

Binary Search

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Given a sorted array `arr[]` of `n` elements, write a function to search a given element `x` in `arr[]`.

A simple approach is to do **linear search**, i.e., start from the leftmost element of `arr[]` and one by one compare `x` with each element of `arr[]`, if `x` matches with an element, return the index. If `x` doesn't match with any of elements, return -1.

```
// Linearly search x in arr[]. If x is present then return its
// location, otherwise return -1
int search(int arr[], int n, int x)
{
    int i;
    for (i=0; i<n; i++)
        if (arr[i] == x)
            return i;
    return -1;
}
```

The time complexity of above algorithm is $O(n)$.

The idea of binary search is to use the information that the array is sorted and reduce the time complexity to $O(\log n)$. We basically ignore half of the elements just after one comparison.

- 1) Compare `x` with the middle element.
- 2) If `x` matches with middle element, we return the mid index.
- 3) Else If `x` is greater than the mid element, then `x` can only lie in right half subarray after the mid element. So we recur for right half.
- 4) Else (`x` is smaller) recur for the left half.



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Following is **Recursive** C implementation of Binary Search.

```
#include <stdio.h>

// A recursive binary search function. It returns location of x in
// given array arr[l..r] is present, otherwise -1
int binarySearch(int arr[], int l, int r, int x)
{
    if (r >= l)
    {
        int mid = l + (r - l)/2;

        // If the element is present at the middle itself
        if (arr[mid] == x) return mid;

        // If element is smaller than mid, then it can only be present
        // in left subarray
        if (arr[mid] > x) return binarySearch(arr, l, mid-1, x);

        // Else the element can only be present in right subarray
        return binarySearch(arr, mid+1, r, x);
    }

    // We reach here when element is not present in array
    return -1;
}

int main(void)
{
    int arr[] = {2, 3, 4, 10, 40};
    int n = sizeof(arr)/ sizeof(arr[0]);
    int x = 10;
    int result = binarySearch(arr, 0, n-1, x);
    (result == -1)? printf("Element is not present in array")
                  : printf("Element is present at index %d", result);

    return 0;
}
```

Output:

Element is present at index 3

Following is **Iterative** C implementation of Binary Search.

```
#include <stdio.h>
```

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```
// A iterative binary search function. It returns location of x in
// given array arr[l..r] if present, otherwise -1
int binarySearch(int arr[], int l, int r, int x)
{
    while (l <= r)
    {
        int m = l + (r-l)/2;

        if (arr[m] == x) return m; // Check if x is present at mid

        if (arr[m] < x) l = m + 1; // If x greater, ignore left half

        else r = m - 1; // If x is smaller, ignore left half
    }
    return -1; // if we reach here, then element was not present
}

int main(void)
{
    int arr[] = {2, 3, 4, 10, 40};
    int n = sizeof(arr)/ sizeof(arr[0]);
    int x = 10;
    int result = binarySearch(arr, 0, n-1, x);
    (result == -1)? printf("Element is not present in array")
                  : printf("Element is present at index %d", result);

    return 0;
}
```

Output:

Element is present at index 3

Time Complexity:

The time complexity of Binary Search can be written as

$$T(n) = T(n/2) + c$$

The above recurrence can be solved either using Recurrence Tree method or Master method. It falls in case II of Master Method and solution of the recurrence is .

Auxiliary Space: $O(1)$ in case of iterative implementation. In case of recursive implementation, $O(\log n)$ recursion call stack space.

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The Ubiquitous Binary Search

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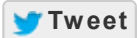
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