SIMON FRASER UNIVERSITY
ENGAGING THE WORLD

CMPT 120: Introduction to Computing Science and Programming 1

Searching

Today’s Topics

1. Searching
2. Linear Search
3. Binary Search

Introduction to Searching

- Have your ever used **Ctrl-F** keys?
  - We use it to **search** a **value**.
  - How to search a value – how to search it fast?
- **Searching**: Locating an item in a list of data.
- Two of search algorithms are:
  1. **Linear** or Sequential Search.
  2. **Binary** Search.
     - Half-interval search.
     - Logarithmic search.

Linear Search

- Starting at the first element, this algorithm steps through an array **sequentially**, examining each element until it locates the desired value.
  - Suppose, an array **list** contains following values:

17	23	5	11	2	29	3

list[0] list[6]

  - To search a **value 11**, Linear Search compares 17, 23, 5, and 11.
  - Say, we define two variable:
  - **VALUE = 11**
  - **found = False**
  - How you will perform this Linear Search?

Linear Search

- **Algorithm:**

```
list = [45,  12, 34, 2, 5, 40]
Set search value = 2
  for i in range(len(list)):
      if list[i] is equal to search value
           return i
      return -1
```

Linear search **algorithm**

```
linearSearch(list, target)

  set result to value TARGET_NOT_FOUND
  set targetNotFound to value true

  if list not empty
    set currentElement to first element of list
    while targetNotFound AND
         have not looked at every element of list
      if currentElement == target
        set result to current element
        set targetNotFound to false
      otherwise
        set currentElement to next element of list

  return result
```

Linear Search

- **Algorithm:**

Worst-case performance	*O(n)*
Best-case performance	*O(1)*
Average performance	*O(n)*

Linear Search - Tradeoffs

- Benefits:
  - Easy algorithm to understand
  - List can be in any order

- Disadvantages:
  - Inefficient (slow): for a list of N elements it examines:
    - **N/2** elements on average for value in array,
    - **N** elements for value not in array.

Binary Search

- **Binary Search** is a another search algorithm.
- It requires array elements to be ordered (sorted).

1. Divides the array into **three** sections:
   i. middle element
   ii. elements on one side of the middle element
   iii. elements on the other side of the middle element
2. If the middle element is the correct value, done. Otherwise, go to step 1. Using only the half of the array that may contain the correct value.
3. Continue steps 1. and 2. until either the value is found or there are no more elements to examine.

Binary search algorithm

- **Question 1:** does your word start with a letter <= M?
- Possible answer:
  - **Yes**, so we can ignore ½ of the alphabet

    A B C D E F G H I J K L M ~~N O P Q R S T U V W X Y Z~~

  - **No**, so we can ignore the other ½

    ~~A B C D E F G H I J K L M~~ N O P Q R S T U V W X Y Z

Binary search algorithm

Next question:

- Question 2: **does your word start with a letter <= G?**
- Possible answer:
  - Yes, so we can ignore ½ of the alphabet

    A B C D E F G ~~H I J K L M~~
  - No, so we can ignore the other ½

    ~~A B C D E F G~~ H I J K L M

OR

- Question 2: **does your word start with a letter <= T?**
- Possible answer:
  - Yes, so we can ignore ½ of the alphabet

    N O P Q R S T ~~U V W X Y Z~~
  - No, so we can ignore the other ½

    ~~N O P Q R S T~~ U V W X Y Z

One possible algorithm -> binary search algorithm

Next question:

- Question 3: does your word start with a letter <= D?
- Possible answer:
  - Yes, so we can ignore ½ of the alphabet

    A B C D ~~E F G~~
  - No, so we can ignore ½ of the alphabet

    ~~A B C D~~ E F G

OR

Question 3: does your word start with a letter <= J?

H I J K L M

Question 3: does your word start with a letter <= Q?

N O P Q R S T

Question 3: does your word start with a letter <= W?

U V W X Y Z

etc...

Another example

- Suppose we have a sorted list:

1 3 4 7 9 11 12 14 21

- Using Binary Search algorithm, we can search for **target = 7** without having to look at every element.

Animation: How it works – 1

1. We start with a list and a **target = 7**

1 3 4 7 9 11 12 14 21

2. We find the *middle* element

1 3 4 7 9 11 12 14 21

3. Is this element == target?
   - Yes, then we are done!
   - No, then we throw away half of the list in which we know target cannot be located (grey part)

1 3 4 7 9 11 12 14 21

and we consider only the part in which target could be located.

We repeat steps 2 and 3 until we found target or run out of list.

Animation: How it works – 2

2. We find the *middle* element

1 3 4 7 | 9 11 12 14 21

3. Is this element == target?
   - Yes, then we are done!
   - No, then we throw away half of the list in which we know target cannot be located (grey part)

1 3 | 4 7 | 9 11 12 14 21

and we consider only the part in which target could be located

We repeat steps 2 and 3 until we found target or run out of list.

Animation: How it works - 3

2. We find the *middle* element

1 3 4 7 9 11 12 14 21

3. Is this element == target?
   - Yes, then we are done!
   - No, then we throw away half of the list in which we know target cannot be located (grey part)

1 3 4 7 9 11 12 14 21

and we consider only the part in which target could be located

We repeat steps 2 and 3 until we found target or run out of list.

