



{Binary Search}

Foundation Course on Data Structures & Algorithm - Part I

Questions:

✓ Implement Binary Search

✓ First and Last Position of Element in sorted Array

✓ Find total number of Occurences in a sorted array

✓ Find (value = index) in a sorted array

→ Easy

✓ Find pivot element in an array

✓ Search in a Rotated and sorted Array

✓ Peak in mountain array

✓ Square Root using Binary Search

✓ Check if N and its Double Exists - LeetCode

✓ Search in a Sorted array of Unknown Size

2
D
1
P.S

L.S
n
H

6 F 9

L + m
=

L C

}

→ Binary

Search:-

monotonic \neq

→ T.C →

$O(\log n)$

$n = 2^{10}$

→ 1024 →

L.S

↓
1024 cmp

B.S

↓
10 cmp

2^{100}

→ Base

↓

D.S

↓
100

→ 2^{100} → value

→

1	3	7	9	11
---	---	---	---	----

inc

→

11	10	9	1
----	----	---	---

 → dec

← Linear Search

→ T.C → $O(n)$



single traversal

pre-requisite

condn

↓
sorted order



B.S → $O(\log n)$ → How?
 → why?
 inc/dec mid mid mid+1
 (cond)



search
 $arr[mid] = 9$
 $9 == 15$

inc order
 $15 > 9$

target = 15
 ↓
 present or absent

app #1 → Linear Search → $O(n)$ →

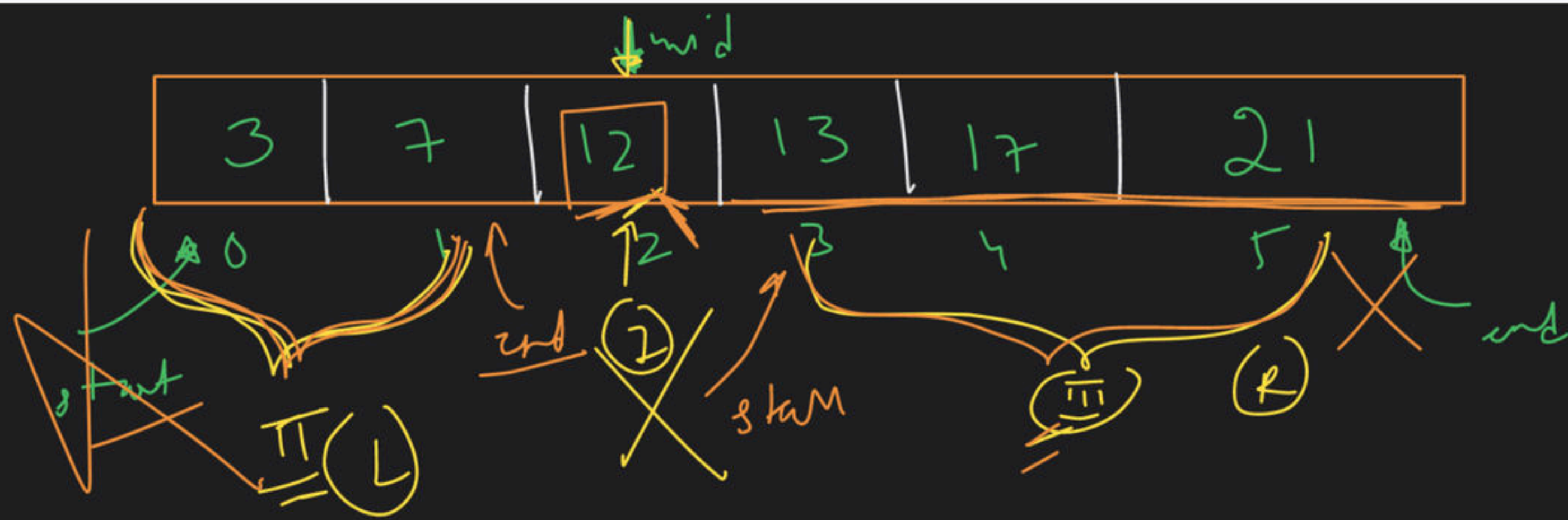
app #2 → Binary Search

$$mid = \left(\frac{s + e}{2} \right) = \frac{0 + 6}{2} = 3$$

if (arr[mid] == target)
return true;

if (target < arr[mid])
e = mid - 1;

if (target > arr[mid])
s = mid + 1;



$$mid = \frac{start + end}{2}$$

$$= \frac{0 + 5}{2} = 2$$

$$target = 17$$

$$arr[mid] == target ==$$

$$12 == 17 \rightarrow F$$

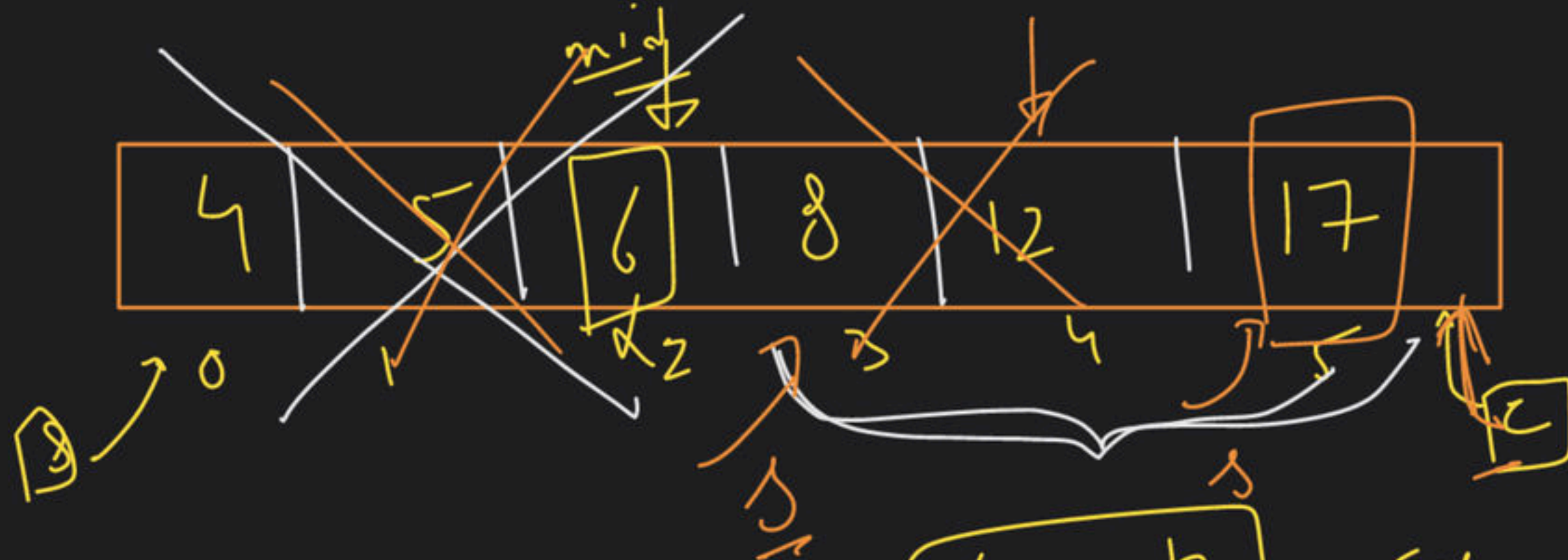
$$if (target < arr[mid]) \text{ (Left)}$$

