

→ more important note

→ Heading

→ Subheading or important point

→ Data Structure

→ Complexities

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DSA-SUPREME

**CODES**

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If you like these notes,  
Give me job opportunities

And give party to bhaiya after placement

# IMPORTANT POINTS

- Focus on work on skill and build networks those work in companies and can talk to HR for you
- Internship- do if you want to learn or convert it as PPO
- Rough sols. and dry run are very important
- Do documentation to promote and mail everything you discuss with HR or team
- Think twice, Code once
- To clarify any code you are confused, use cout statements every where to know what is going on in the code
- Code all approaches you can think of and can find & understand from google
- Revise all incorrect & skipped questions in quizes regularly
- Watch sol. only after attempting the question
- Interviewer will ask Time & Space complexity after every sol. you give

→ 2 websites

- cplusplus.com
- cplusplus.com

→ Think on paper → with 5 testcases atleast

→ Write readable codes

→ In interviews, tell approaches of questions using example

→ Signs of beginner → no logic build



can't solve new ques

forget the approach

memorizing the ans

Improve → with more no. of questions

with time

with dry run on mind logic, not on code

with your new approach

(even brute force)

with a lot of practice on syntax

with consistency

→ Focus on placement, not on feeling

You are not studing to get fun

You are studing to get placed

First placement, then fun and interest.

Also focus on health of you and your parents

Bhaad me gya interest yaar, placement ke baad karna

Jo duniya sunna chahati hai, use sunado

Growth is important

Week 4 [Connect] Class 1:45 - 2:01

→ 20-30 interview experience

↳ to break Google pattern

→ Web Dev and DSA → both are important

CP → do if you enjoy it.

→ At least learn one more approach if you are doing questions with map

Many times if you tell map approach, interviewer asks another approach

→ Tag all khatarnak questions

↳ Otherwise you will forget them after some time

→ Revise and code all, every after 2 weeks

→ For 6<sup>th</sup> sem student (like me),

↳ At least do potd on leetcode everyday along with course

→ Make notes

→ In dev, you should have at least 2 major projects

1 → in dot batch  
2 → group project if you want

→ Focus on Networking,  
After 5 months, you should have atleast 2 friends in every company

→ All questions doing in batch, should be on your tips

- Focus on accuracy more than speed
- Resume is made company specific
- Make sure others don't take your credits
- Higher position  $\propto$  Development  
in career DSA Complexity
- Interview experience before interview
- Flex se kuch nhi hota
- Comparision se kuch nhi hota
- Don't forcefully try to increase the speed of DSA learning,  
Try to increase the number of hours spent everyday in DSA learning
- if ques seems tough in another datatype but easy in another datatype, then first do that in later datatype and after solving the sol. change datatypes

→ In interview, you must have clarity and strong concepts and strong argument behind the things you say.

whether the ans comes right or wrong is another thing

→ Start writing code for smallest problem / test case and then eventually find solution pattern

→ Dont rush to make an optimised code, start from brute force

# IMPORTANT C++ NOTES

→ -1 in binary 1.....1  
-2<sup>31</sup> in binary 10...0

→ In left shift, vacant bit will be filled by 0  
In right shift, vacant bit will be filled by MSB  
1 → in -ve no.  
0 → in +ve no.

$(-1) \gg n \longrightarrow$  (-1) no change  
any no. of times

→ int a = 5;  
 $\text{cout} \ll (++a) * (++a);$        $\text{cout} \ll (a++) * (a++);$   
a \* (++a), a = 6      5 \* (++) , a = 6  
a \* a, a = 7      5 \* a, a = 7  
7 \* 7 = 49      5 \* 7 = 35

$\text{cout} \ll (++a) * (a++);$        $\text{cout} \ll (a++) * (a++);$   
a \* (a++) , a = 6      5 \* (a++) , a = 6  
a \* 6 , a = 7      5 \* 6 , a =  
7 \* 6 = 42      30

→ Continue cannot be used in switch case  
can only used in loops

→ int main () {

return 0; —————> returns to OS

{} 0 is used to represent successful execution

→ A cpp file can't have more than 1 main function

→ main() can't have return type other than int  
in offline compiler

→ % is heavy operator, so try to use it less

→ array name returns address of first index

Integer Array -

cout << arr ;  $\longrightarrow$  A1  $\longrightarrow$  address of first index of array  
address of integer  $\underline{\hspace{100px}}$

→ To find max., initialize ans with INT-MIN

To find min., initialize ans with INT-MAX

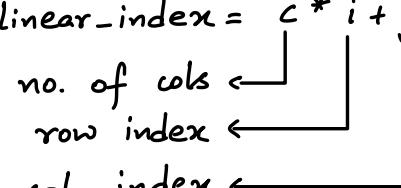
→ xor → cancels out same element

$$\rightarrow 0 \wedge \text{ans} = \text{ans}$$
$$0 \wedge 1 = 1$$
$$0 \wedge 0 = 0$$

