Discussion 9

Joins & Project 4 Intro

EECS 484

Logistics

- **HW 4** due **Today** at 11:45 PM ET
- **HW 5** due **Nov 15th** at 11:45 PM ET
- **Project 4** released, due **Nov 22nd** at 11:45 PM ET

Joins

Joins

- Powerful tool in SQL
  - A join B join C …
  - But how does this actually work?
  - Different ways to represent a join
    - Simple/Stupid Nested Loop
    - Block Nested Loop
    - Index Nested Loop
      - See lecture slides
    - Sort-Merge
    - Grace Hash Join
      - Will be your new best friend

Problem Setup

- We would like to join R with S using the column ID (both share)
- R and S are some relations
- m = Number of tuples in R, n = Number of tuples in S
- M = Number of pages in R, N = Number of pages in S
- Sometimes we use |T| to represent *number of pages* in T and ||T|| to represent *number of tuples* in T
- Will use this to compute number of IOs in each scheme

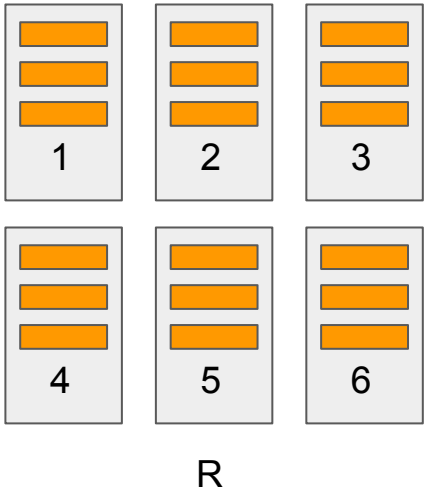
Stupid Nested Loop Join

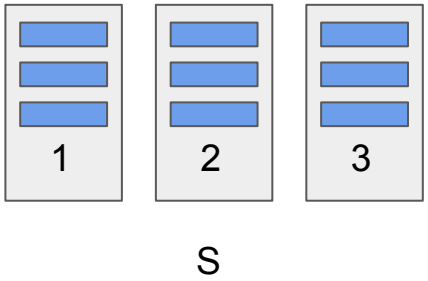
- For each tuple r in R
  - For each tuple s in S
    - If r.ID=s.ID
      - Add <r, s> to the final result
- Super simple!
  - Intuitively makes sense (hopefully)
- Performance
  - IO Cost = Iterate through all M pages of R + Iterate through all N pages of S m times
    - M + N*m

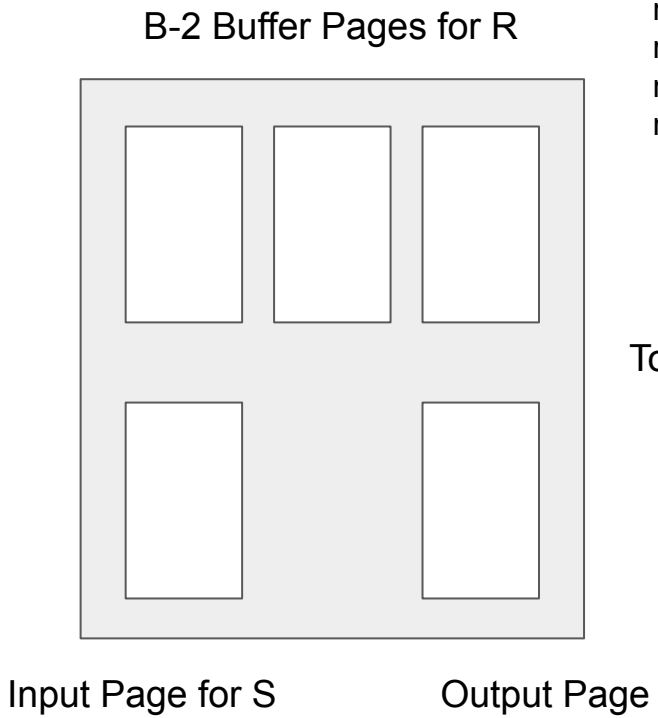
Block Nested Loop Join

- Use B buffer pages
  - Read B-2 pages of R at a time
  - 1 page of S at a time
  - 1 page for output
- For each block of B-2 pages in R
  - For each Page of S
    - For each tuple in the B-2 pages of R
      - For each tuple in the page of S
        - Do the join
- 4 loops???
  - IO Cost = Load all M pages of R but load each N pages of S only (M/(B-2)) times
    - M+N*ceiling(M/(B-2))

```
for(int w=0; w<0; w++)
{
    for(int e=0; e<0; e++)
    {
        for(int l=0; l<0; l++)
        {
            for(int c=0; c<0; c++)
            {
                for(int o=0; o<0; o++)
                {
                    for(int m=0; m<0; m++)
                    {
                        for(int e=0; e<0; e++)
                        {
                            for(int t=0; t<0; t++)
                            {
                                for(int o=0; o<0; o++)
                                {
                                    for(int h=0; h<0; h++)
                                    {
                                        for(int e=0; e<0; e++)
                                        {
                                            for(int l=0; l<0; l++)
                                            {
                                                for(int l=0; l<0; l++)
                                                {
                                                    System.out.pr
```

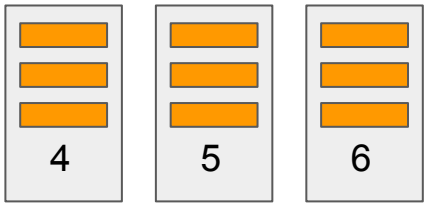




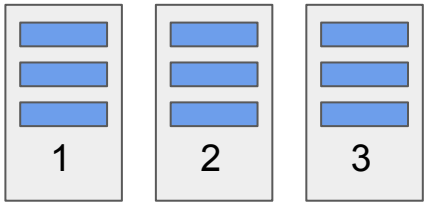


Note: the color of a bar doesn't represent the value of the record. It's used to distinguish records from 2 relations (Blue means it's from S while yellow means it's from R).

Total B=5 Buffer Pages

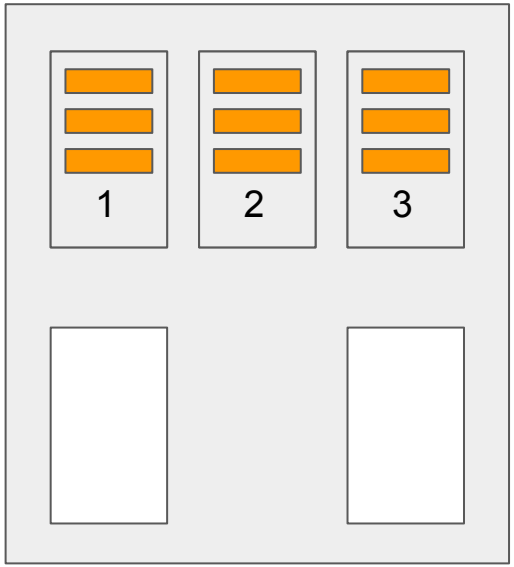


R



S

B-2 Buffer Pages for R



Input Page for S

Output Page

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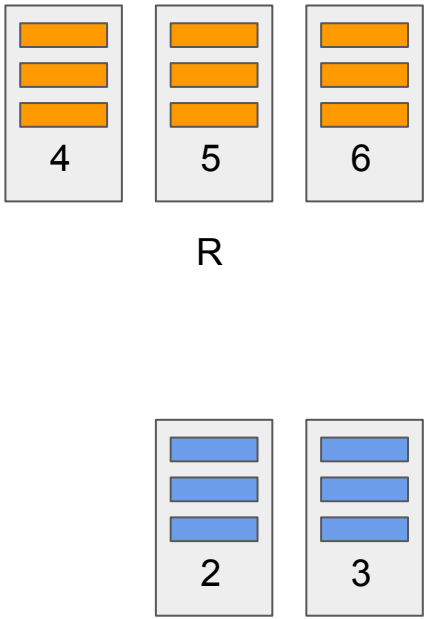

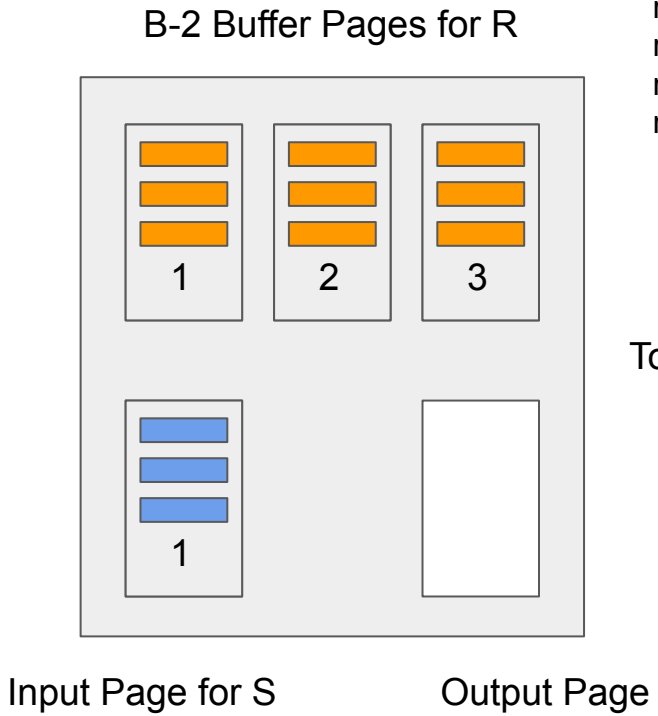

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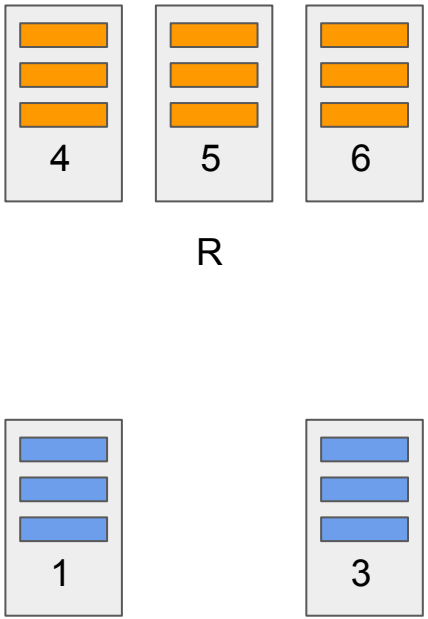

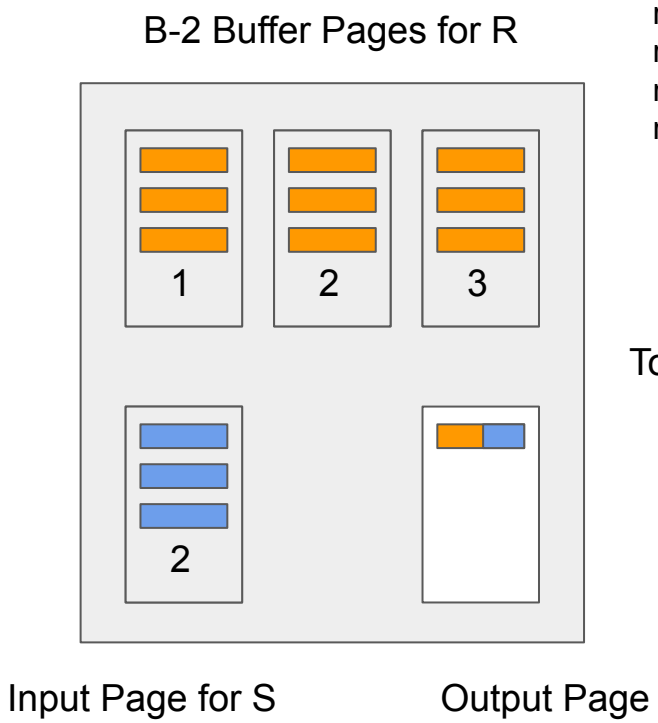

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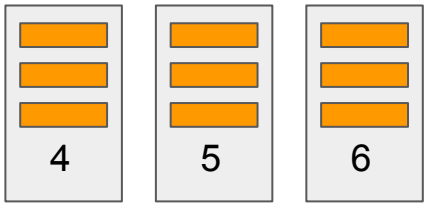