$$end = mid - 1$$

$$if (target > arr[mid]) \rightarrow \text{Right}$$

$$start = mid + 1$$

→ code



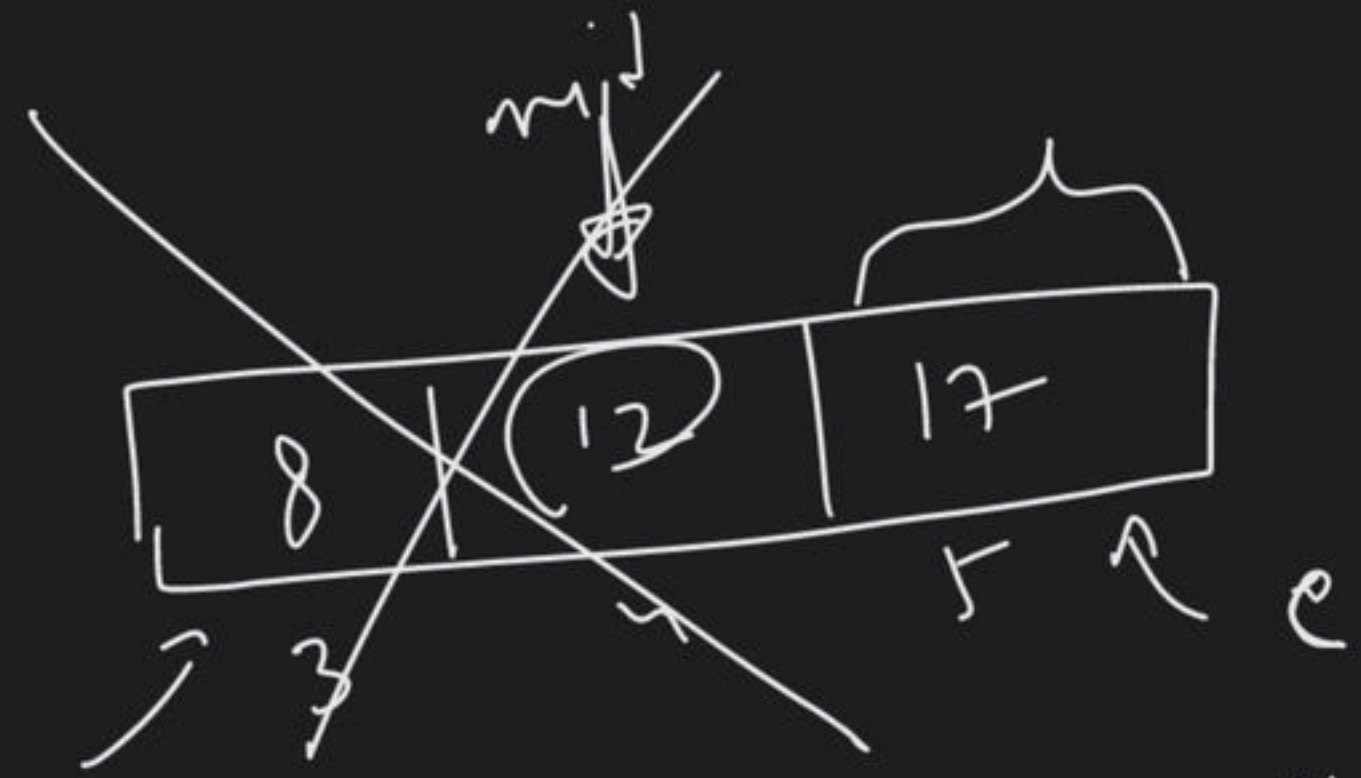
target = 17

$s = 0$
 $e = 5$ → $mid = \frac{0+5}{2} = 2$

$6 == 17$ → False

Left → $17 < 6$ → False

Right → $17 > 6$ → True



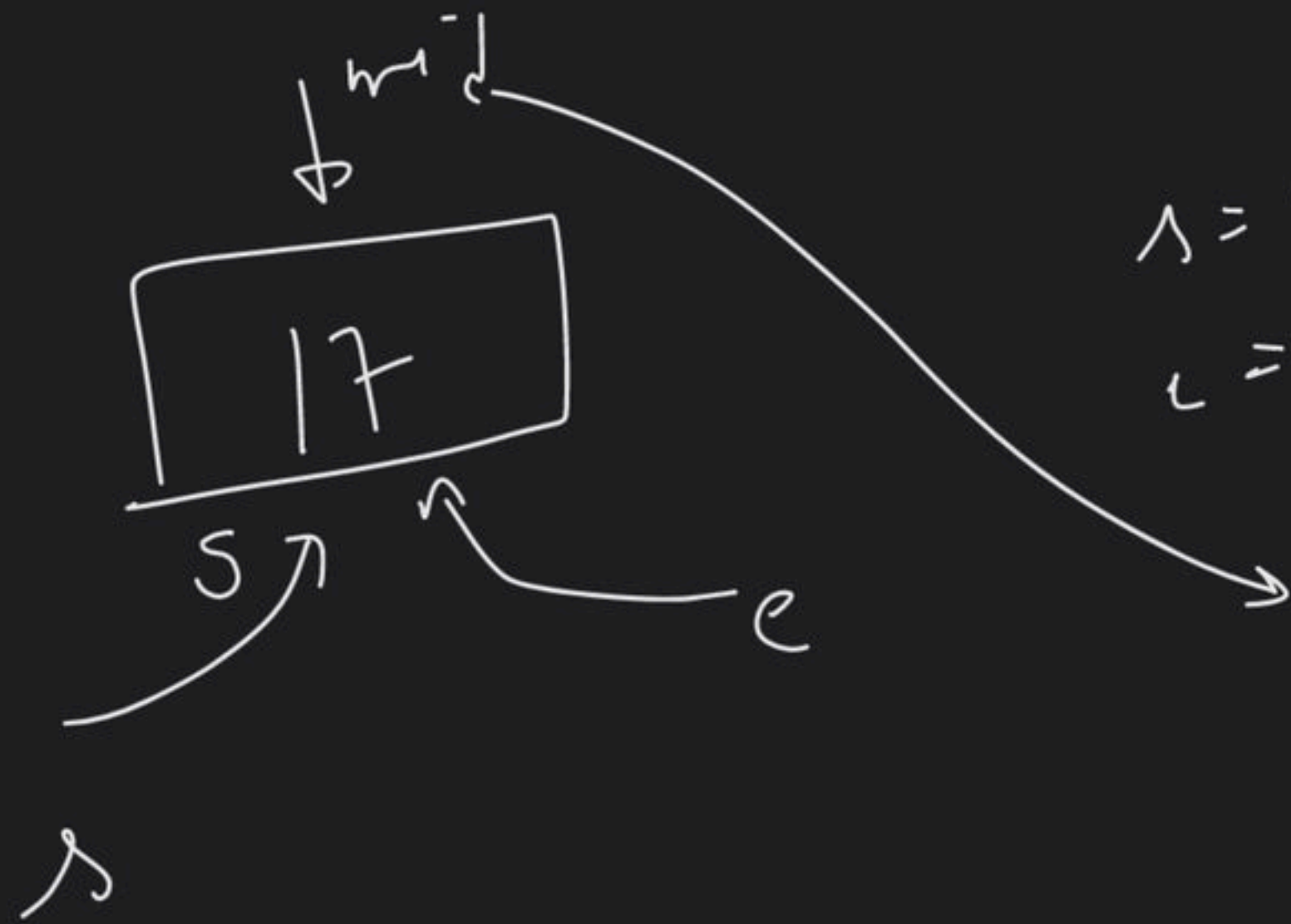
$s \leq e$

$s = 3$
 $e = 5$ → $mid = \frac{3+5}{2} = 4$

→ $12 == 17$ → false

Left, $17 < 12$ → False

Right → $17 > 12$ → T



$$L = 5 \rightarrow mid = \left(\frac{0 + 5}{2} \right) = 2$$
$$R = 5$$

$$arr[mid] = 17 \stackrel{target}{=} 17 \rightarrow \text{True}$$

return True

K iteration

$$N = 2^k$$

$$\log N = \log(2^k)$$

$$\log N = k \log 2$$

$$\log N = k$$

$$2^{N/2^k} =$$

$$N = 2^k$$

$$k = \log N$$

T.C

single block



$$size = N$$

$$\rightarrow \frac{N}{2}$$

$$\rightarrow \frac{N}{2^2}$$



$$\frac{N}{2}$$

$$\rightarrow \frac{N}{2^2}$$



$$\frac{N}{4}$$

$$\rightarrow \frac{N}{2^2}$$

$$2^k = 2^k$$



$$\frac{N}{2^k}$$

$$\frac{N}{2^k} = 1$$

$$N = 2^k$$

$$\log N = k$$



$$s \leq c \rightarrow p$$

$$s > c \rightarrow p \text{ is false}$$

$$s < c$$

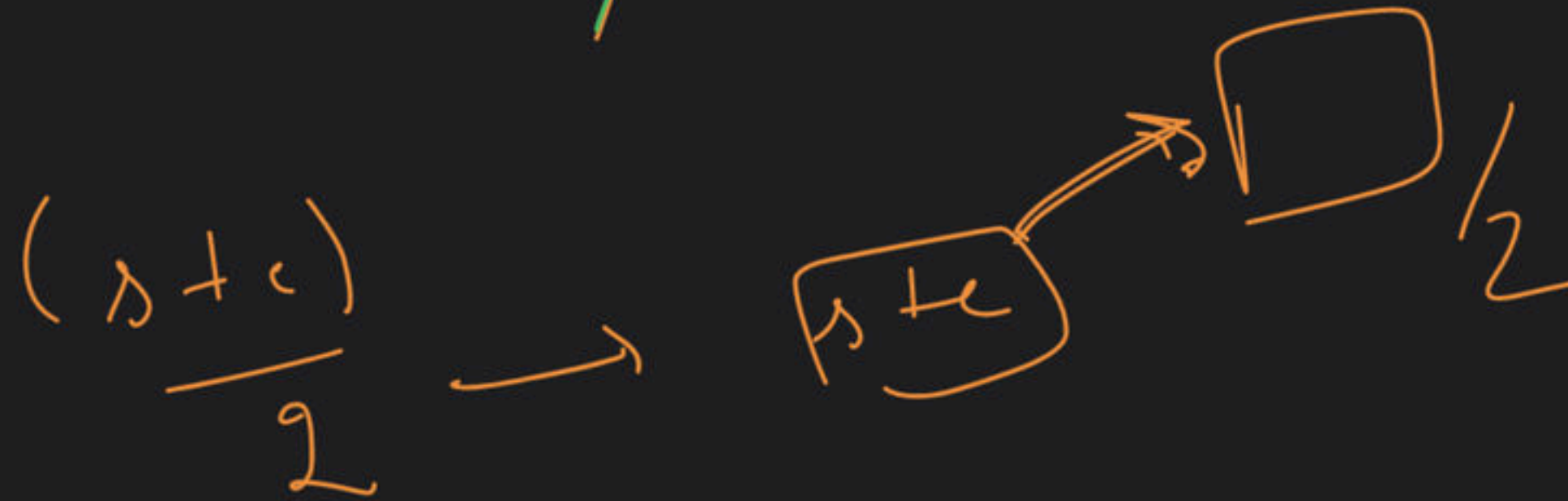
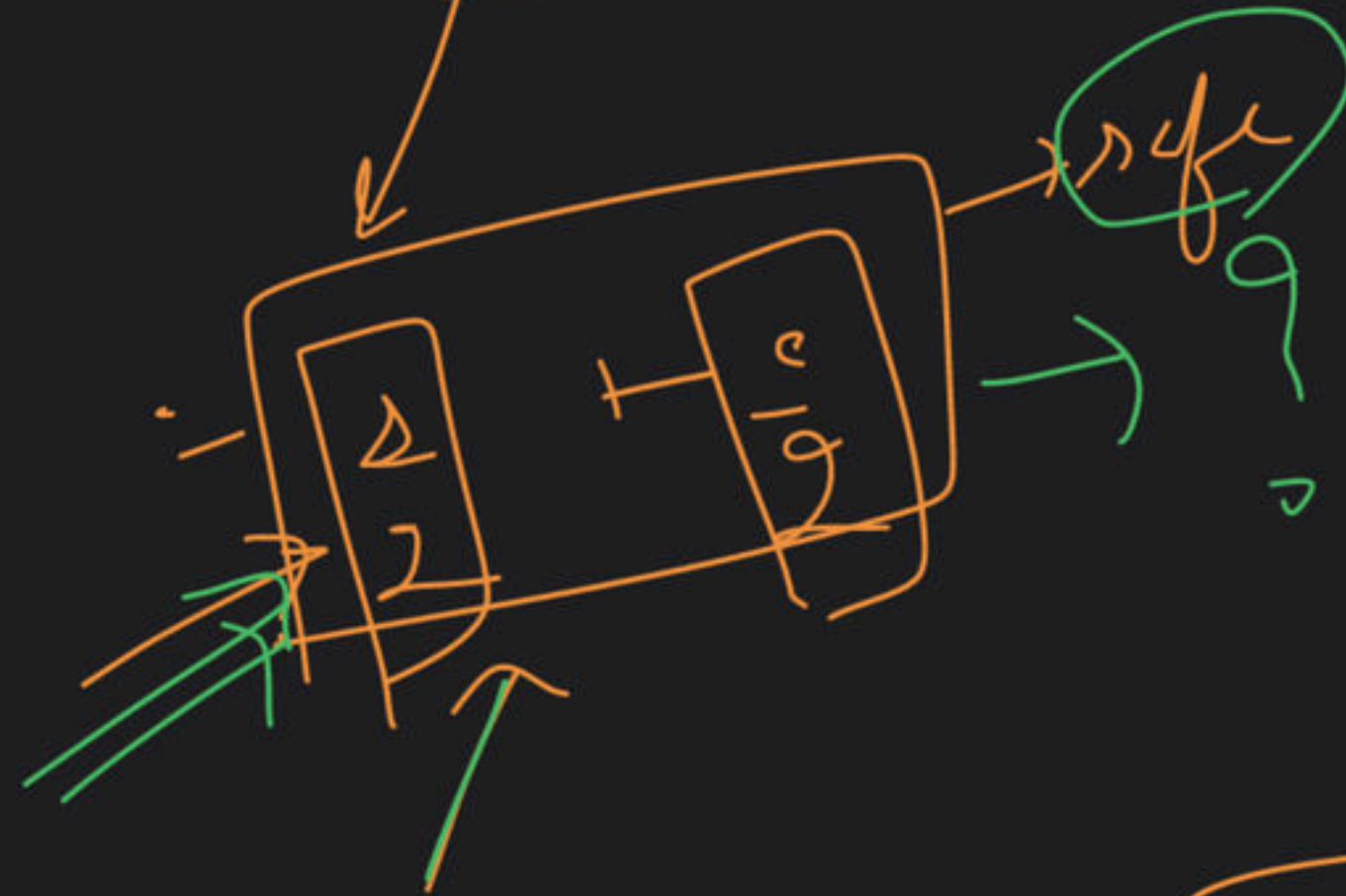
$$s \leq c$$



