DS 4300

Large Scale Information Storage and Retrieval

Foundations

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Searching

- Searching is the most common operation performed by a database system
- In SQL, the SELECT statement is arguably the most versatile / complex.
- Baseline for efficiency is **Linear Search**
  - Start at the beginning of a list and proceed element by element until:
    - You find what you're looking for
    - You get to the last element and haven't found it

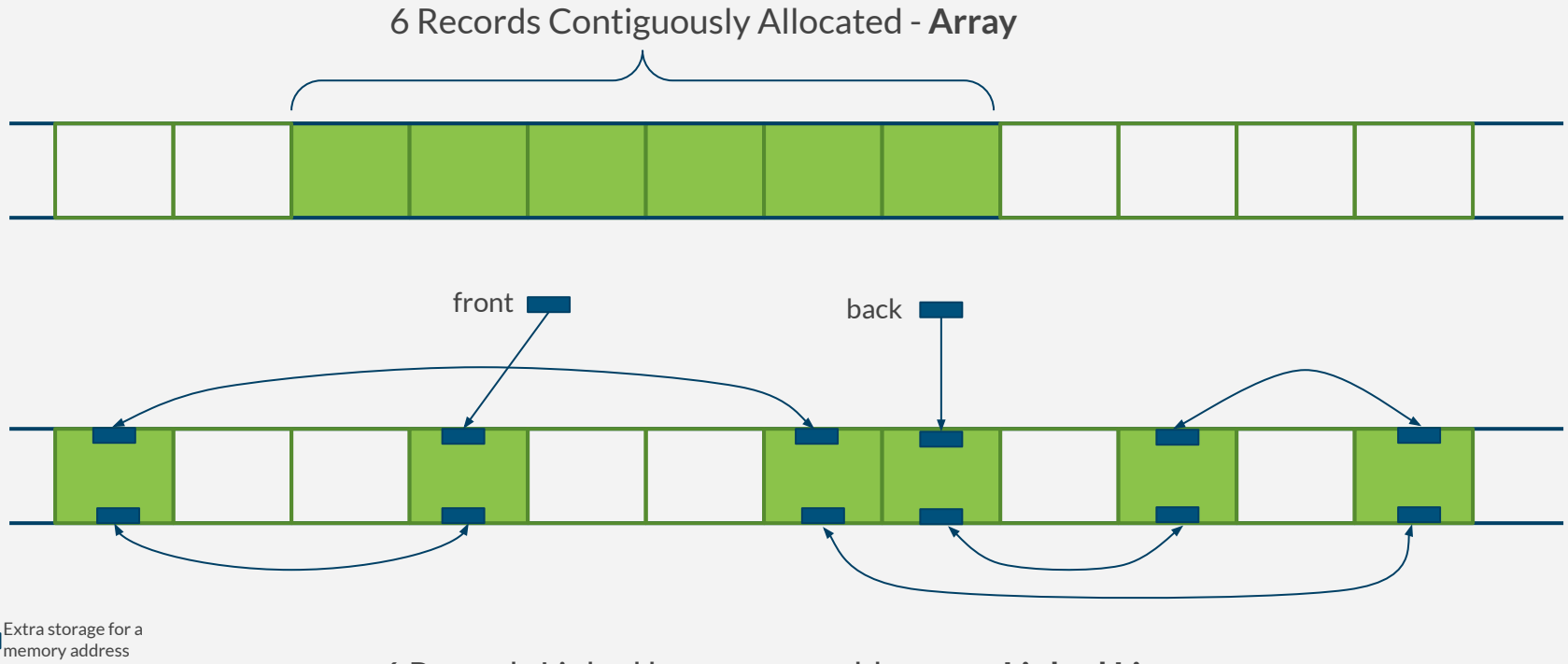
Searching

- **Record -** A collection of values for attributes of a single entity instance; a row of a table *(tuple)
- **Collection -** a set of records of the same entity type; a table
  - Trivially, stored in some sequential order like a list
- **Search Key** - A value for an attribute from the entity type
  - Could be >= 1 attribute