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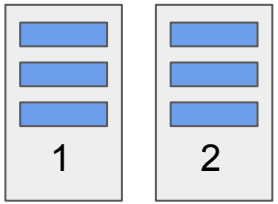

S

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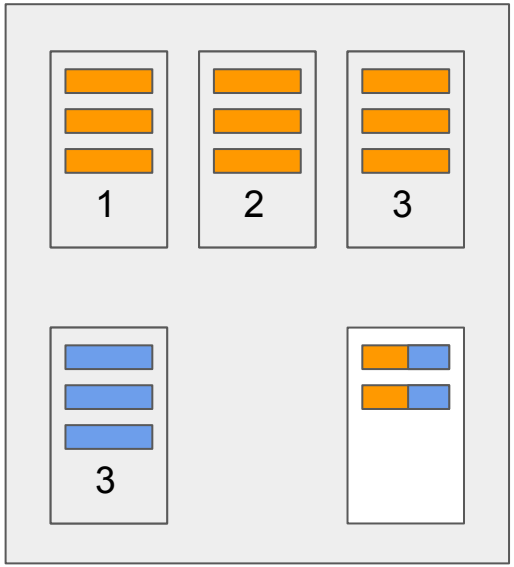

Input Page for S

Output Page

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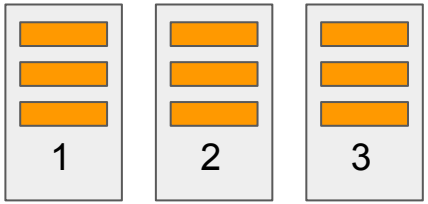

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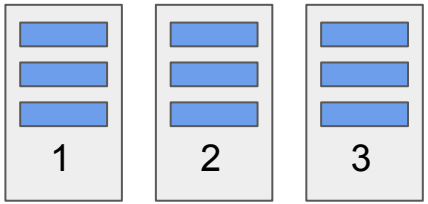

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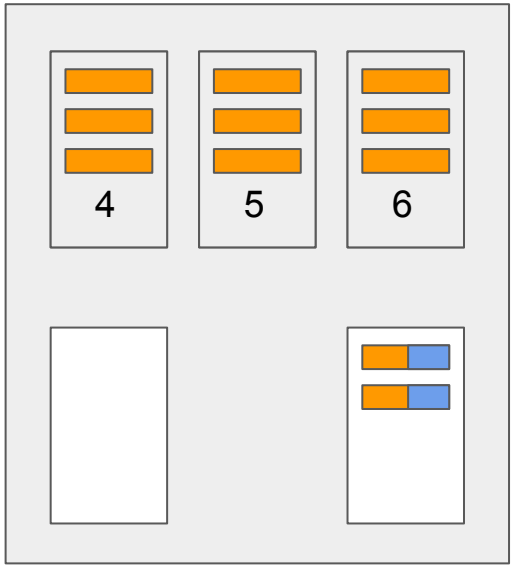

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Output Page

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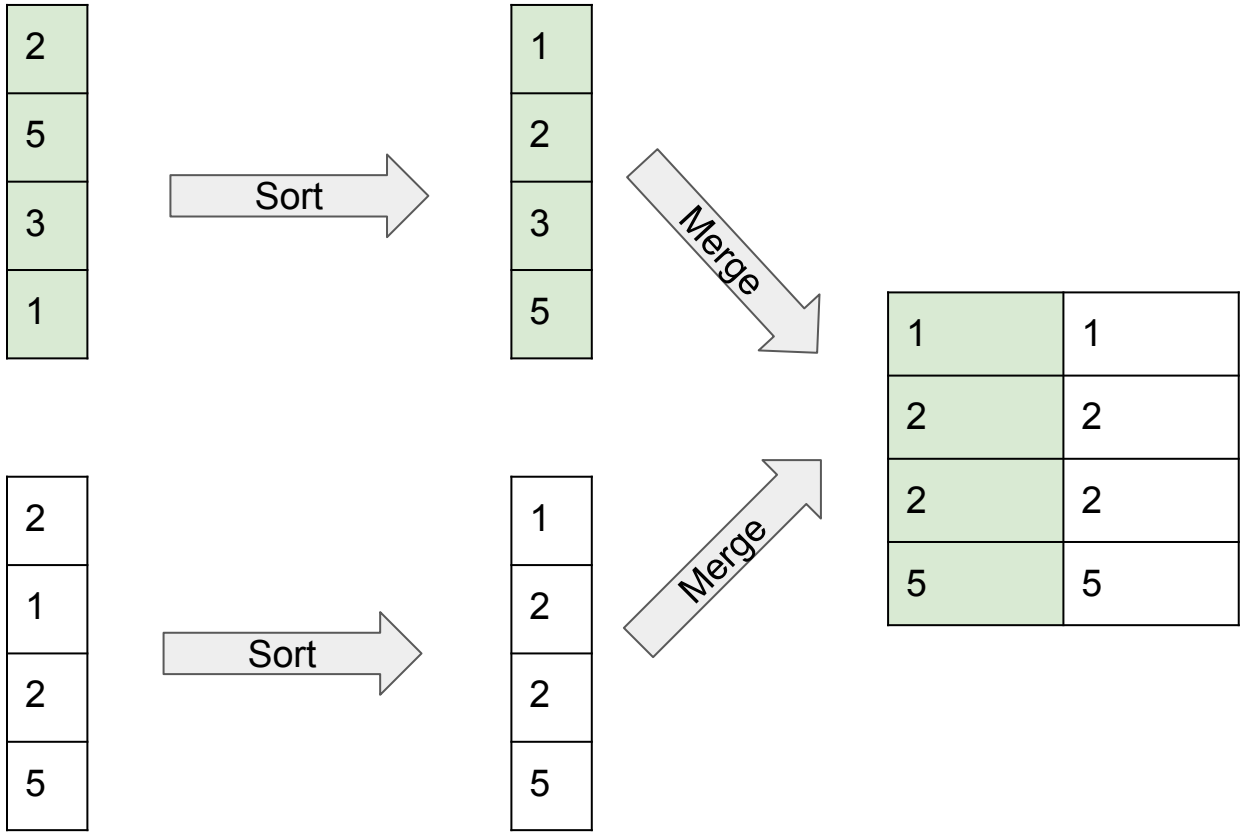
Total B=5 Buffer Pages

Sort-Merge Join

- **Sort** both relations on the join attribute
  - May omit one final passe if the number of sorted runs from two relations is smaller than the number of buffer pages
- Look for qualifying by **merging** the two relations
- I/O Cost:
  - Sort R: 2M * #passes needed to sort R
  - Sort S: 2N * #passes needed to sort S
  - Typical merge cost: M + N
  - Worst merge cost: M * N
    - When?
  - Typical Sort-Merge Join cost:
    - 2M * 2 + 2N * 2 + M + N = 5(M + N)
    - Possible to finish in 3(M + N)! When?

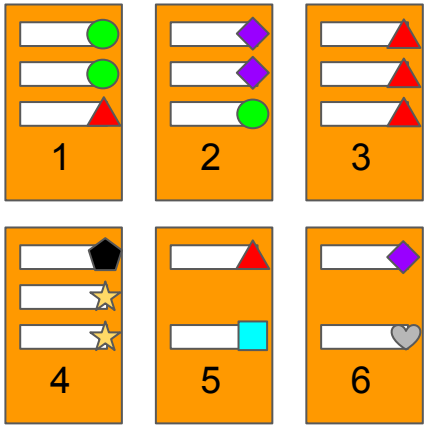

2
5
3
1
Sort
1
2
3
5
Merge
1 1
2 2
2 2
5 5
2
1
2
5
Sort
1
2
2
5
Merge

Grace Hash Join

- What if we used advanced data structures(hash tables) to help us sort?
  - If h(r) = h(s) then very likely that r = s!
    - Assume we take the hash on the columns we are joining on
- 2 phases
  - Phase 1: Build
    - Put each tuple r and s into partitions
    - Any two elements in the same partition share a hash
    - Might have multiple partition rounds - need to enforce that each partition fits into buffer space
  - Phase 2: Probe
    - Load in each partition of the smaller relation (assume R for this case) and rehash
    - Read the corresponding partition for the larger relation (assume S for this case) and rehash
    - Compare the tuples and add to output if they match

Grace Hash Join

- IO Cost: (2p+1)(M+N) where p is number of partition rounds
  - Partition = 2p(M+N) - Read + Write each page across both relations once
  - Probe = M+N - Read each page across both relations once more



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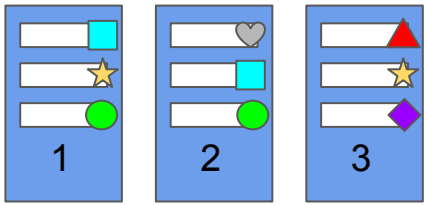
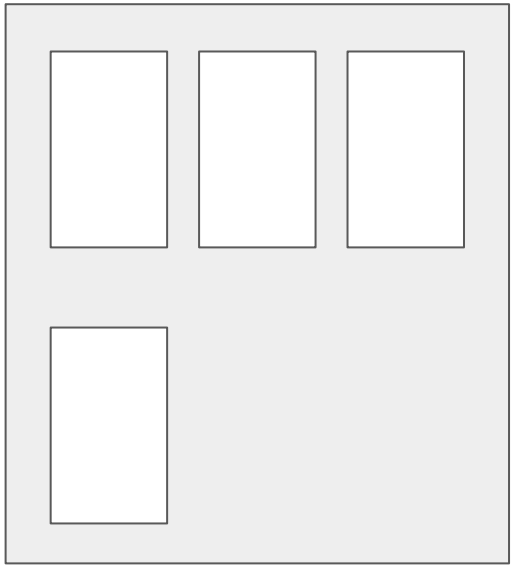


S

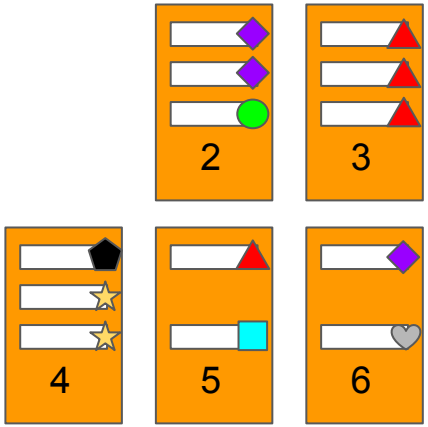
B-1 Buffer Pages for Partitions



Input Page

Total B=4 Buffer Pages

Grace hash join example borrowed from Prof. Joseph Hellerstein's CS186 course at UC Berkeley



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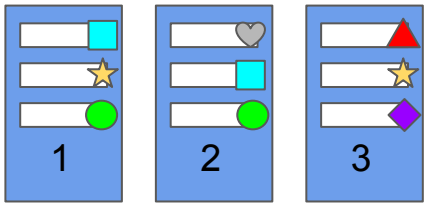

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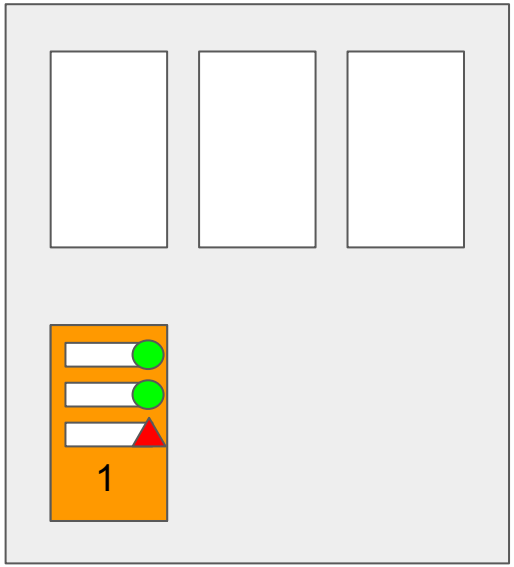