$$s \geq c$$

$$c \neq s$$

int mid = $\frac{(s + e)}{2};$



integer overflow

$$\text{int} \rightarrow [-2^{31}, 2^{31} - 1]$$

$$s = 2^{31} - 1$$

$$e = 2^{31} - 1$$

$$s + e \rightarrow \text{you} \rightarrow 2^{31} - 1 + 2^{31} - 1$$

$$= 2^{31} + 1$$

~~131462~~

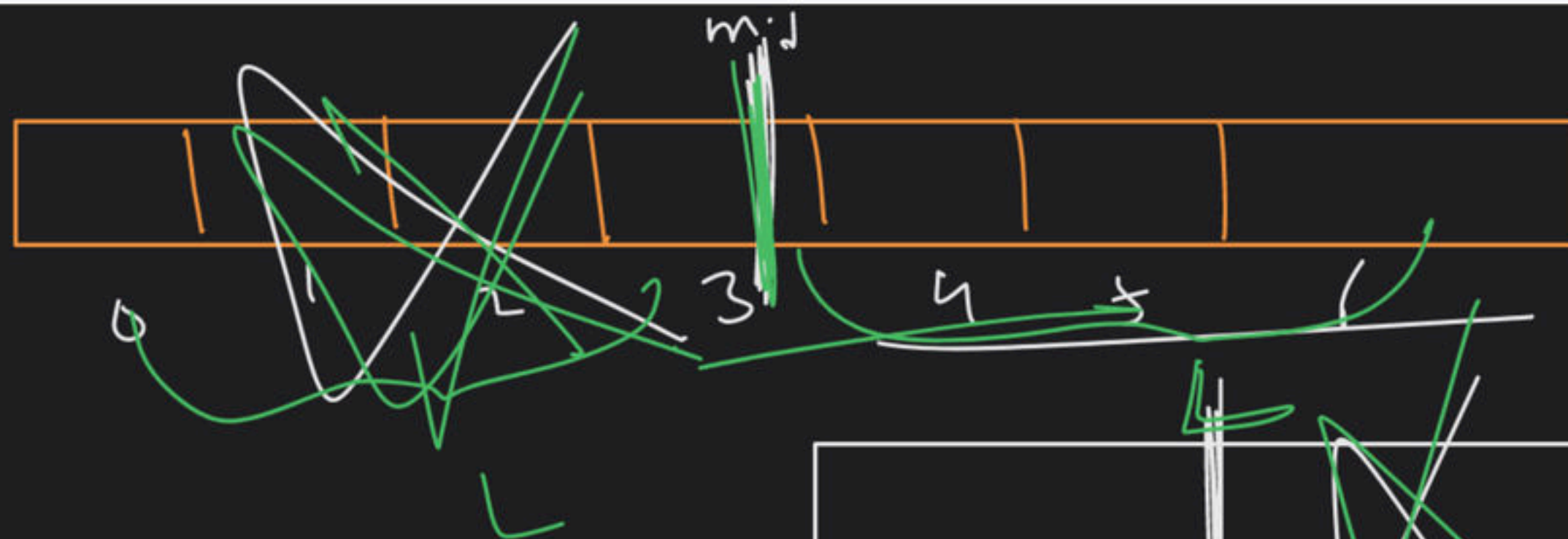
$$\boxed{\text{mid} = \frac{a + (e - a)}{2}}$$

$$= \frac{a + (e - a)}{2}$$

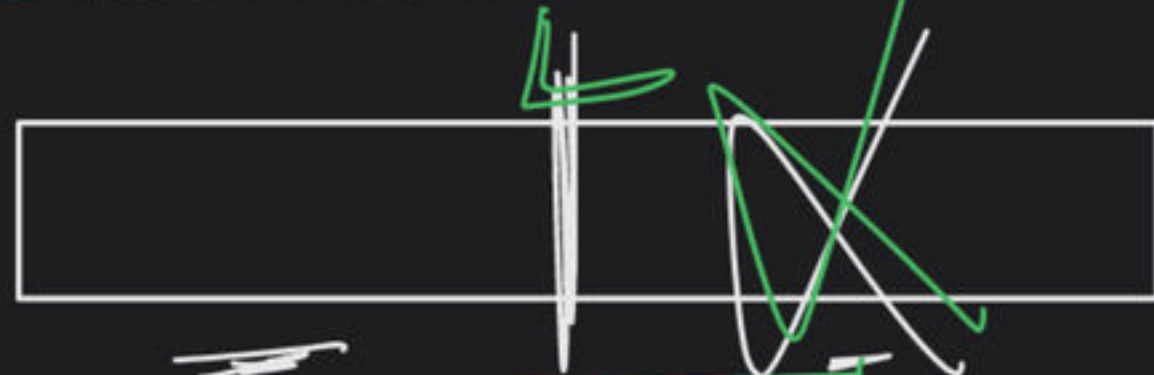
$$= \frac{a + e - \frac{a}{2} - \frac{a}{2}}{2}$$

$$= \frac{a}{2} + \frac{e}{2} = \frac{a + e}{2}$$

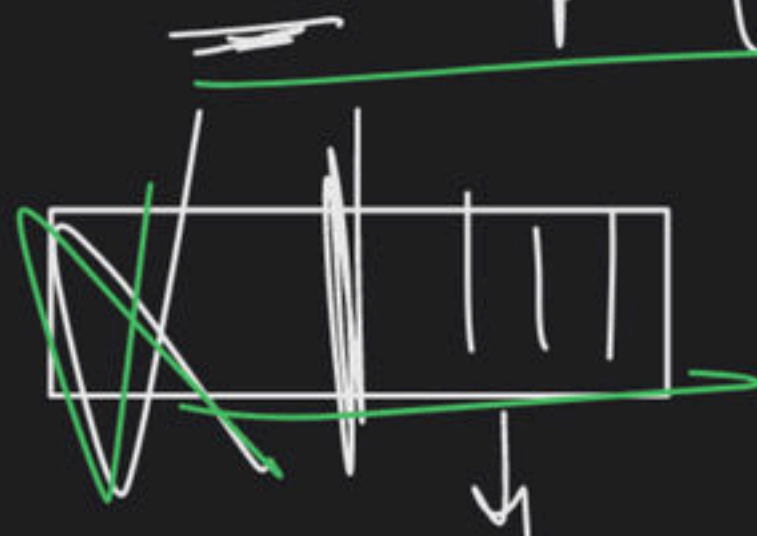
ip \rightarrow



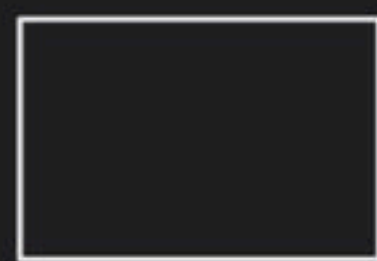
$$\rightarrow \#1 \rightarrow \text{size} \rightarrow \underline{N} \rightarrow \frac{N}{2}$$