Lists of Records

- If each record takes up ***x*** bytes of memory, then for ***n*** records, we need ***n*x*** bytes of memory.
- Contiguously Allocated List
  - All ***n*x*** bytes are allocated as a single “chunk” of memory
- Linked List
  - Each record needs *x* bytes + additional space for 1 or 2 memory addresses *(for linking -> this times n is total space it takes up)
  - Individual records are linked together in a type of chain using memory addresses

Contiguous vs Linked

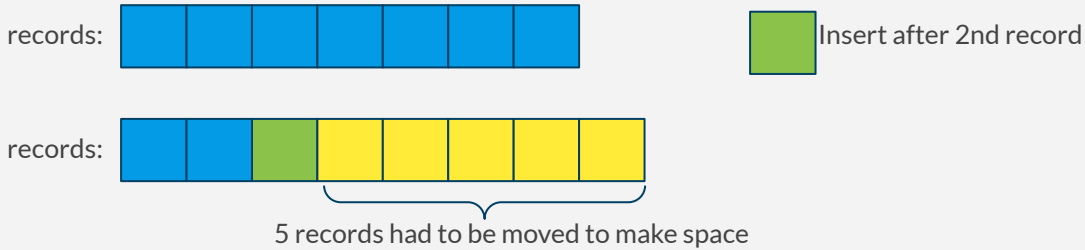


* for linked lists, start at front or back and follow arrows through list

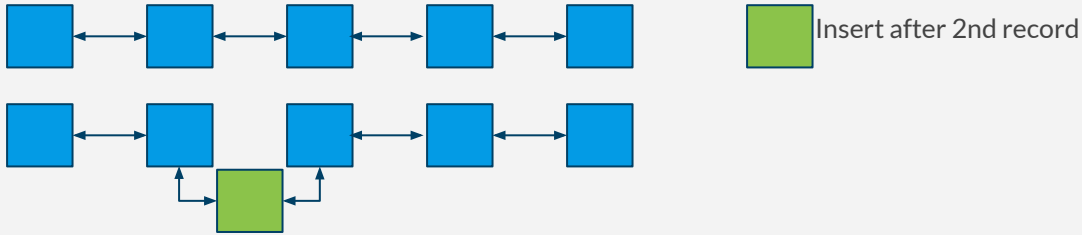
Pros and Cons

- Arrays are faster for random access *(bc everything is in an order, no memory addresses), but slow for inserting anywhere but the end

*Numpy arrays are contiguously allocated



- Linked Lists are faster for inserting anywhere *(don't have to move anything down) in the list, but slower for random access *(have to always start at first element and follow path)



Observations:

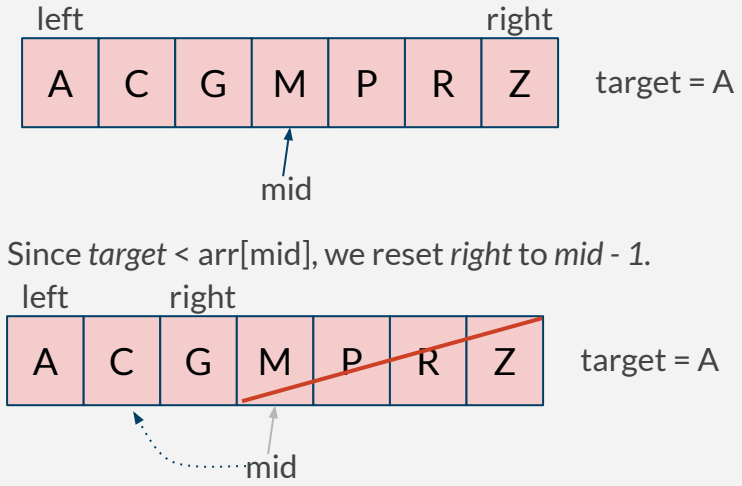
- Arrays
  - fast for random access
  - slow for random insertions
- Linked Lists
  - slow for random access
  - fast for random insertions

