      - Join by combining R and S (only read, write not counted - 1 I/O)
    - Assumption: B(R) <= M^2 , B(S)) <= M^2
  - Implementation 2:
    - Cost: 3B(R) + 3B(S)
    - Assumption: B(R) + B(S) <= M^2