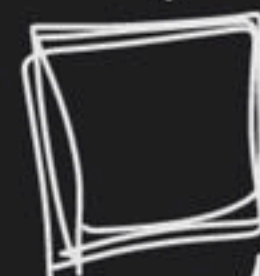
$$\rightarrow \#2 \rightarrow \frac{N}{2} \rightarrow \frac{N}{2^2}$$



$$\rightarrow \#3 \rightarrow \frac{N}{4} \rightarrow \frac{N}{2^3}$$



$$\rightarrow \#4 \rightarrow \frac{N}{8} \rightarrow \frac{N}{2^4}$$



single block

$$\rightarrow \#K \rightarrow \frac{N}{2^{K-1}}$$

size $\frac{N}{2^{K-1}}$

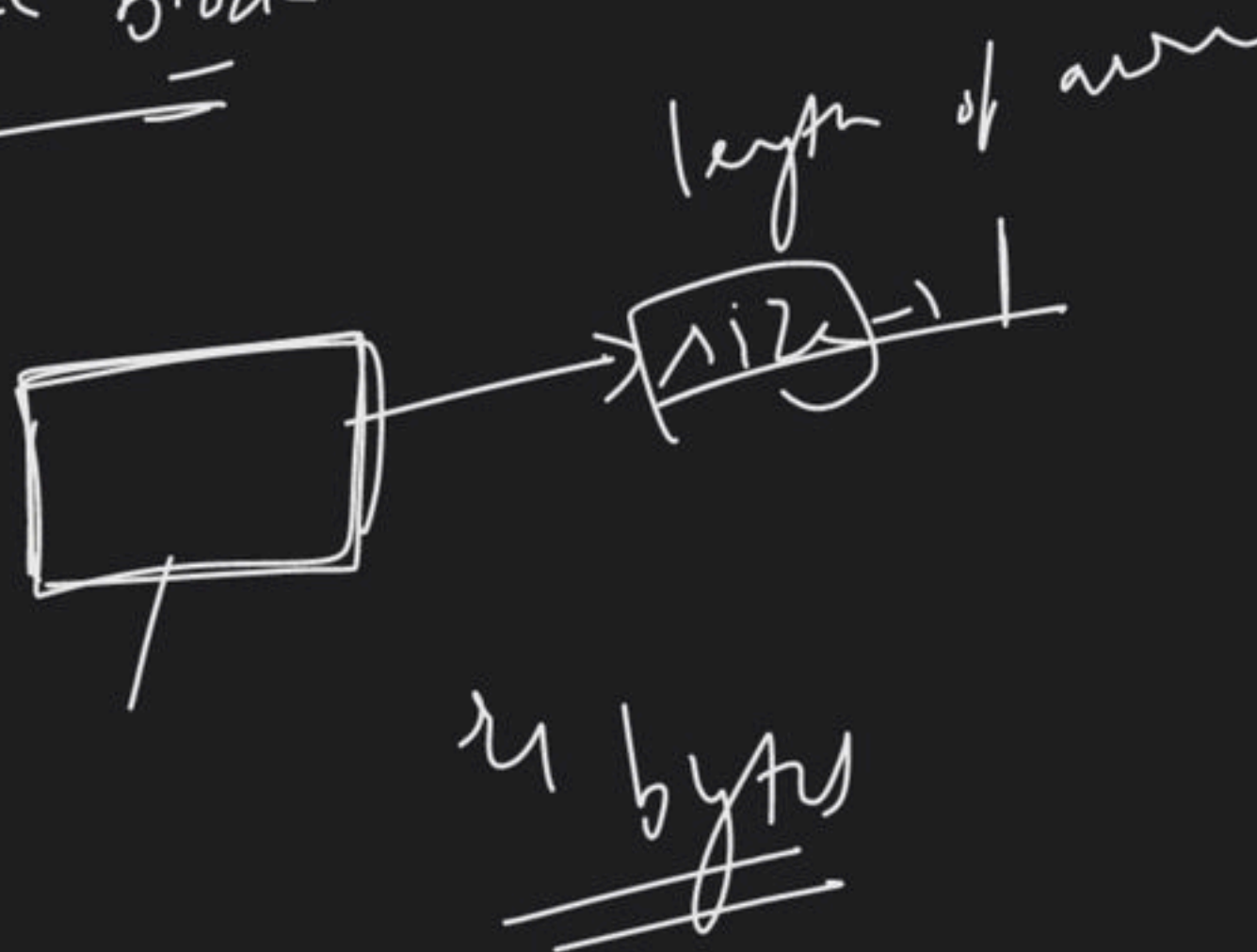
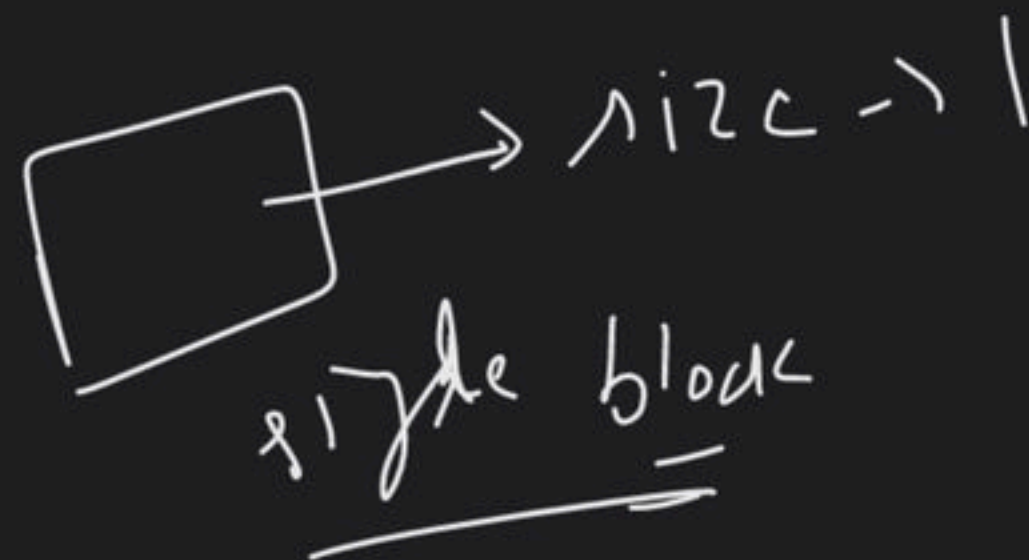
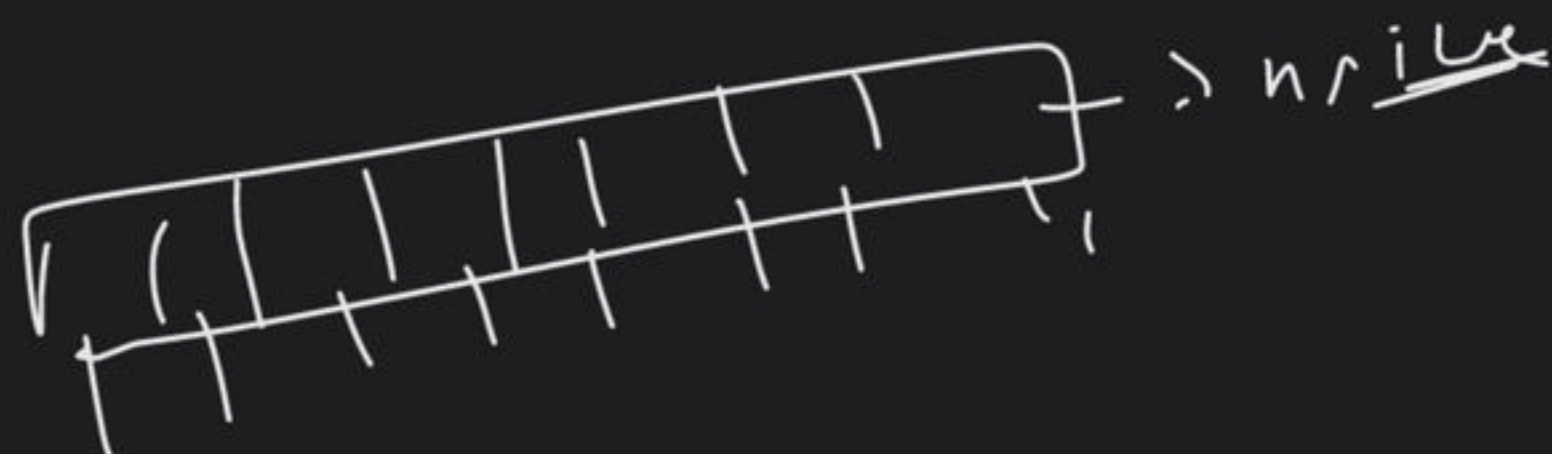
$$L = \frac{N}{2^{K-1}}$$