*cannot perform binary search on unordered array

Binary Search

- Input: array of values in sorted order, target value
- Output: the location (index) of where target is located or some value indicating target was not found

```
def binary_search(arr, target)
  left, right = 0, len(arr) - 1
  while left <= right:
    mid = (left + right) // 2
    if arr[mid] == target:
      return mid
    elif arr[mid] < target:
      left = mid + 1
    else:
      right = mid - 1
return -1 *(if target is not there)
```



*for binary search, keep cutting search in half until target is found

*you could do binary search on linear array, but inefficient because you still have to iterate up to middle starting point

Time Complexity

- Linear Search
  - Best case: target is found at the first element; only 1 comparison
  - Worst case: target is not in the array; *n* comparisons
  - Therefore, in the worst case, linear search is *O(n)* time complexity.
- Binary Search
  - Best case: target is found at *mid*; 1 comparison (inside the loop)
  - Worst case: target is not in the array; $log_2 n$ comparisons
    *(cutting search in half a number of times)
  - Therefore, in the worst case, binary search is $O(log_2 n)$ time complexity.

Back to Database Searching

- Assume data is stored on disk by column id's value
- Searching for a specific id = fast.
- But what if we want to search for a specific *specialVal*?
  - Only option is linear scan of that column *(specialVal is not in sorted order (no binary)
- Can't store data on disk sorted by both id and specialVal (at the same time)
  - data would have to be duplicated → space inefficient

id	specialVal
1	55
2	87
3	50
4	108
5	122
6	149
7	145
8	120
9	50
10	83
11	128
12	117
13	119
14	119
15	51
16	85
17	51
18	145
19	73
20	73

Back to Database Searching

- Assume data is stored on disk by column id's value
- Sea
- Bu
  sp
  - nn
- Ca
  an
  - data would have to be duplicated → space inefficient

We need an external data structure to support faster searching by *specialVal* than a linear scan.

id	specialVal
1	55
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16	85
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18	145
19	73
20	73

What do we have in our arsenal?

1) An array of tuples (specialVal, rowNumber) sorted by specialVal
   a) We could use Binary Search to quickly locate a particular specialVal and find its corresponding row in the table
   b) But, every insert into the table would be like inserting into a sorted array - slow…
2) A linked list of tuples (specialVal, rowNumber) sorted by specialVal
   a) searching for a specialVal would be slow - linear scan required
   b) But inserting into the table would theoretically be quick to also add to the list.

Something with Fast Insert and Fast Search?

- Binary Search Tree - a binary tree where every node in the left subtree is less than its parent and every node in the right subtree is greater than its parent.

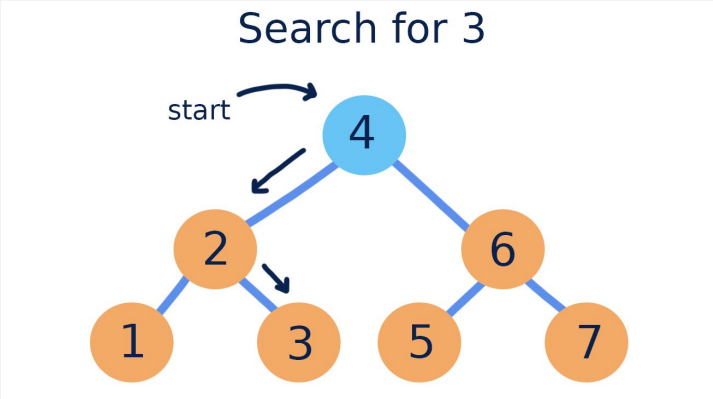

Image from: https://courses.grainger.illinois.edu/cs225/sp2019/notes/bst/

*Tree traversals: PreOrder, PostOrder, InOrder, ->LevelOrder

*deque (double-ended queue) -> can insert from front and back

To the Board!

*class BinaryTreeNode(self, value, left=None, right=None):
    value = integer
    left = BinaryTreeNode
    right = BinaryTreeNode'

example:
root = BinaryTreeNode(23)
root.left = BinaryTreeNode(17)
root.right= BinaryTreeNode(43)
root.left.right = BinaryTreeNode(20)