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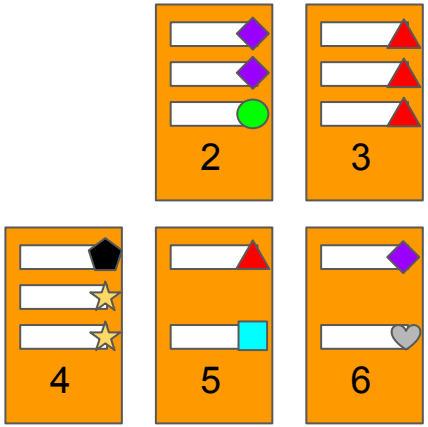

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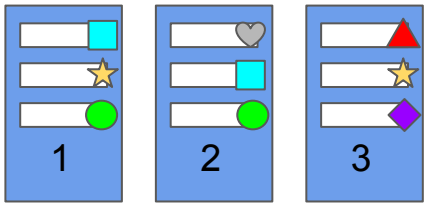

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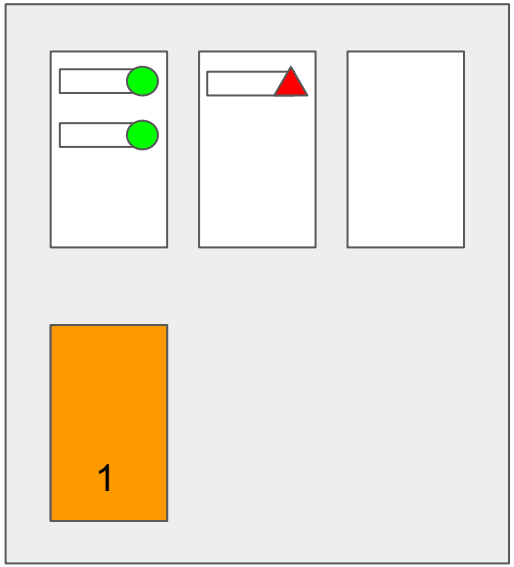

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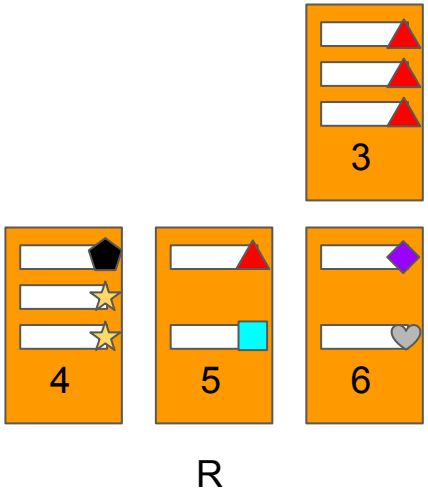

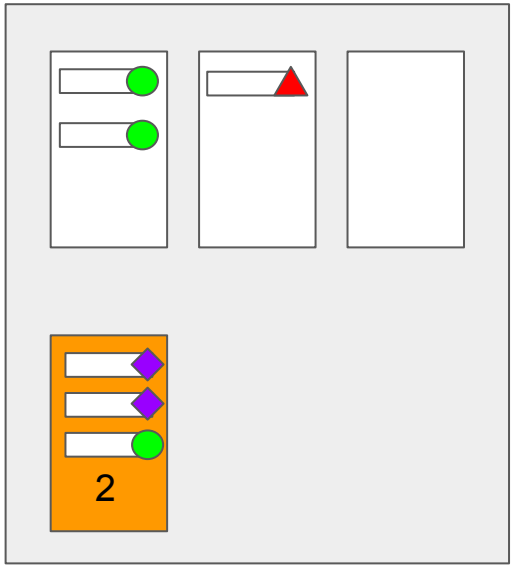

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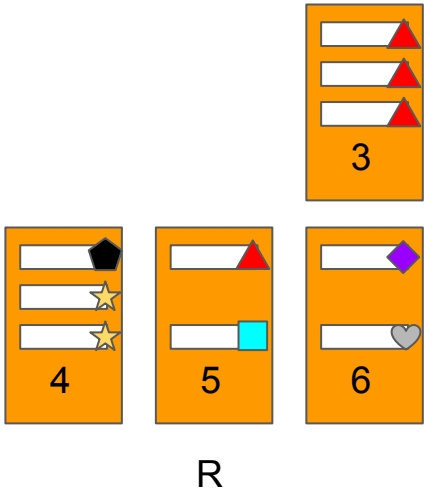

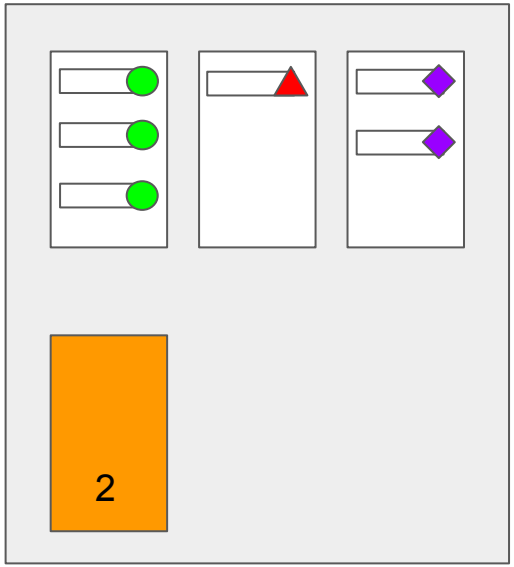

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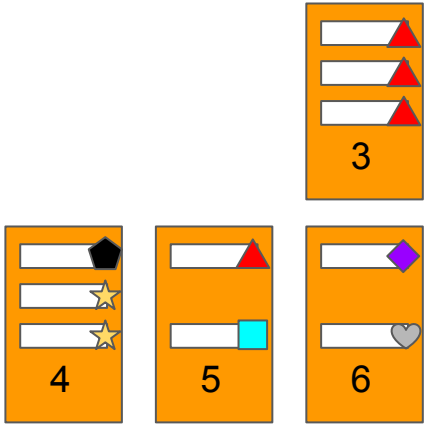
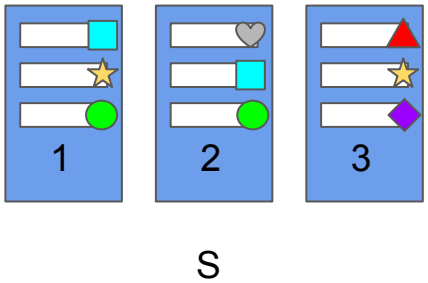
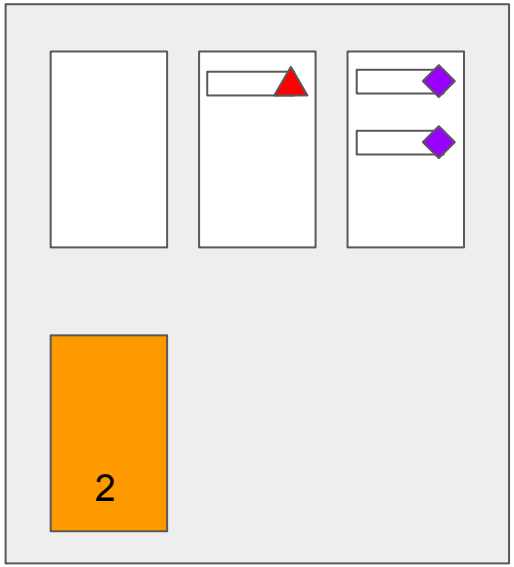
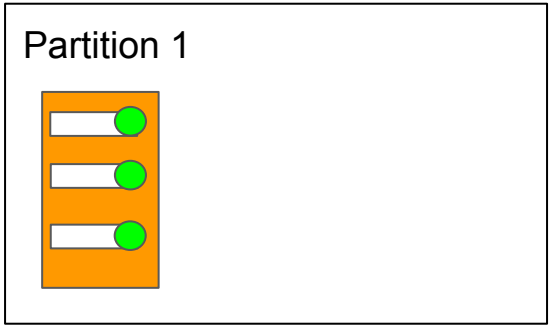




B-1 Buffer Pages for Partitions





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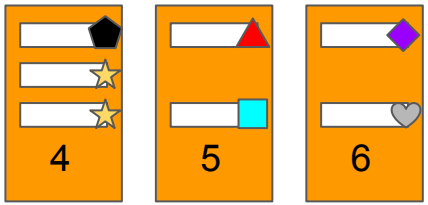
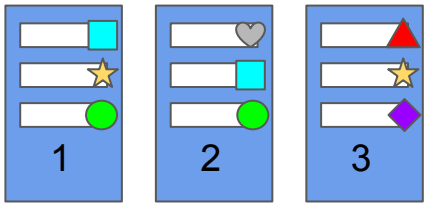


R



S

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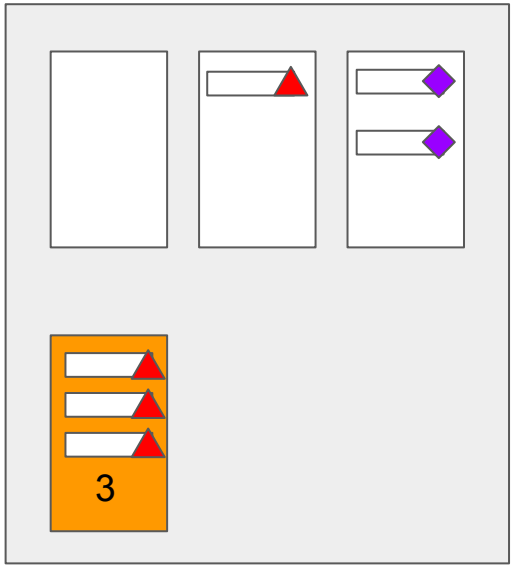
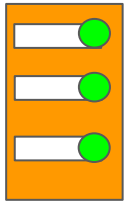


Input Page

Partition 1



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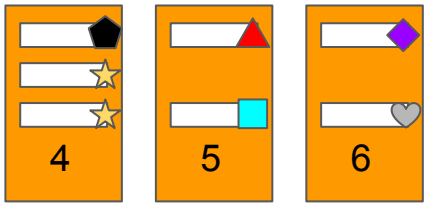

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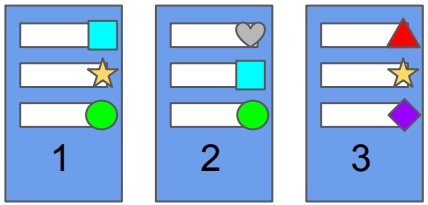

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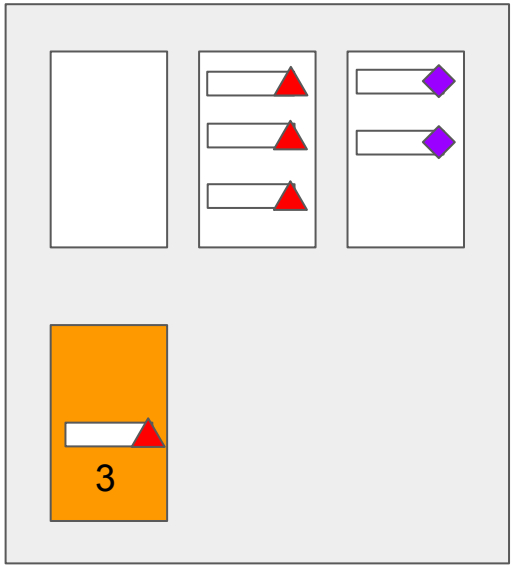

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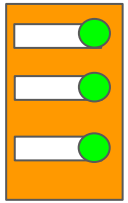

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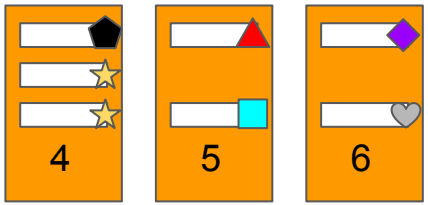
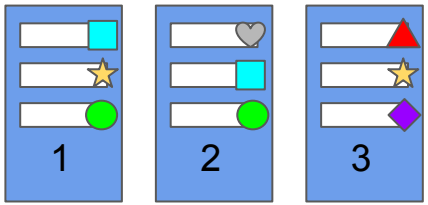