$$2^{K-1} = N$$

$$\log(2^{K-1}) = \log N$$

$$K \cdot \log 2 = \log N$$

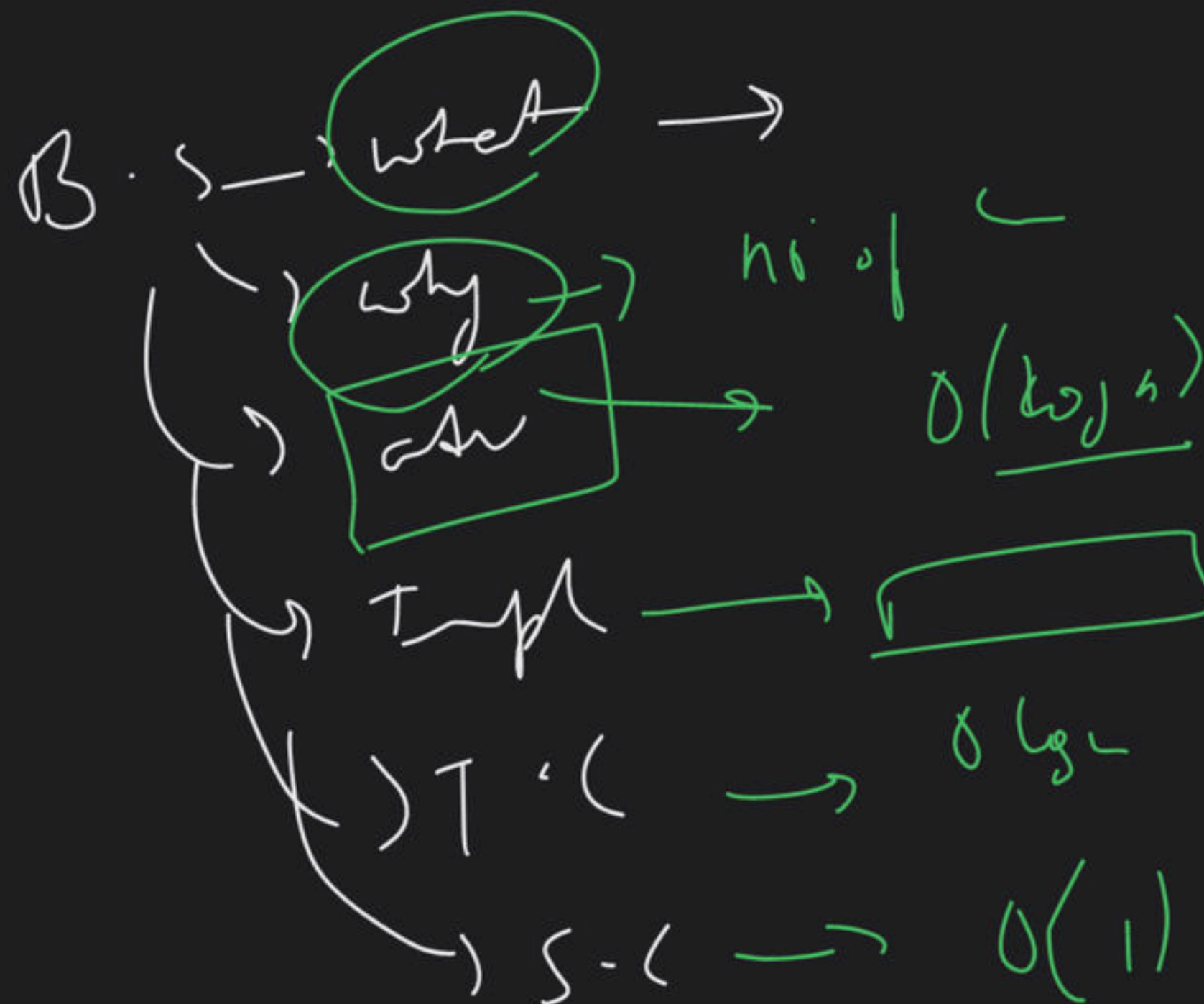
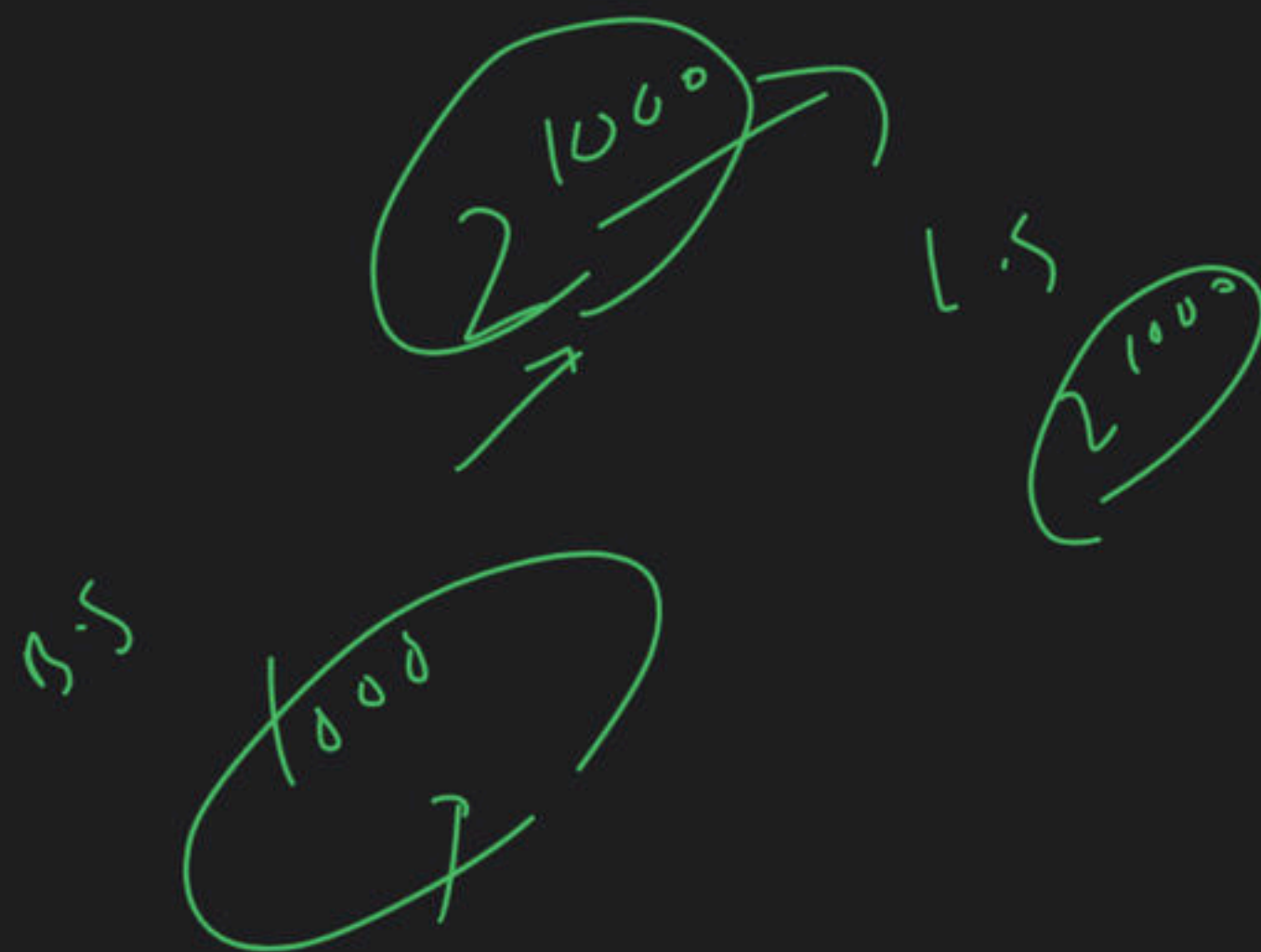
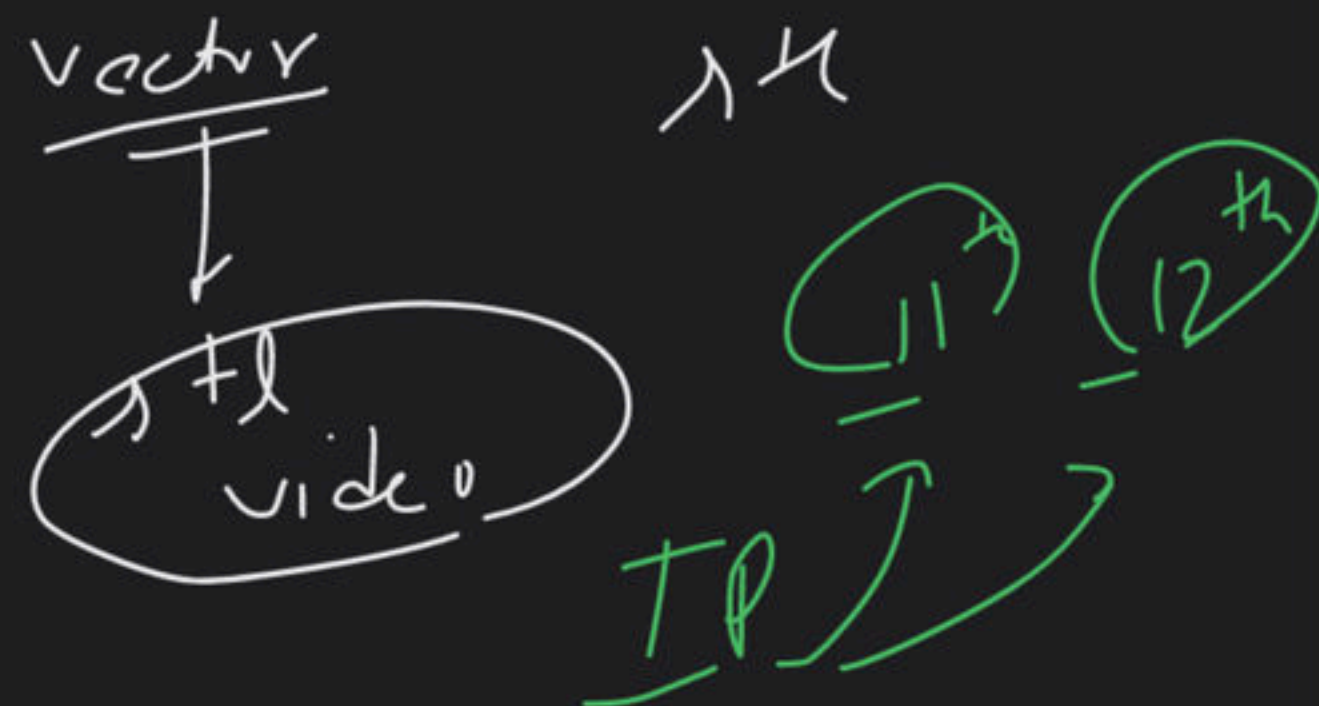
$$\underline{\underline{K = \log N}}$$



Count
 ↓
 Binary Search
 ↓
addr →
 ==

$$\min \left(\frac{s}{2} + \frac{e}{2} \right) \rightarrow \text{good or not?}$$

$$1 + \left(\frac{e-s}{2} \right) \rightarrow \text{good} =$$



S1L

arr

→ binary_search (arr, arr+1, target);

#include <algorithm.h>

kinh

#include <bits/stdc++.h>

lower-bound () —————> explore
upper-bound () —————> explore



target = 5

first occurrence \rightarrow 2

$s=0$
 $e=7$
 $\rightarrow mid = \frac{0+7}{2}$ ③

$midElement = arr[mid]$

$arr[mid] == target$

$5 == 5$

$ans = mid$

$s = mid + 1$

target < midElement

Left $\rightarrow e = mid - 1$

target > midElement

$s = mid + 1$

$s \geq mid + 1$

ans = ~~1~~ ~~2~~ ~~3~~ ~~4~~ ~~5~~ ~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~ ~~11~~ ~~12~~ ~~13~~ ~~14~~ ~~15~~ ~~16~~ ~~17~~ ~~18~~ ~~19~~ ~~20~~ ~~21~~ ~~22~~ ~~23~~ ~~24~~ ~~25~~ ~~26~~ ~~27~~ ~~28~~ ~~29~~ ~~30~~ ~~31~~ ~~32~~ ~~33~~ ~~34~~ ~~35~~ ~~36~~ ~~37~~ ~~38~~ ~~39~~ ~~40~~ ~~41~~ ~~42~~ ~~43~~ ~~44~~ ~~45~~ ~~46~~ ~~47~~ ~~48~~ ~~49~~ ~~50~~ ~~51~~ ~~52~~ ~~53~~ ~~54~~ ~~55~~ ~~56~~ ~~57~~ ~~58~~ ~~59~~ ~~60~~ ~~61~~ ~~62~~ ~~63~~ ~~64~~ ~~65~~ ~~66~~ ~~67~~ ~~68~~ ~~69~~ ~~70~~ ~~71~~ ~~72~~ ~~73~~ ~~74~~ ~~75~~ ~~76~~ ~~77~~ ~~78~~ ~~79~~ ~~80~~ ~~81~~ ~~82~~ ~~83~~ ~~84~~ ~~85~~ ~~86~~ ~~87~~ ~~88~~ ~~89~~ ~~90~~ ~~91~~ ~~92~~ ~~93~~ ~~94~~ ~~95~~ ~~96~~ ~~97~~ ~~98~~ ~~99~~ ~~100~~ ~~101~~ ~~102~~ ~~103~~ ~~104~~ ~~105~~ ~~106~~ ~~107~~ ~~108~~ ~~109~~ ~~110~~ ~~111~~ ~~112~~ ~~113~~ ~~114~~ ~~115~~ ~~116~~ ~~117~~ ~~118~~ ~~119~~ ~~120~~ ~~121~~ ~~122~~ ~~123~~ ~~124~~ ~~125~~ ~~126~~ ~~127~~ ~~128~~ ~~129~~ ~~130~~ ~~131~~ ~~132~~ ~~133~~ ~~134~~ ~~135~~ ~~136~~ ~~137~~ 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~~1344~~ ~~1345~~ ~~1346~~