Animation: How it works - 4

2. We find the *middle* element

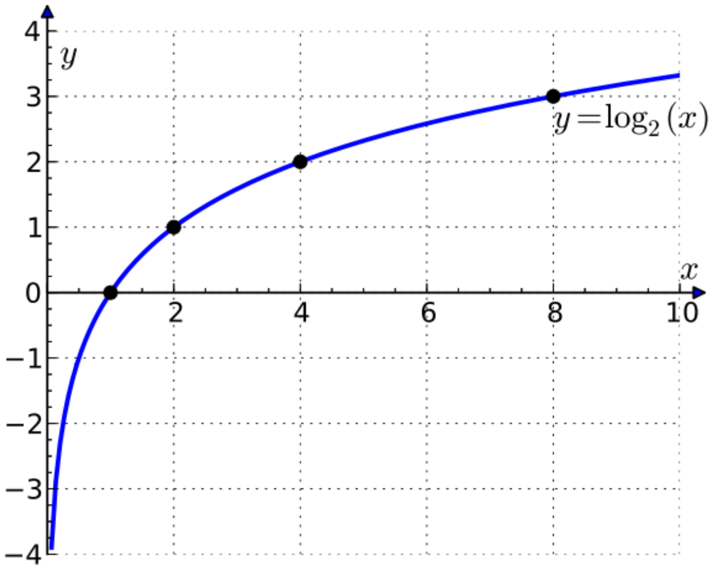
1	3	4	7	9	11	12	14	21

3. Is this element == target?
   - Yes, then we are done! ☺

Binary Search - Tradeoffs

- Benefits:
  - Much more efficient than linear search. For array of N elements, performs at most $\boldsymbol{log_2 N}$ comparisons.
  - Faster because does not have to look at every element (at every iteration, ignores ½ of list).

- Disadvantages:
  - Requires that array elements be sorted



Time efficiency of binary search algorithm

Result of binary search algorithm efficiency analysis:

- The worst case scenario of the **binary search algorithm** is of order $\log_2 n$ i.e., has a time efficiency of $O(\log_2 n)$.

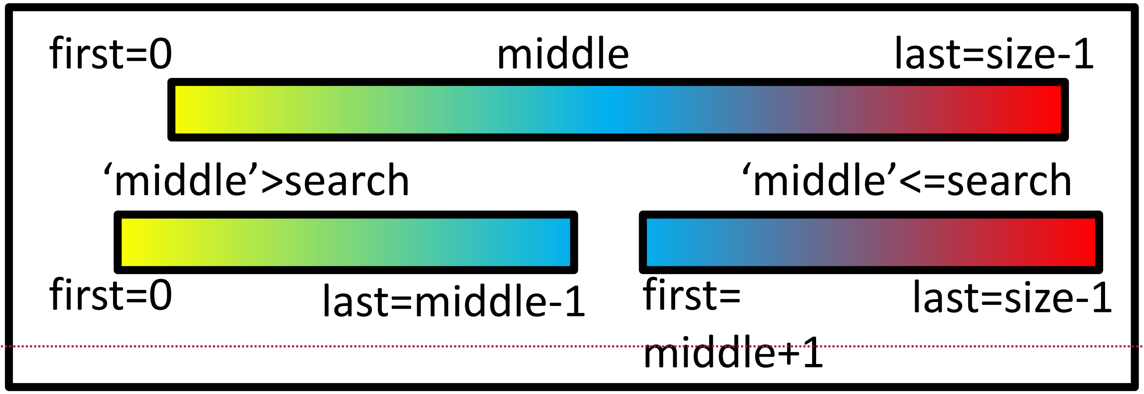
since the time required (i.e., number of times the critical operation is executed) by the binary search algorithm (under the worst case scenario) to find “target” in a list of length **n** is proportional to the log of the number of elements in the list, i.e., **n.**

Binary search **algorithm: Time Complexity**

- **Worst-case space complexity**: O(1)
- **Worst-case performance**: O(log n)
- **Best-case performance**: O(1)
- **Average performance**: O(log n)

Binary Search

*Set **first** to 0*
*Set **last** to the last subscript in the array*
*Set **found** to false*
*Set **position** to -1*
*While **found** is not true and **first** is less than or equal to **last***
    *Set **middle** to the subscript half-way between array[first] and array[last].*
    If array[middle] equals the desired value
        Set found to true
        Set position to middle
    Else If array[middle] is greater than the desired value
        Set last to middle - 1
    Else
        Set first to middle + 1
    End If.
End While.
Return position.



Binary Search algorithm - iterative

```
PreCondition: data must be sorted
binarySearch(list, target)
  set position to value TARGET_NOT_FOUND
  set targetNotFound to value true
  if list not empty
  while targetNotFound AND have not looked or discarded every element of list
      find middle element of list
      if middle element == target
        set position to position of target in original list
        set targetNotFound to false
      else
        if target < middle element
          list = first half of list
        else
          list = last half of list
  return position
```

We ignore 2nd half of the list and middle element

We ignore 1st half of the list and middle element

Questions?