R



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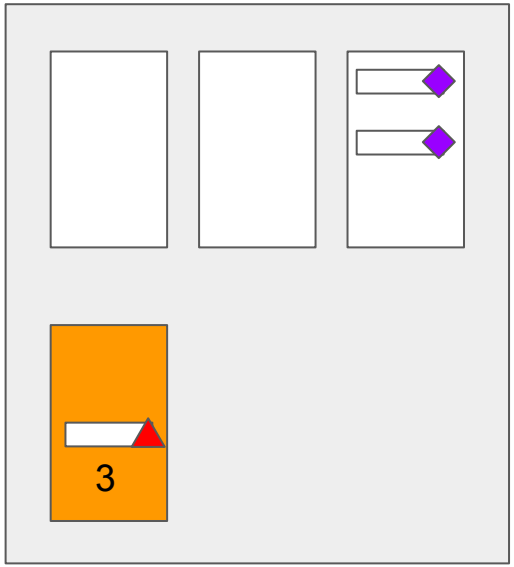

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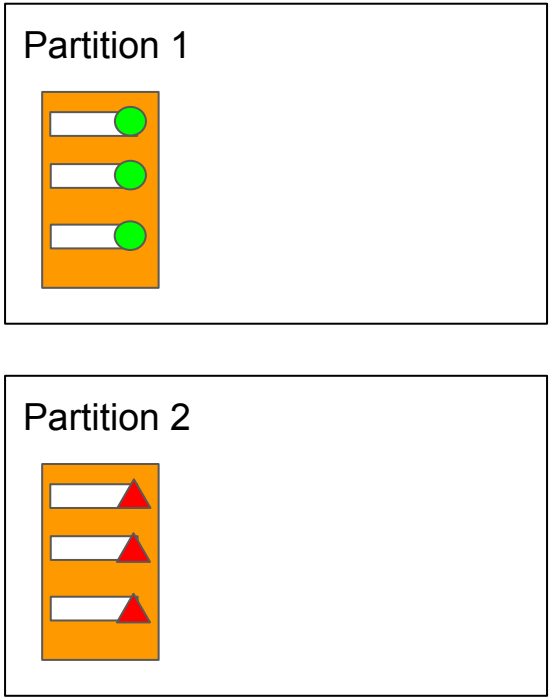

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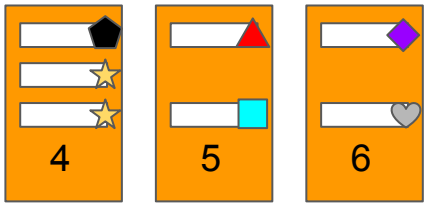

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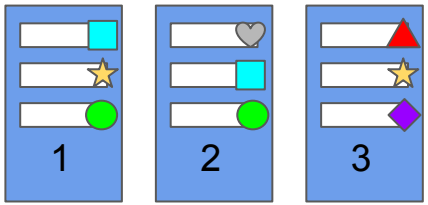
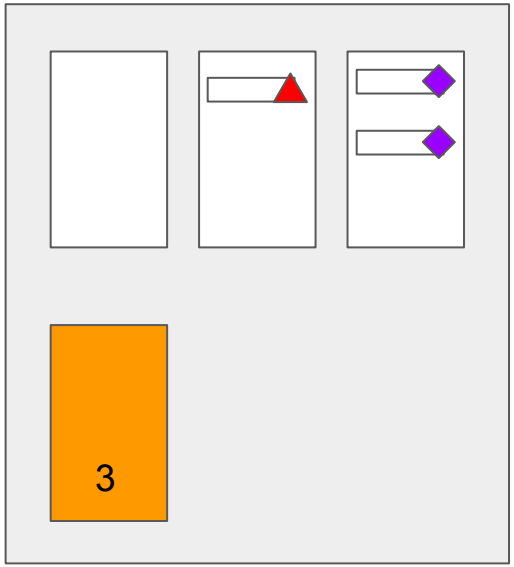
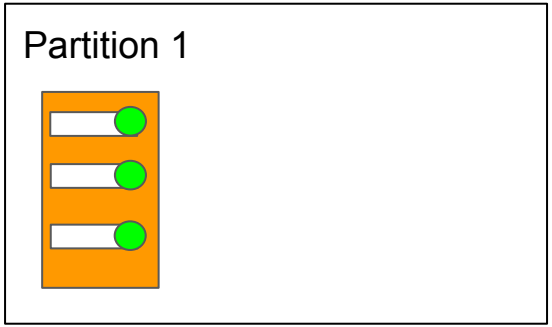


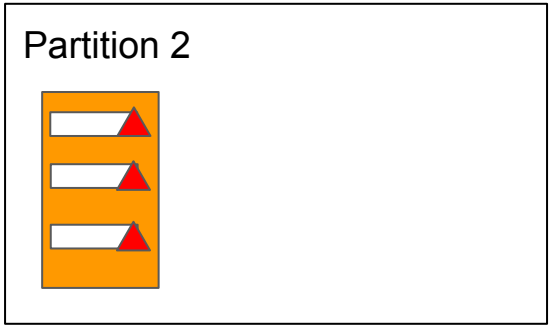
S

B-1 Buffer Pages for Partitions



Input Page





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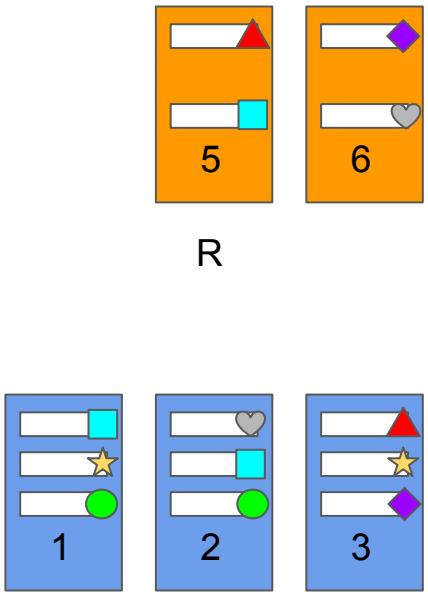

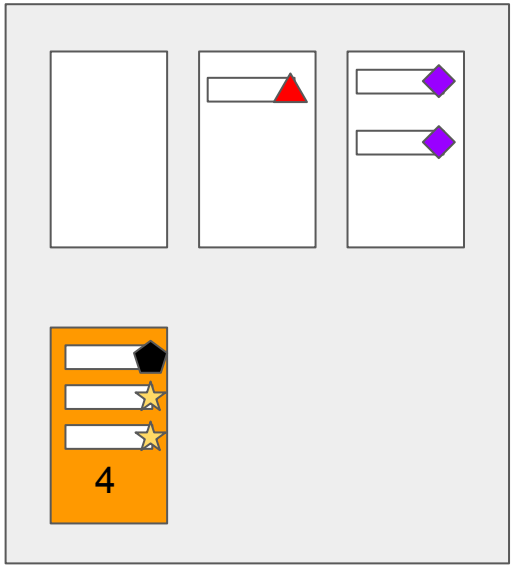

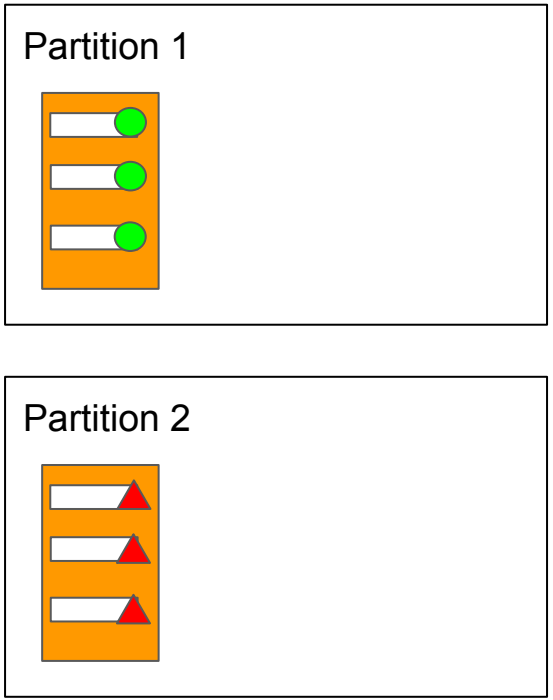

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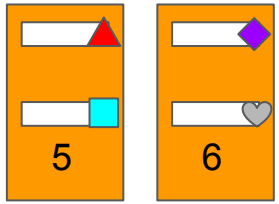

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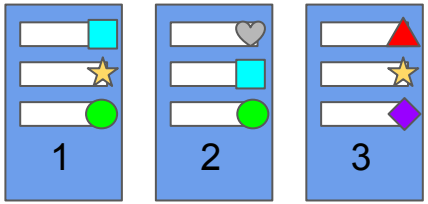

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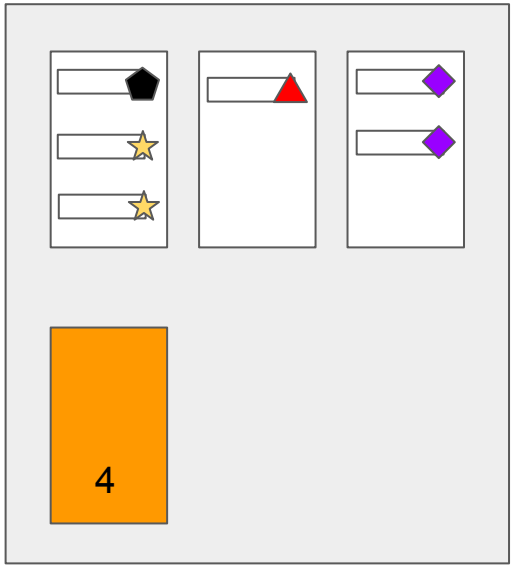
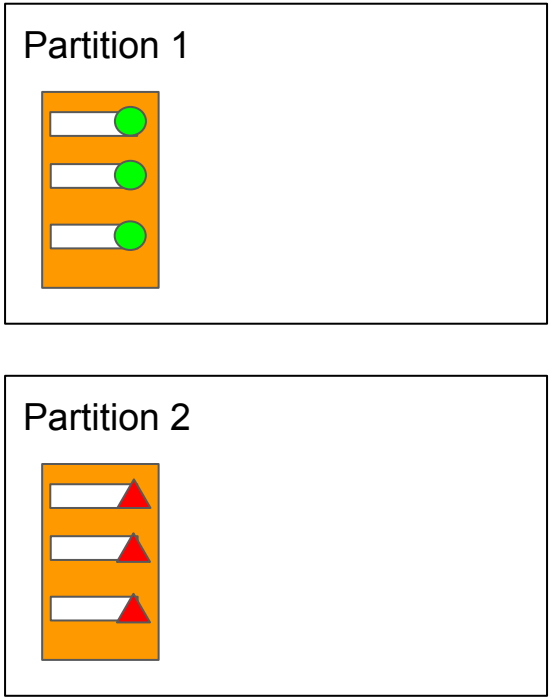


Input Page



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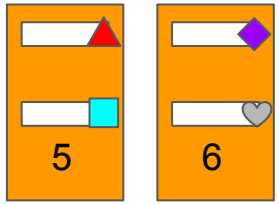

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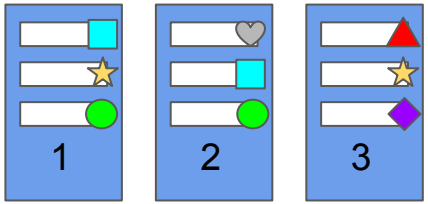

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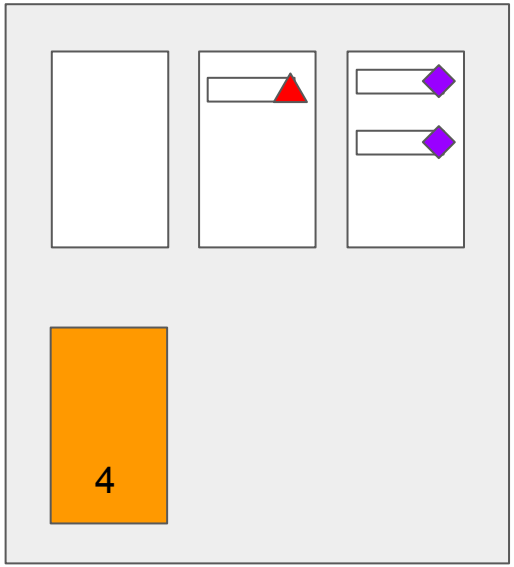