$$s = 0 \rightarrow mid = 0$$

$$e = 0$$

$$\boxed{2}$$

0

$$2 = 3 \rightarrow F$$

$$3 < 2 \rightarrow F$$

$$3 > 2 \rightarrow T$$

↳ right

$$s = mid + 1$$

$$s = 0 + 1 = 1$$

$$s = 1$$

$$e = 0$$

$$s > e \quad \& \quad mid < \underline{\underline{low}}$$

→ find first/last Occ. of element in sorted arr

→ find total no. of occurrence of element in sorted array

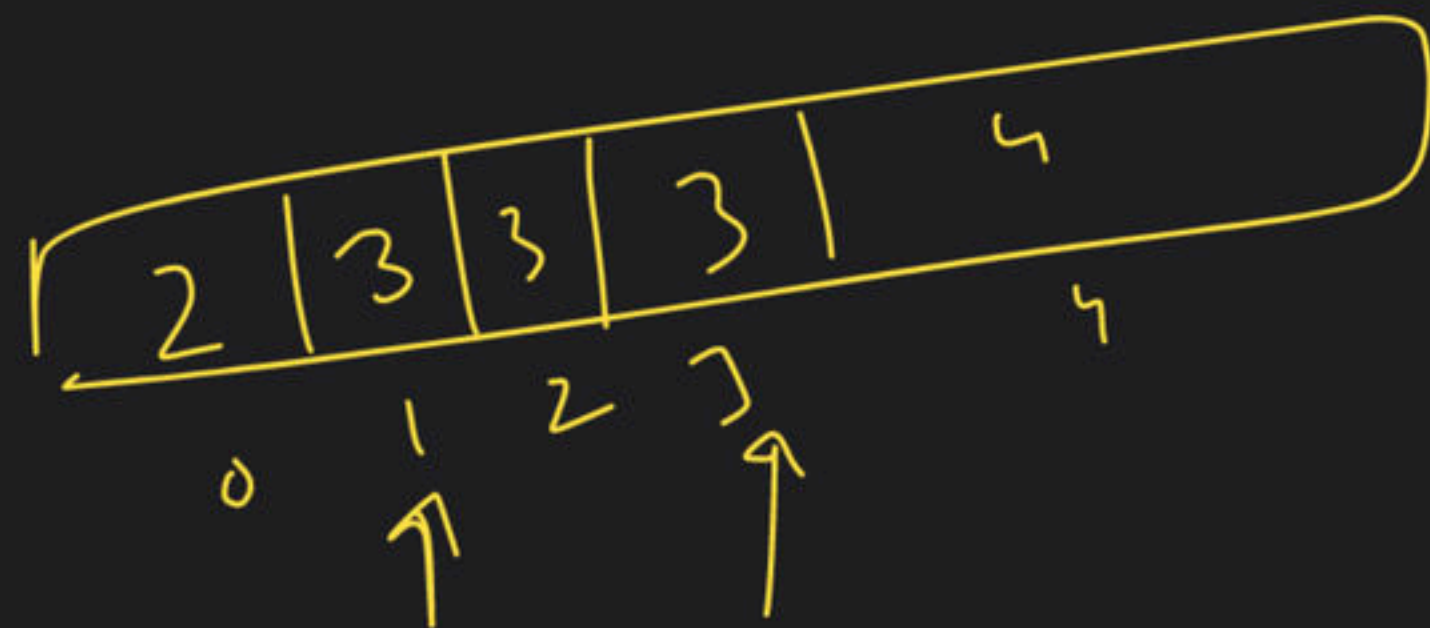
#1

#2

Linear search → $O(n)$

last = first + 1

→ $O(\log n)$ → Binary !!



$\text{Last} = 3$
 $\text{first} = 1$

$\text{Last} - \text{first}$

$$= 3 - 1 = \boxed{2} \quad \text{✓}$$

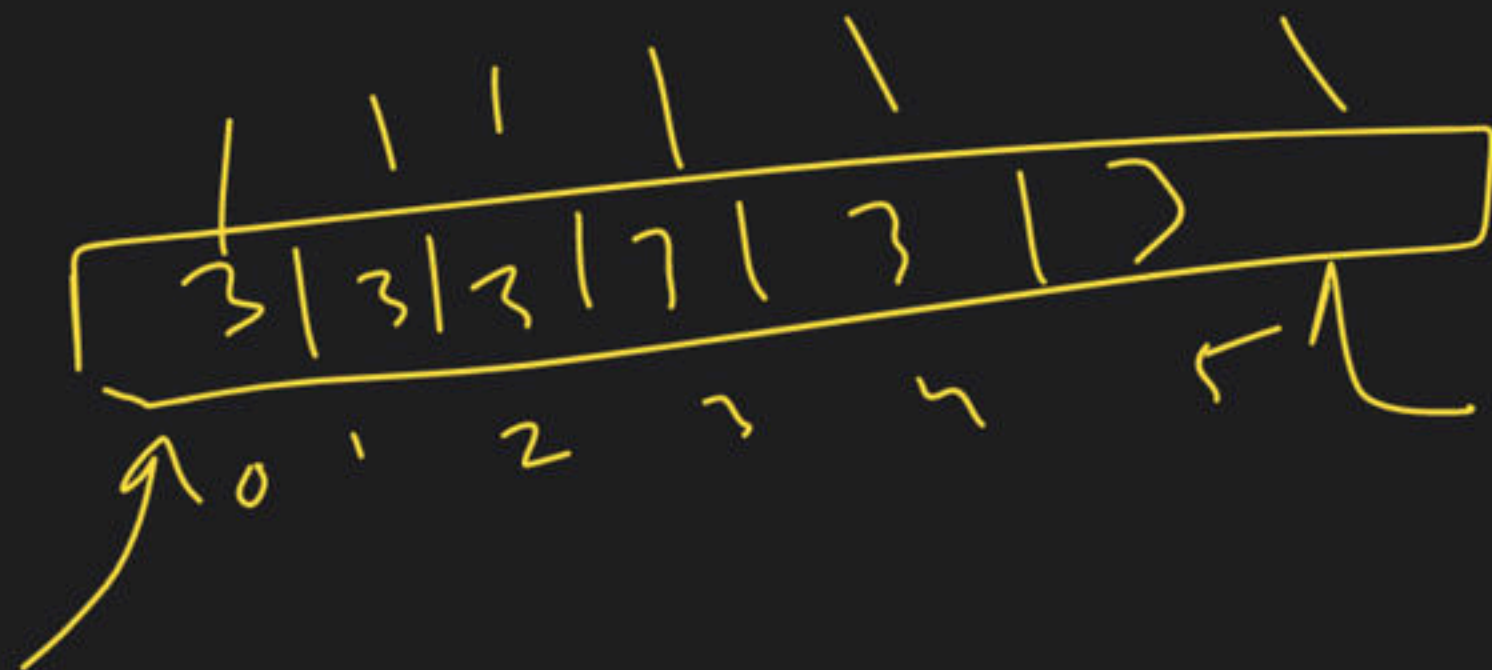
$$= \boxed{3}$$

- BS
 → STL $\begin{cases} \text{BS} \\ \text{LB} \rightarrow \\ \text{UB} \rightarrow \end{cases}$

→ first

→ Last

↘ Total no.
 of occ



$$\text{last} - \text{first} + 1$$

$$5 - 0 + 1$$

$$= 6$$

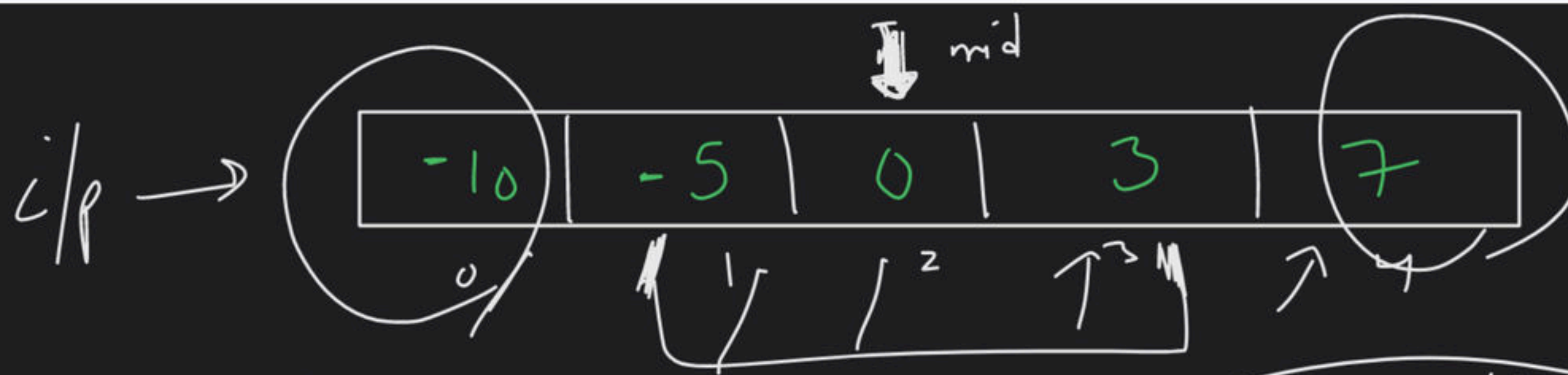
→ find fixed point in a sorted array
 (value = index)

$\frac{e}{r} \rightarrow \{ -10, -5, 0, 3, 7 \}$

ans = 8/1 \rightarrow (3)

#1 Brute ~~force~~
 $\rightarrow O(n)$

→ Binary Search $\rightarrow O(\log n)$



index
target - ?