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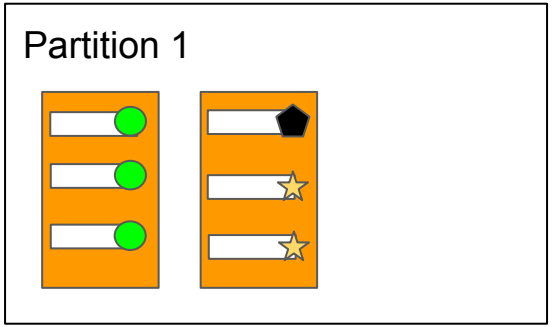

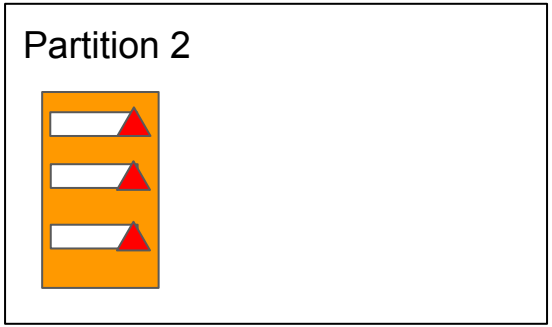

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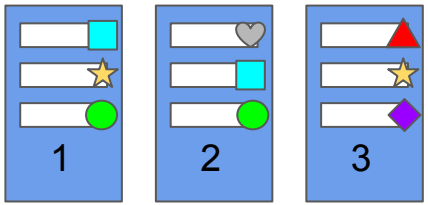

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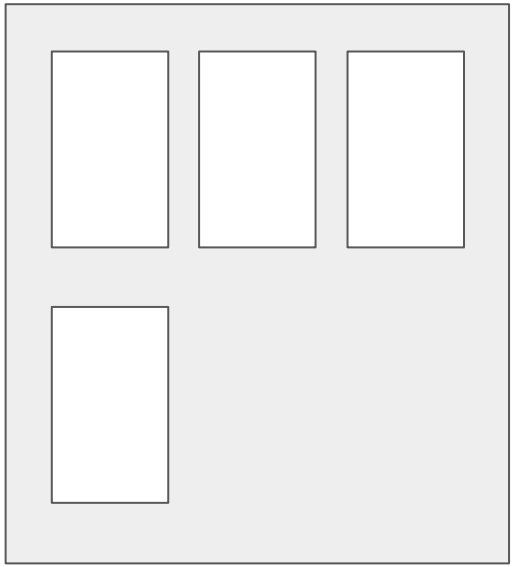
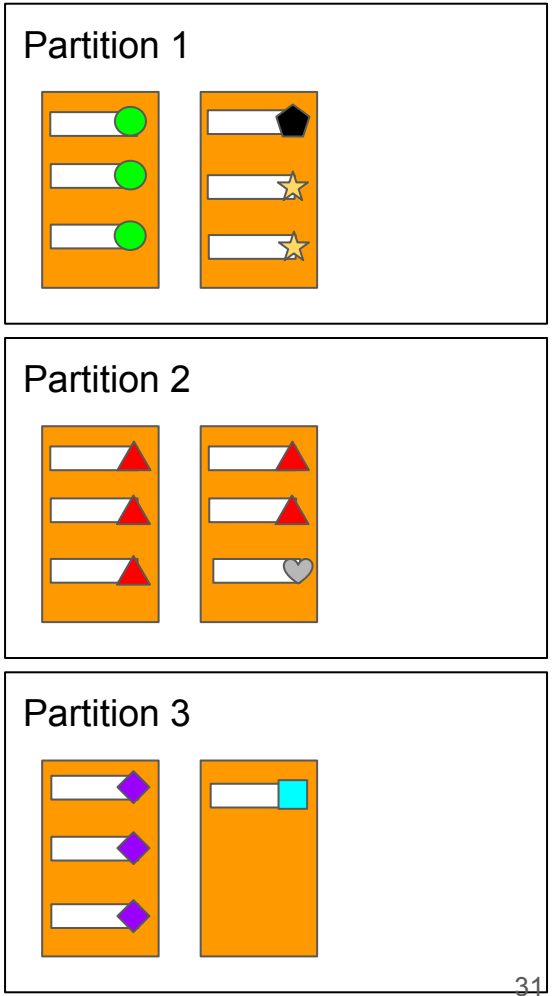


Input Page



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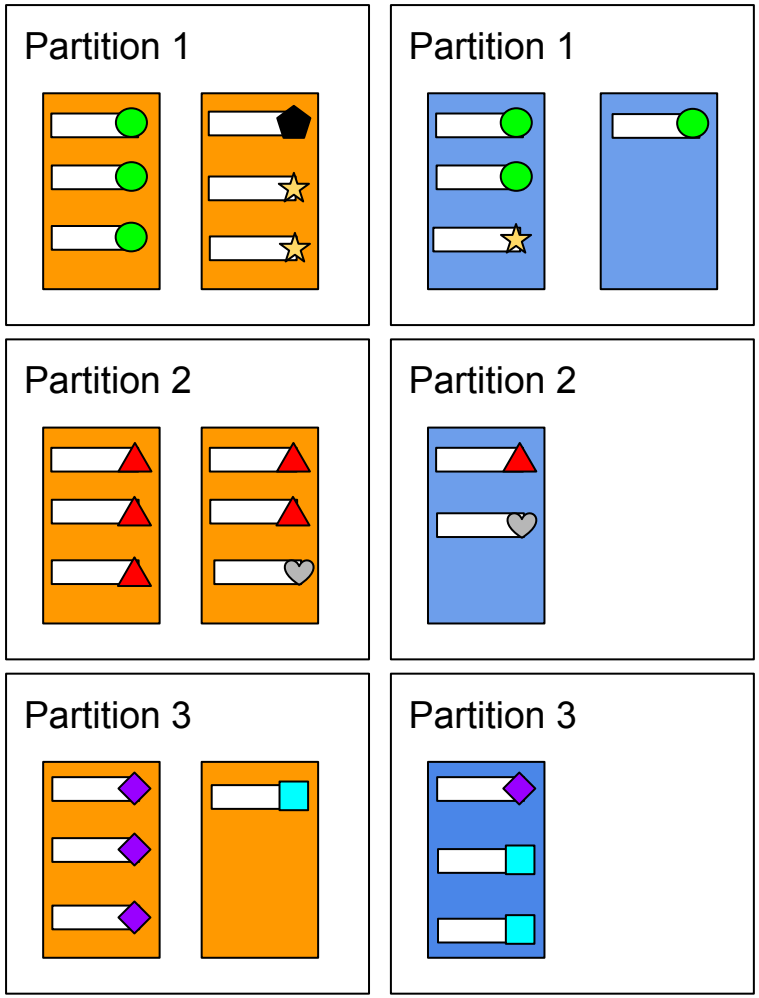

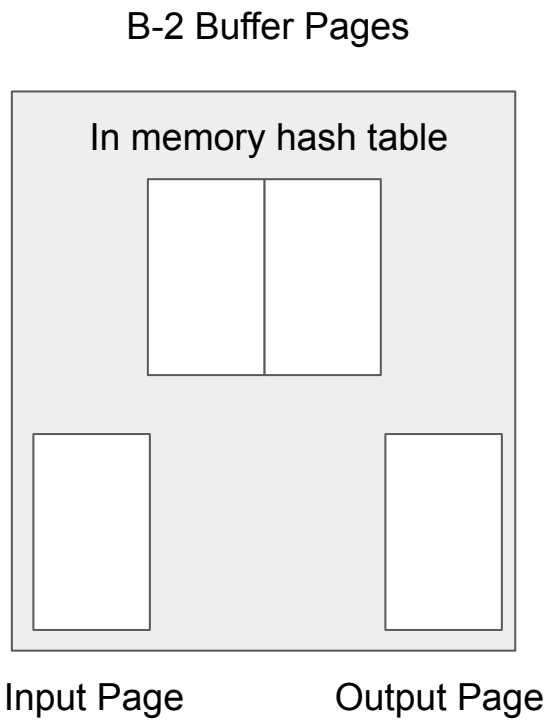

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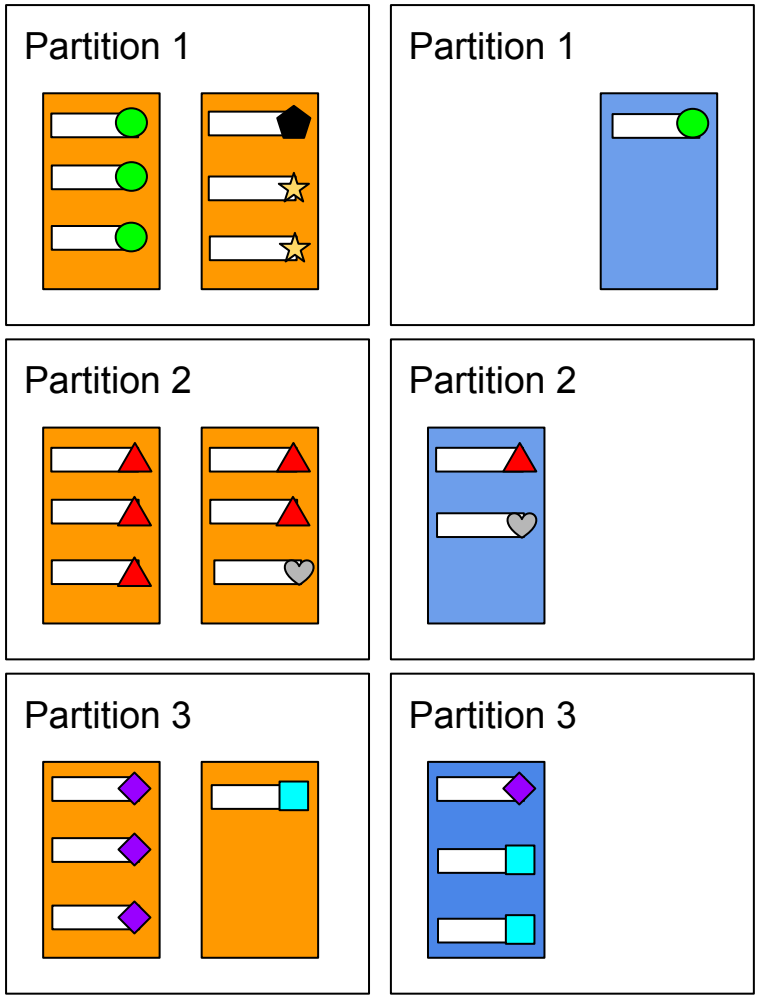