$s=0$
 $e=4$

$\rightarrow mid = \frac{0+4}{2} = 2$

fixed point

\hookrightarrow if (arr[mid] == mid)

{
 return mid;
 }

x $x+1$
 x x

$x+1$ x

\rightarrow

\hookrightarrow if (arr[mid] > mid)

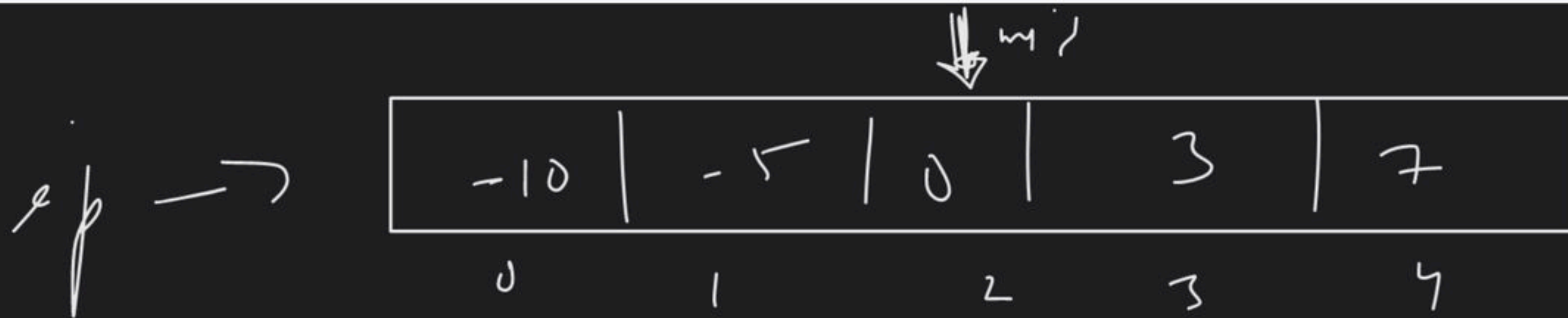
\rightarrow left

{
 }

~~\hookrightarrow if (arr[mid] < mid)~~

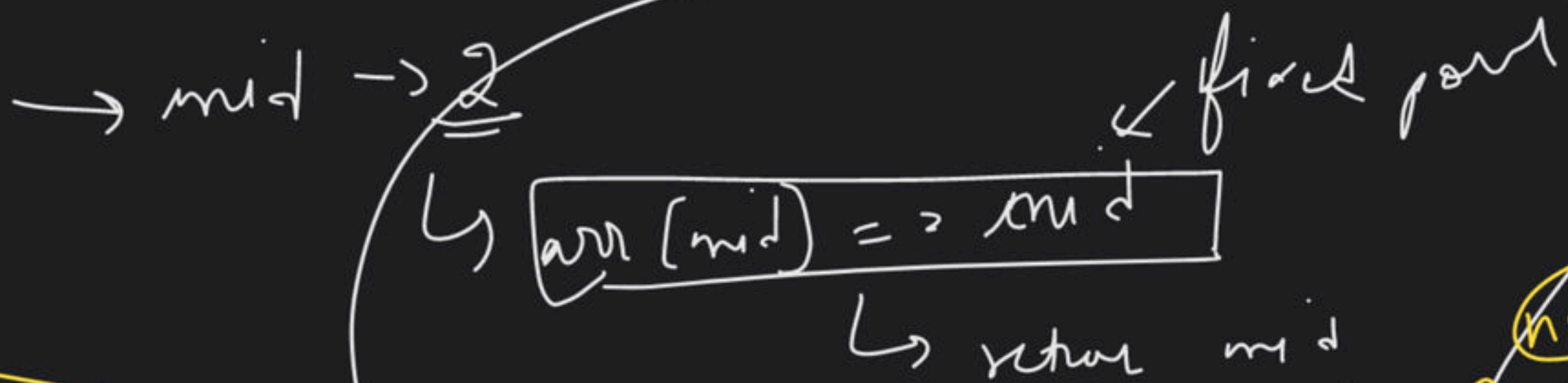
~~{
 }~~

left, right

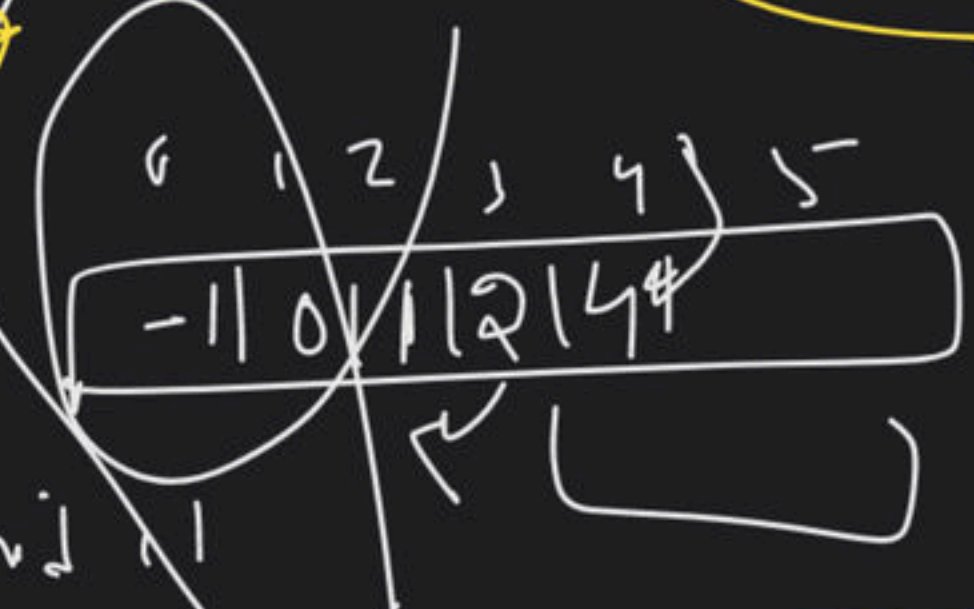
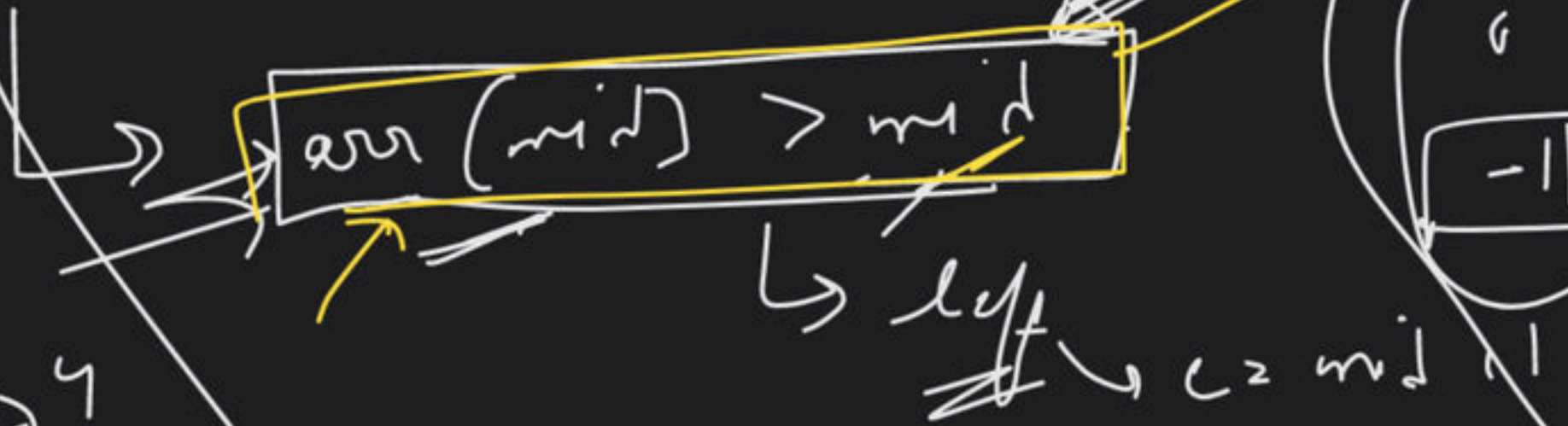