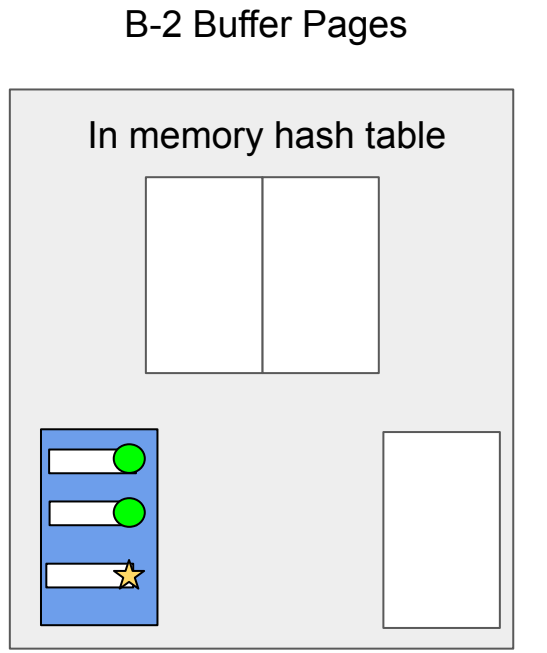

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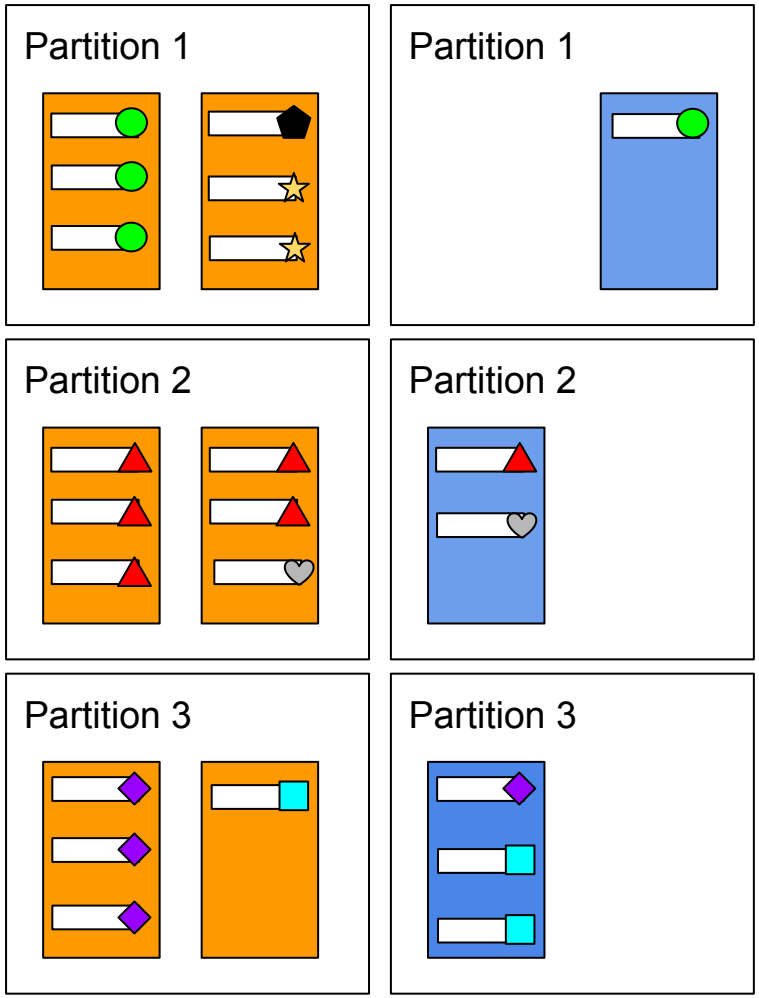

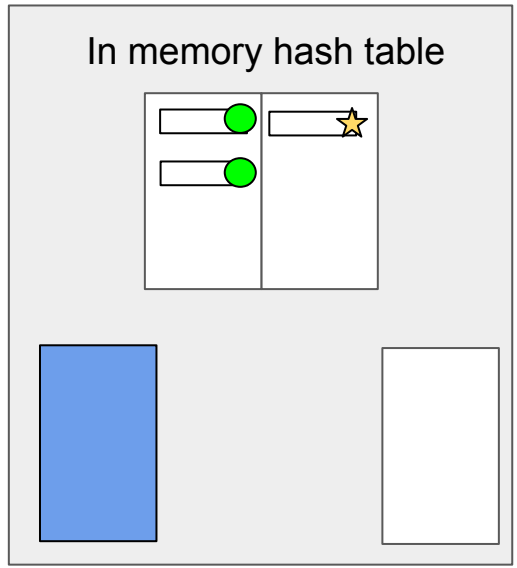

Note: the sections in the hash table represent buckets, rather than pages.

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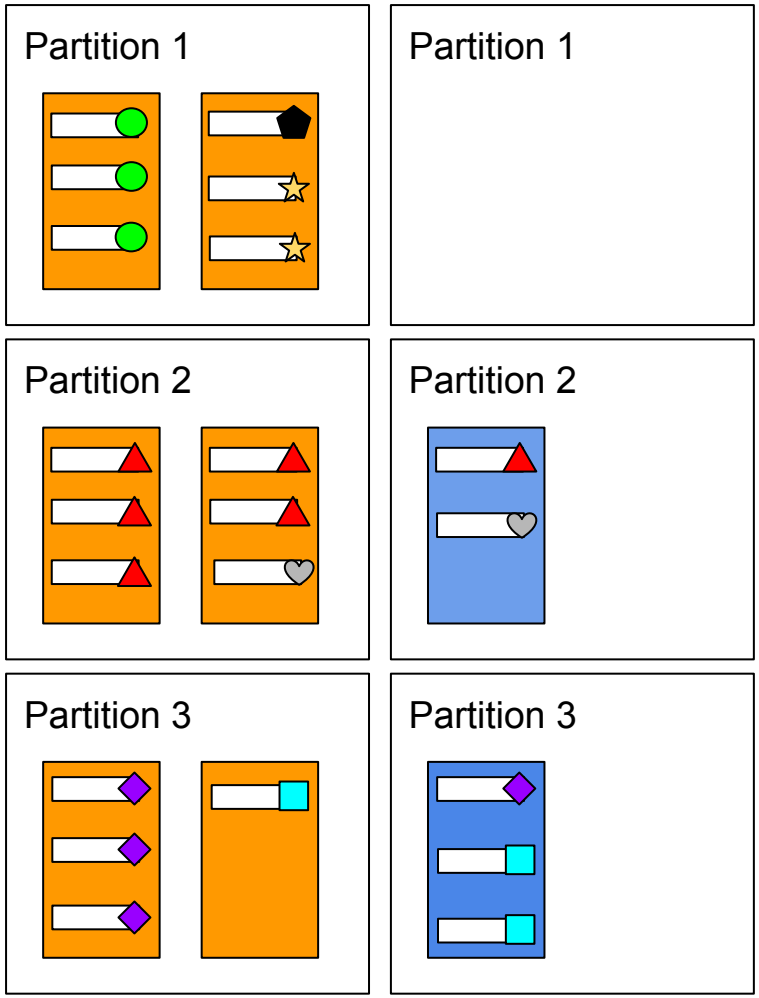

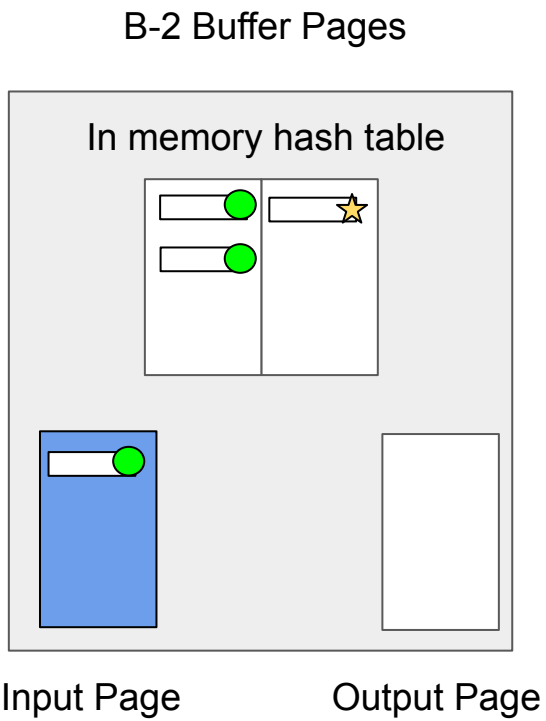

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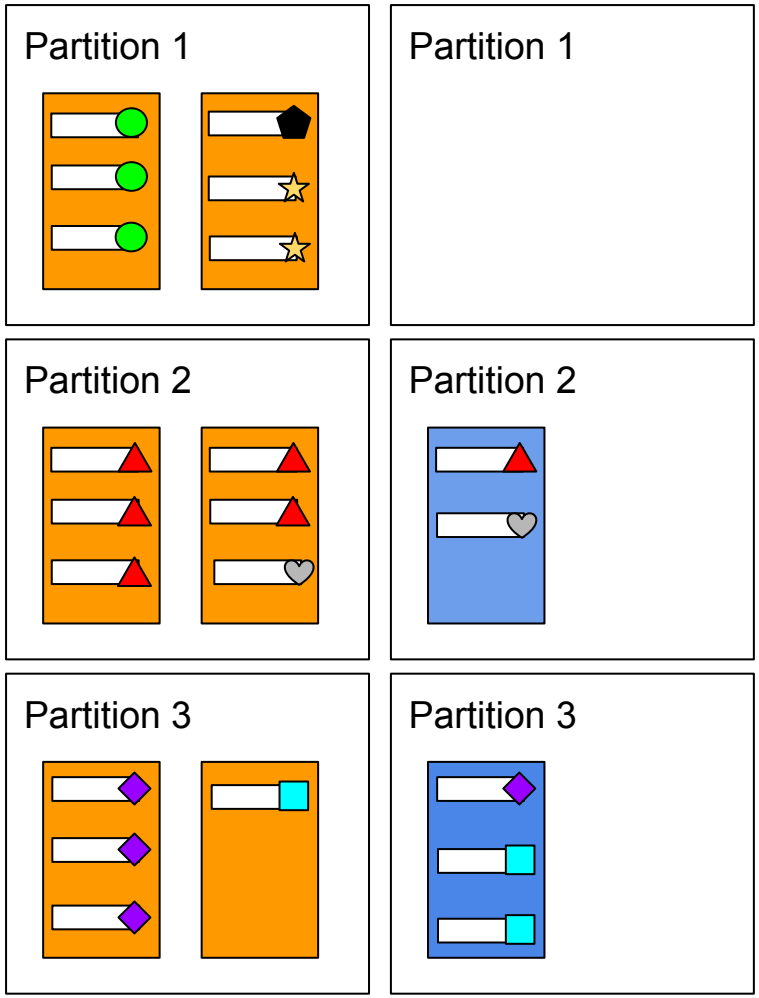

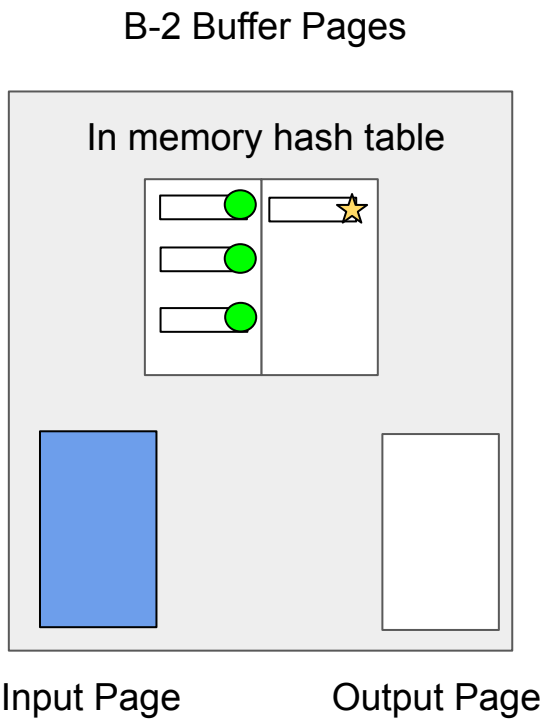

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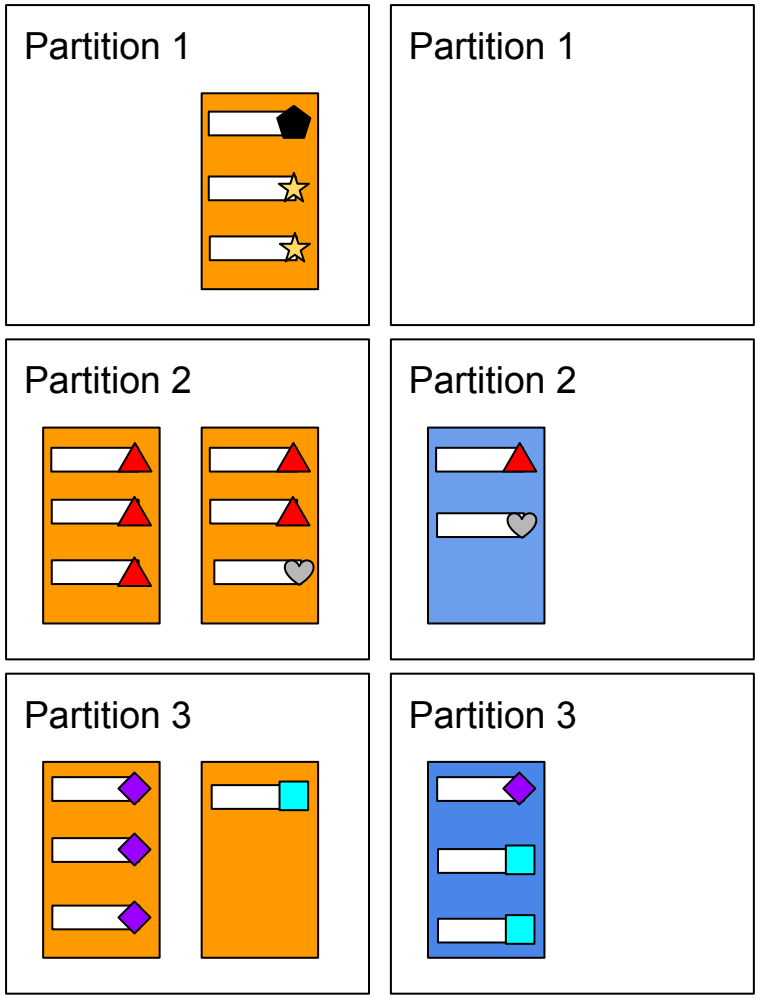