B.S 1 more app next

$s = 0$
 $e = 4$

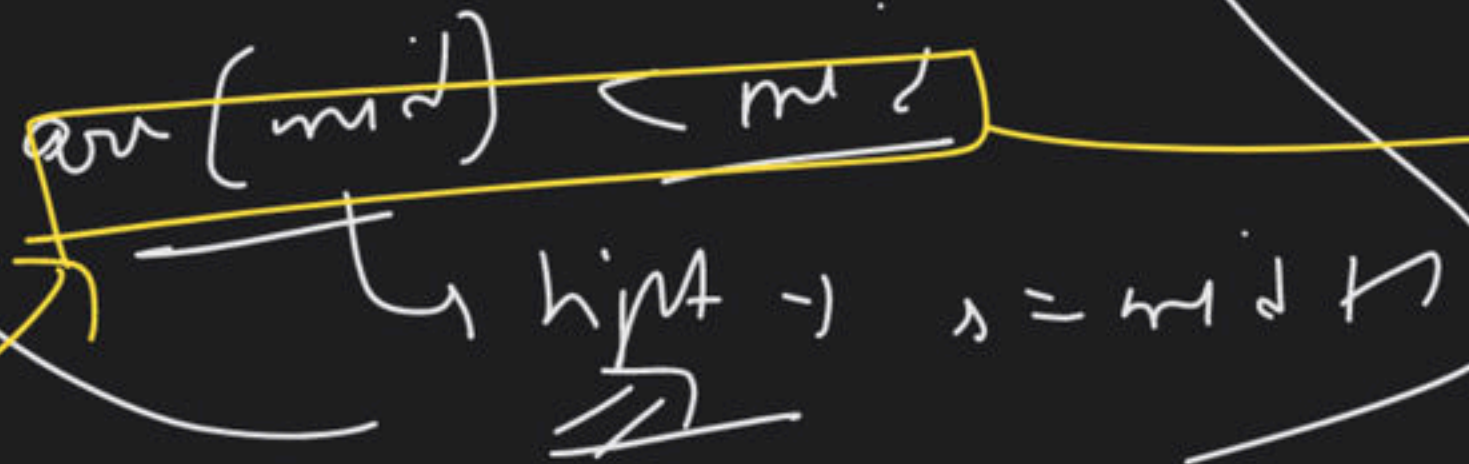
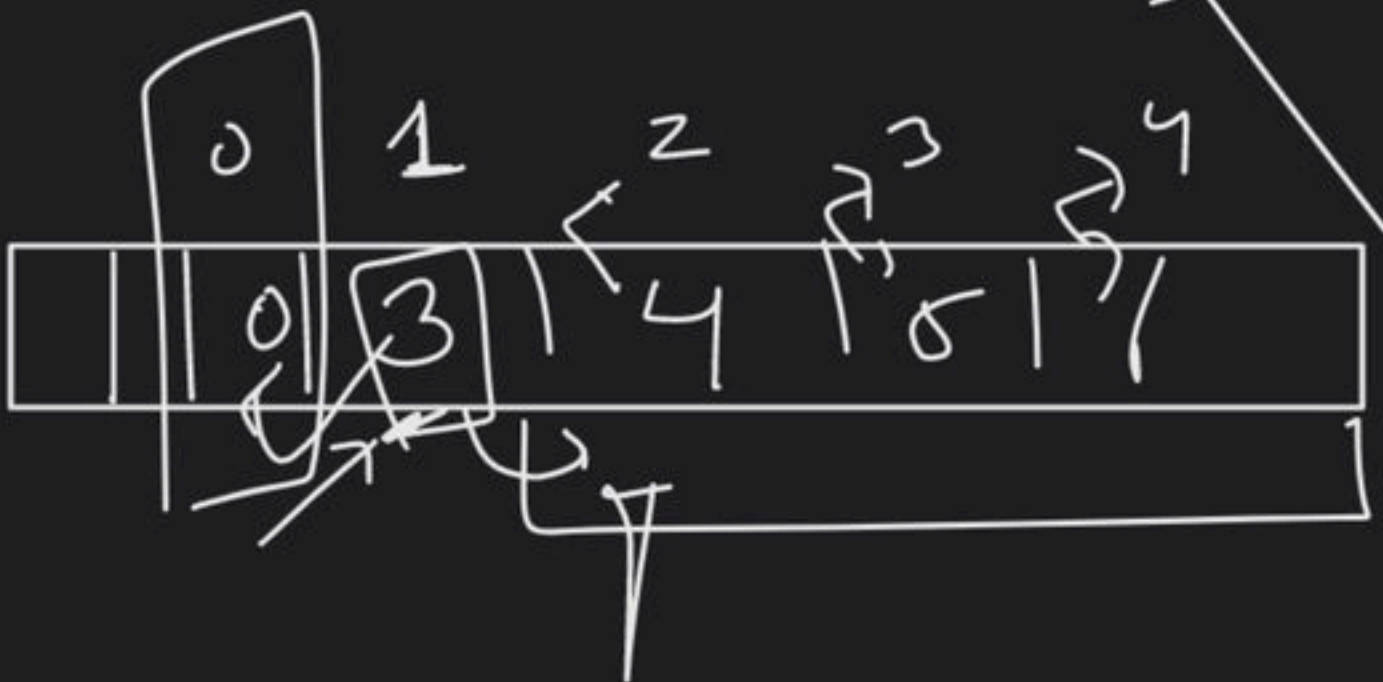


right - 1



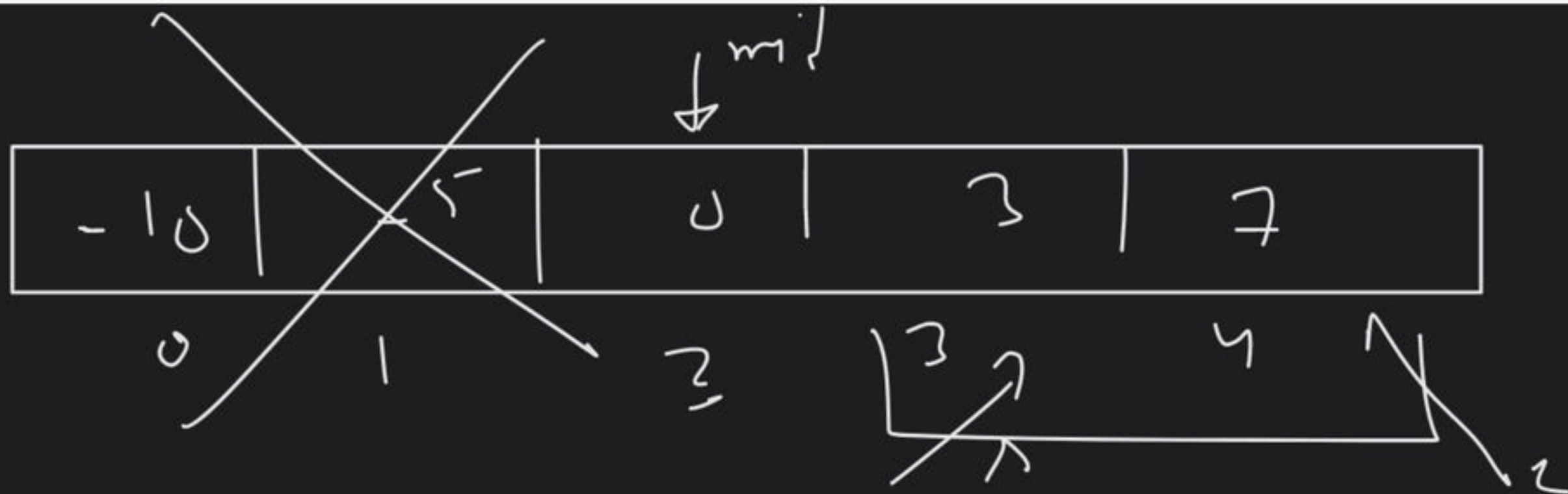
HL

ex



HL

Q1
Q2



multiple
fixed
points

4/5

$d = 0$
 $e = 4$ \rightarrow $mid = 2$

$0 == 2 \rightarrow F$

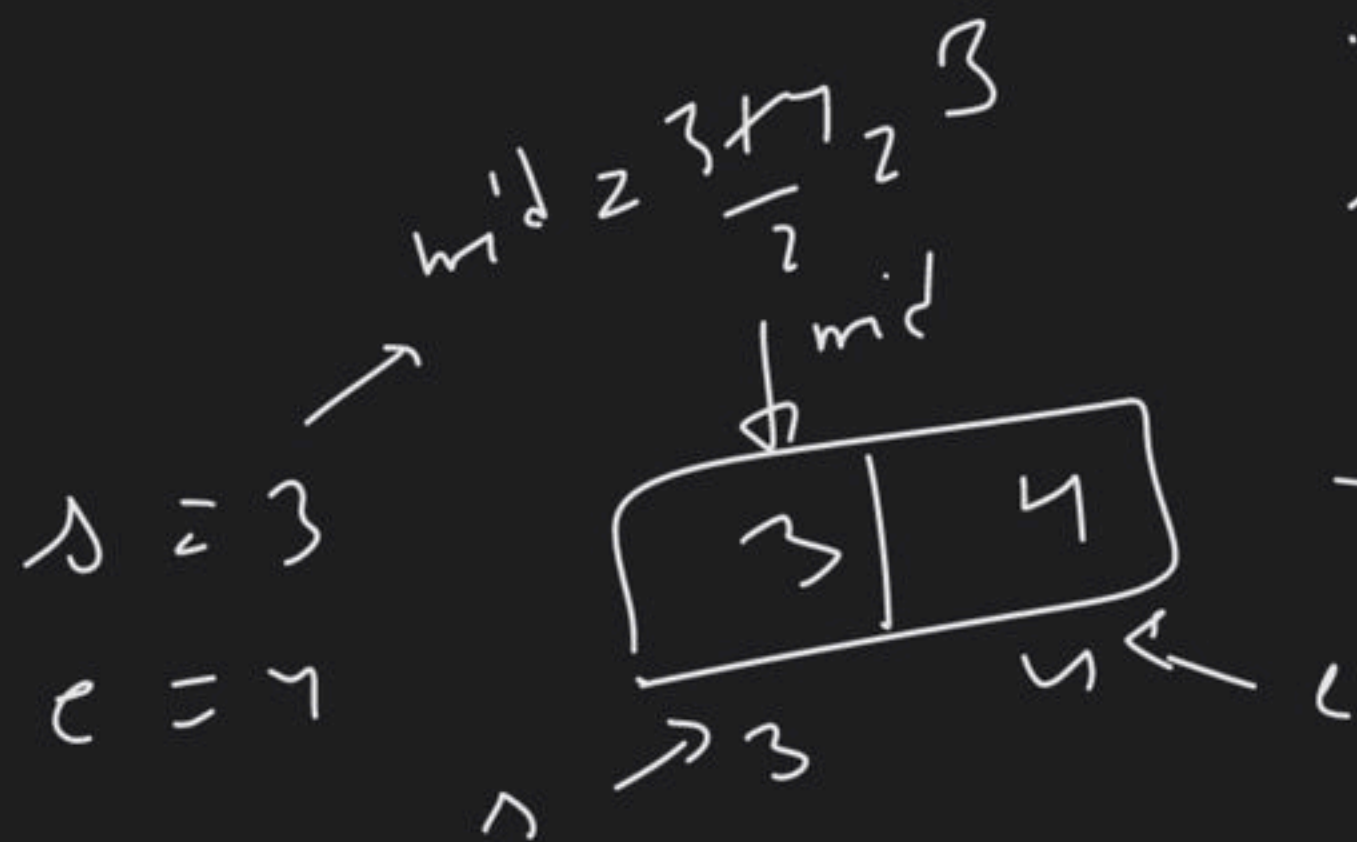
$2 < 0 \rightarrow F$

$2 > 0 \rightarrow$

$arr[mid] \rightarrow right \rightarrow e = mid - 1$

right part

$3 == 3 \rightarrow$ return 3;



$d = 3$
 $e = 1$

TLE