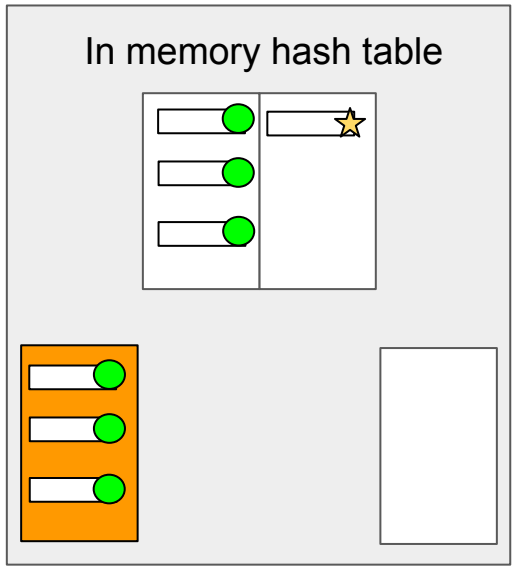

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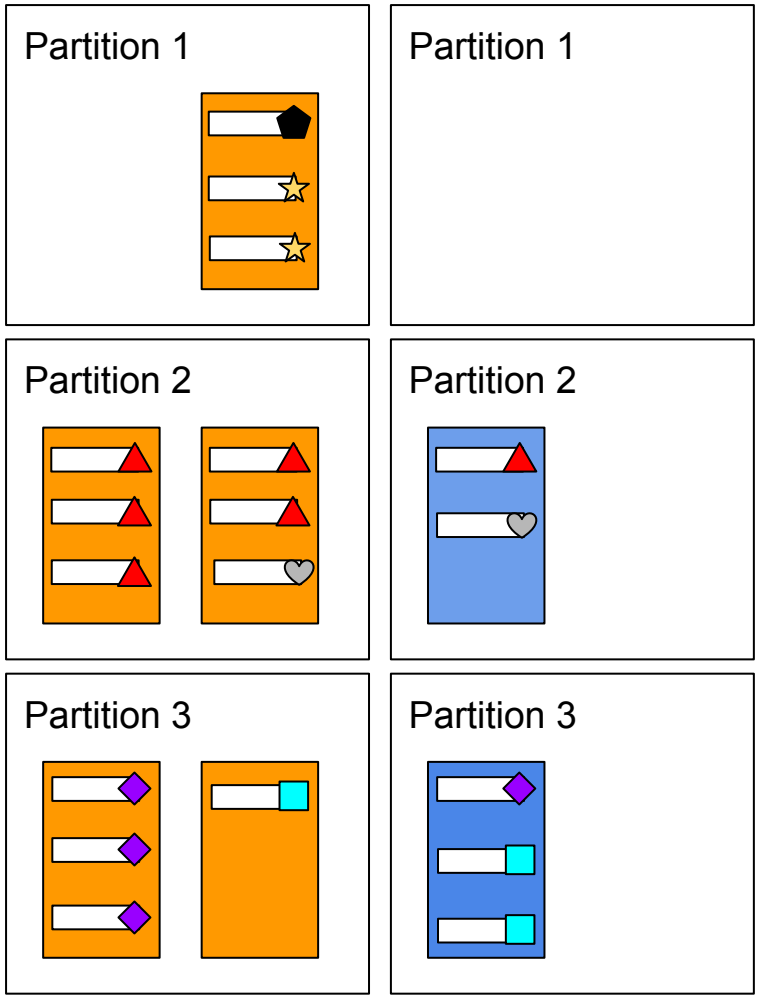

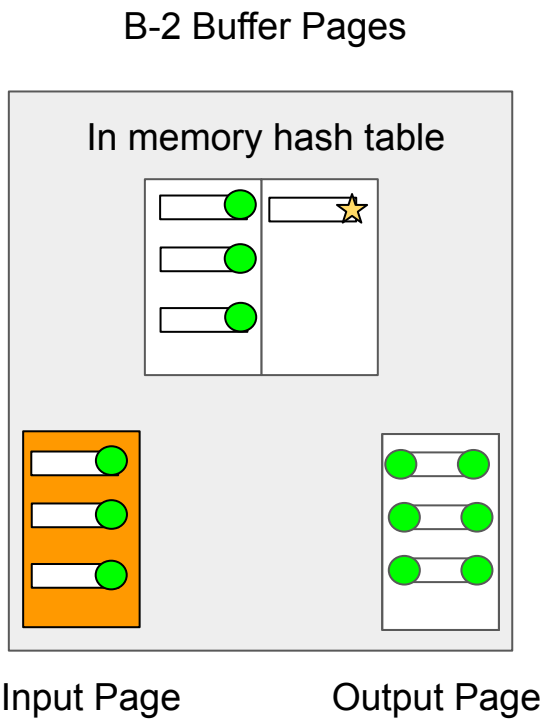

Note: the sections in the hash table represent buckets, rather than pages.

Note: if each page can only hold three records, you could not actually hold 3 joined pairs of records in a single page like this slide is showing. We kept it like this for the sake of convenience.

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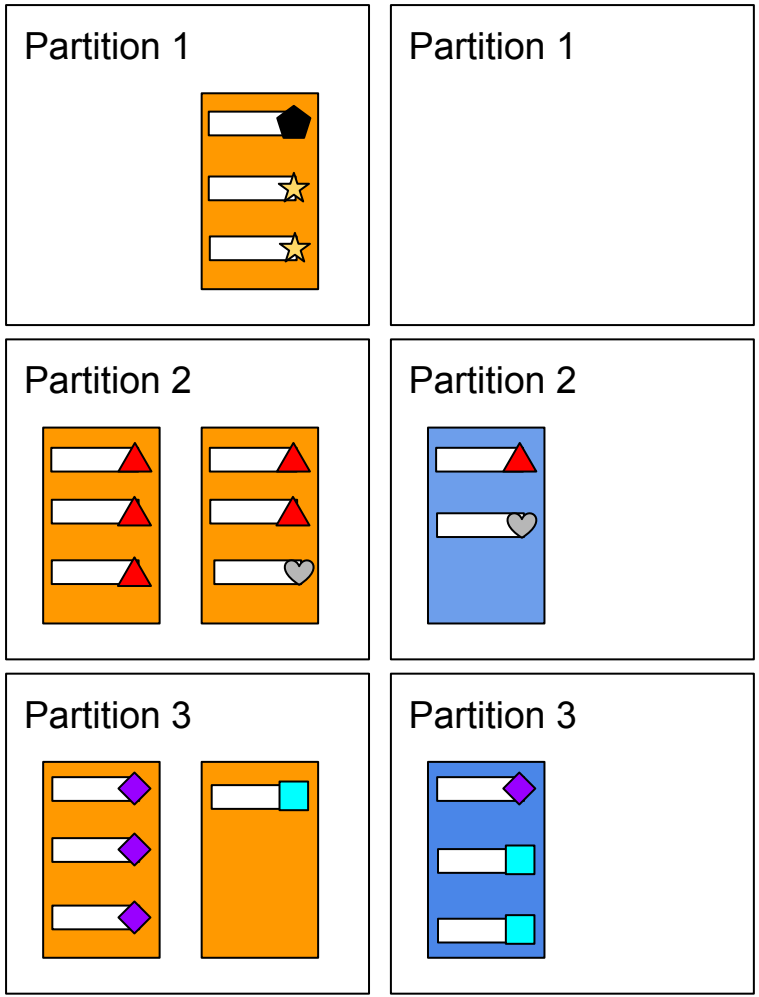

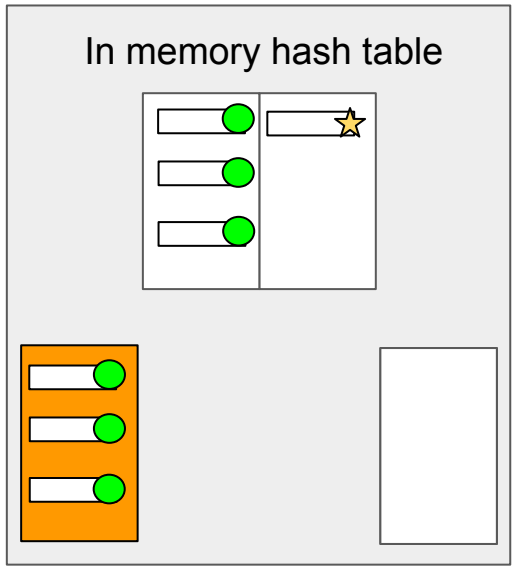

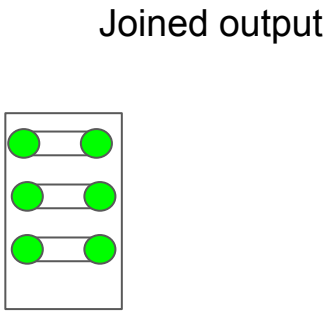

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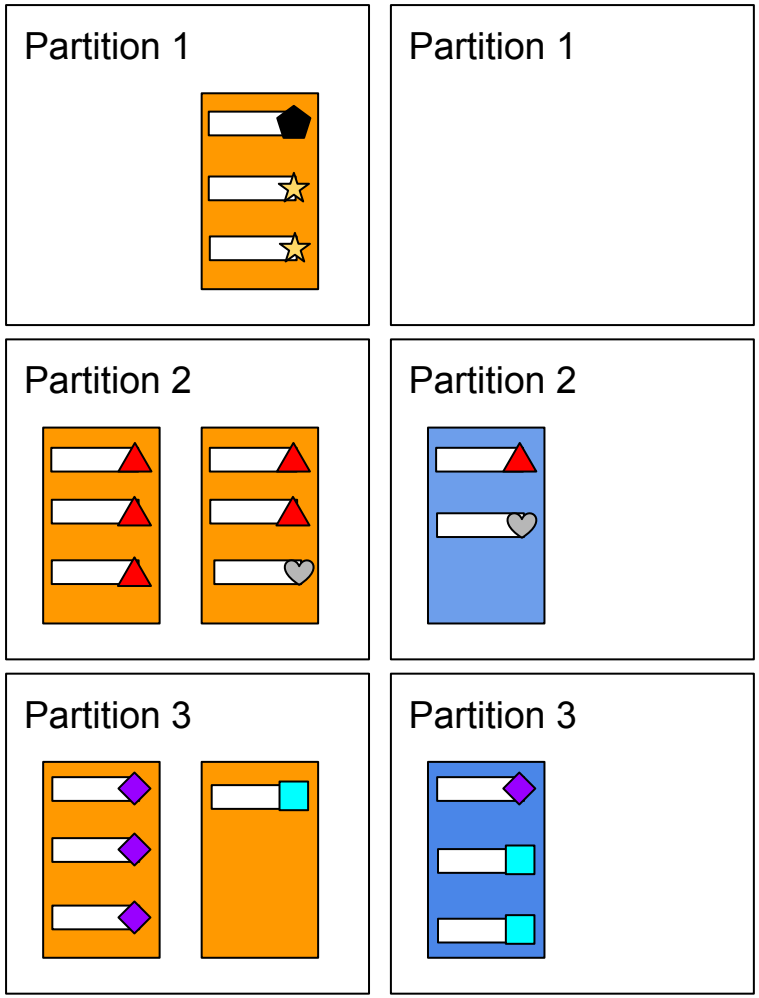

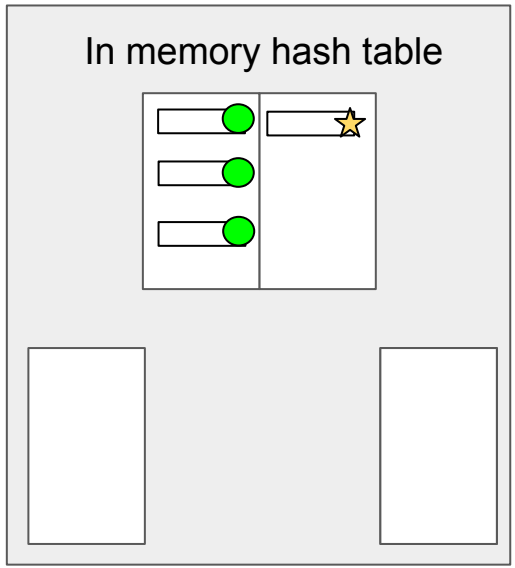

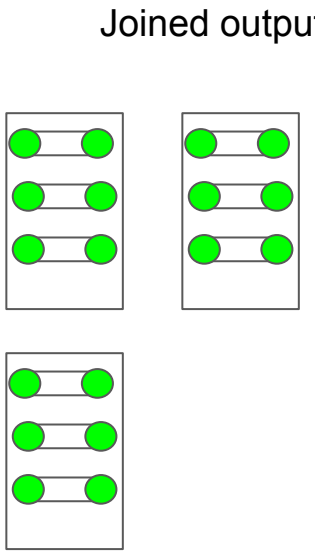

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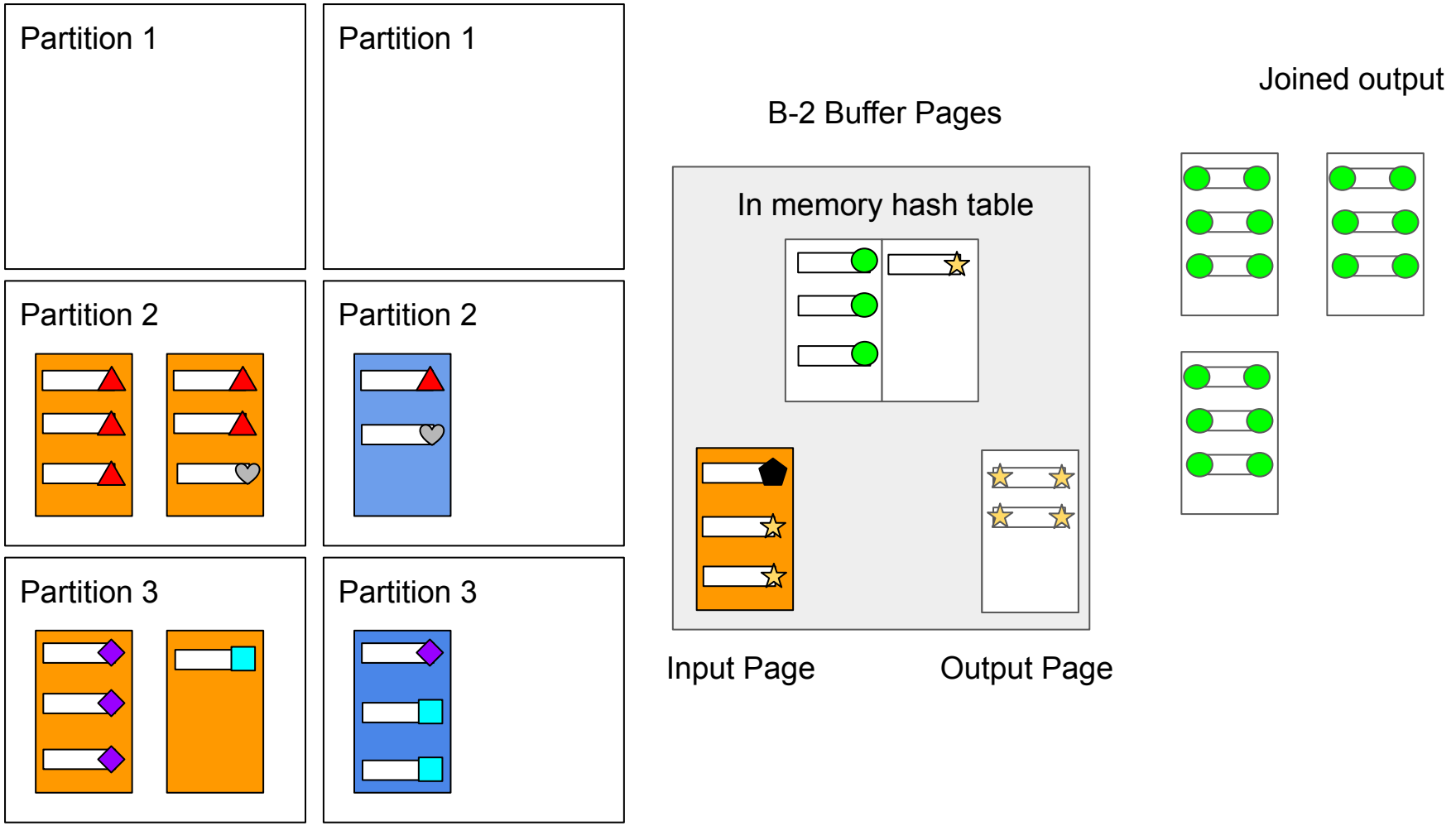

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Practice Problems

- Given Relation X that spans 500 pages, Relation Y that spans 200 pages
  - Both relations have 8 records per page
  - Have access to 12 buffer pages
- Evaluate the number of IO costs for each of the following algorithms:
  - Simple Nested Loop Join
  - Block Nested Loop Join
  - Grace Hash Join
    - Show IOs necessary for both probing and partitioning

Practice Problems

- Given Relation X that spans 500 pages, Relation Y that spans 200 pages
  - Both relations have 8 records per page
  - Have access to 12 buffer pages
- |X|=500 pages, |Y|=200 pages
- ||X|| = |X|*8 records/page = 4000 records
- ||Y|| = |Y|*8 records/page = 1600 records
- B = 12 buffer pages

Practice Problems

- |X|=500 pages, |Y|=200 pages
- ||X|| = |X|*8 records/page = 4000 records
- ||Y|| = |Y|*8 records/page = 1600 records
- B = 12 buffer pages
- Evaluate the number of IO costs for each of the following algorithms:
  - Simple Nested Loop Join
    - |R| + ||R||*|S| = |Y| + ||Y||*|X| = 200 + 1600*500 = 800,200 IOs
  - Block Nested Loop Join
    - |R|+|S|*ceiling(|R|/(B-2)) = |Y|+|X|*ceiling(|Y|/(B-2)) =
      200 + 500*ceiling(200/(12-2)) = 10,200 IOs

Practice Problems

- |X|=500 pages, |Y|=200 pages
- ||X|| = |X|*8 records/page = 4000 records
- ||Y|| = |Y|*8 records/page = 1600 records
- B = 12 buffer pages
- Evaluate the number of IO costs for each of the following algorithms:
  - Grace Hash Join
    - Cost = (2p+1)(M+N) where p is the number of rounds of partitioning
    - Partition size of Y after 1 round of partitioning: 200/ (B-1) = 18.18... > B-2 = 10
    - Partition size of Y after 2 round of partitioning: 200/ $(B-1)^2$ = 1.65... ≤ B-2 = 10
    - Therefore, we need 2 rounds of partitioning.
    - Partition= 2p*(M+N) = 2*2*(500 + 200) = 2800 IOs
    - Probing = (M+N) =500 + 200 = 700 IOs
    - Total = 2800 + 700 = 3500 IOs

Project 4 Intro

Grace Hash Join and You

- Clark Huckelburg has returned from his business trip
  - Personally wants to help optimize Fakebook's join algorithms
- Implement Grace Hash Join
  - Want to optimize to handle join between any relations
  - Have access to a memory and disk simulator
    - Also helper classes for storing partitions(buckets) and records
- Two main methods to implement
  - Partition phase - put data into partitions
    - Each relation has same number of partitions
    - Make sure to simulate memory accesses!
      - Need to write to disk when partition is full
  - Probe phase - compare each partition across relations
    - Look at each partition of the smaller relation and join the other relation when there is a match
      - Each partition of smallest relation is guaranteed to fit into a single page
      - Only one level of recursive hashing (H1 for partition and H2 for probing)

General Tips

- Read the starter code carefully!
- Read the spec carefully!
  - Lots of assumptions that make your life easier
- Start with partitioning then move onto probing
- Remember you have to handle paging and memory accesses
  - All pages live on disk
  - You need to load each page into mem when necessary
    - Load page in by accessing it’s disk page ID
    - Page in mem has different mem page ID
    - Only room for B pages in mem! (Disk unlimited)
  - You need to write each page back to disk when the time comes
    - Use mem page ID
    - Will be given back a disk page ID listing where it lives in disk

Partition Phase

- Create a vector of Buckets!
  - Remember, each bucket gets its own buffer page in memory
  - Need to reserve one page for input from disk
    - B-1 buckets total
- Go one relation at a time
  - Use same hash function for both relation 1 and relation 2
  - Load each relation page by page
    - Need to iterate over records in each page as well
    - Hash each record to correct bucket and add to corresponding page
    - If a page is full you need to write to disk
      - Also need to write to disk all partially full pages once the relation is exhausted!
    - Remember to clear the pages after writing to disk!

Probe Phase

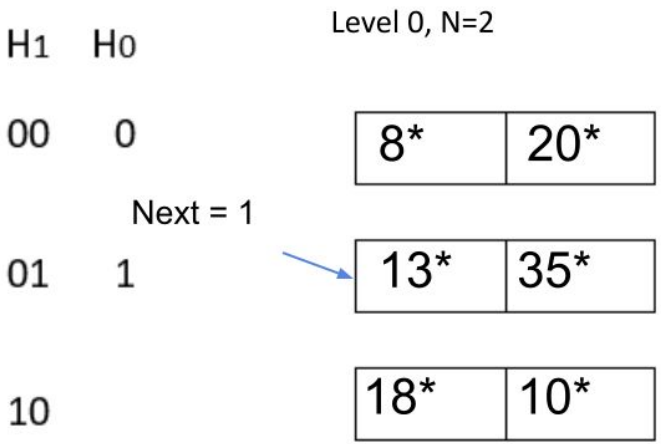
- Use the vector of Buckets!
  - Iterate over the partitions created in the partition phase
  - Repartition each partition into sub partitions
    - Still only have B buffer pages
    - 1 page for input (reading in partition pages from partition page)
    - 1 page for output (output of join)
    - B-2 pages for sub partitions
  - Repartition a partition of one relation, then repartition a partition of the other relation
    - Hint: look at spec to see which one to repartition first to avoid overflows
  - Add any matches to output page
    - Write output page to disk whenever full
    - Accumulate all disk page IDs and return in vector
    - Remember to write output page back to disk at end, even if not full!
  - Remember to clean buffer pages between partitions!

HW4 Q2.2

The hash function that will be used:

$$h_i(value) = value \bmod (2^i N)$$

2.4. Insert 14 = $(1110)_2$ (4 points)



Get started on Homework 5!

We’re here if you need any help!!

- Office Hours: Schedule is here, both virtual and in person offered
- Piazza
- Next week’s discussion!!!