→ Mapping of 2D array with memory 1D array

$$\text{Linear-index} = c * i + j$$

$i = \text{linear-index} / c$   
 $j = \text{linear-index \% c}$



→ Arrays and 2D arrays of any datatype

→ pass by reference

→ Search space

→ range of ans (start and end) in binary search questions

→ store mid in ans if needed in binary search ques

## → In binary search questions

```
while (s <= e){  
    ans = mid;  
    s = mid + 1;  
    left search ← e = mid - 1;  
}  
  
right search
```

convert  
ans = mid  
s = mid + 1

```
while (s < e){  
    s = mid; → right search  
    left search ← e = mid - 1;  
}  
  
OR  
s = mid + 1 → right search  
left search ← e = mid;  
}
```

convert  
ans = mid, e = mid - 1

→ cout << (int)(-3.74);

→ - [ int (3.74) ]

→ - (3) → -3

cout << (-22)/7; → -3

cout << 22/(-7); → -3

→ In ASC II → '0' → 48  
'A' → 65  
'a' → 97

→ In sorted array, try to apply binary search or  
2 pointer / 3pointer approach

→ To maximize or minimize  
try to use binary search using concept of search space

- find search space of answer
- find mid
- if  $\text{isPossibleAns}(\text{mid}) \rightarrow$  go to left / right acc.  
to the ques.

You can use above approach also in other  
ques like find the duplicate number in an array  
having elements range 1 to n

→ Week 6 Lecture 2

→ Magical line for recursion

- Ek case solve krdo baaki recursion smbhali lega
- Just believe on it, dont doubt on recursion

→ Week 7 Lecture 2

→ Week 7 Lecture 3

→ If the recursion ques seems tough,  
use void function and pass ans by reference  
in function

- If in ques. array elements are in range  $[1, n]$  or  $[0, n]$ , try to treat elements as indices of an array  
(Week 3 Assignment)
- Try to make cnts [max element present in array] instead of making cnts [max limit given in question]  
Array more than  $10^6$  ints cant be formed

→ 

```
int digit = 7;
string s;
s.push_back ( digit + '0' );
cout << s; —→ 7
```

$s.push\_back(digit);$   
 $cout << s;$  —→ contains  
char with  
ascii value = digit

'7' to 7 —→ '7' - '0'

7 to '7' —→ 7 + '0'

- Generally in linked list question, you were asked to play with links / pointers without changing data

→ In linked list, when you have to go from right to left, you have 2 options

1) reverse the linked list

2) use head recursion

→ If we pop a data set after pushing in stack, we get the answer in reverse order

So to reverse anything, you can use stack

→ Sets can be used to store only unique / distinct elements

# ERROR / BAD PRACTICE

If let's go page

→ 13

31, 33, 43, 70, 71, 72, 73, 75, 76, 79, 86, 87, 89, 90, 93, 95

→ 14

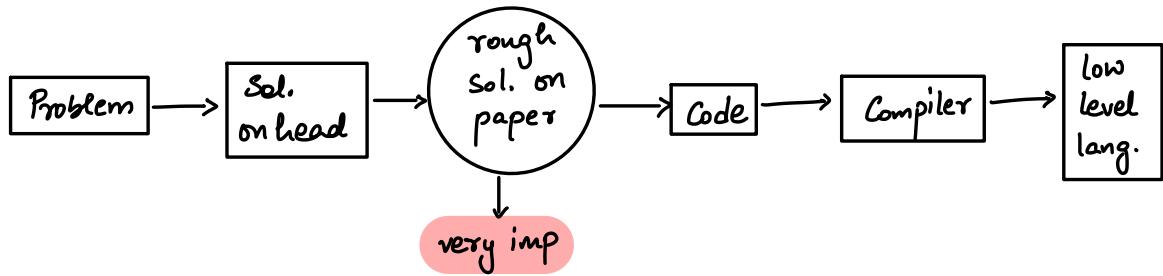
104

LET'S GO

Thought process to solve a problem-

W1-L1

- Understand a problem
- input values
- find approach



Algorithm - Sequence of steps

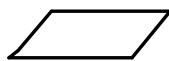
Flowchart - Graphical representation of algo

Components -



terminator

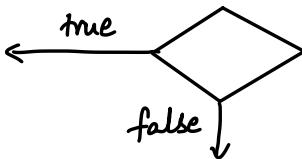
for start / end



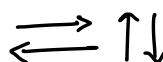
for input /output read /write



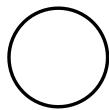
computation / process / declaration



decision making block  
takes condition



flow



Connector  
takes function

Pseudo Code - Generic way of writing algo

Dry Run → **Very Important** to understand any topic

**W1-L2**

IDE - Replit, VS-Code

```
# include <iostream>
using namespace std;
int main () {
    cout << "Namaste Bharat";
}
```

region where scope  
of keyword is defined

used to point on console/  
standard display

→ preheader file contains implementation of keyword

→ using standard namespace implementation of cout  
choosing from multiple types of namespace

→ to end any statement

→ string

cout << endl; → for next line

cout << '\n';

int a;  $\longrightarrow$  a is an integer

cin >> a;  $\longrightarrow$  input a from user

en-7

Diagram illustrating a variable `a` pointing to a box containing `gv`, which is labeled `garbage value`. Below `a` is another box containing `7`.

## Variables

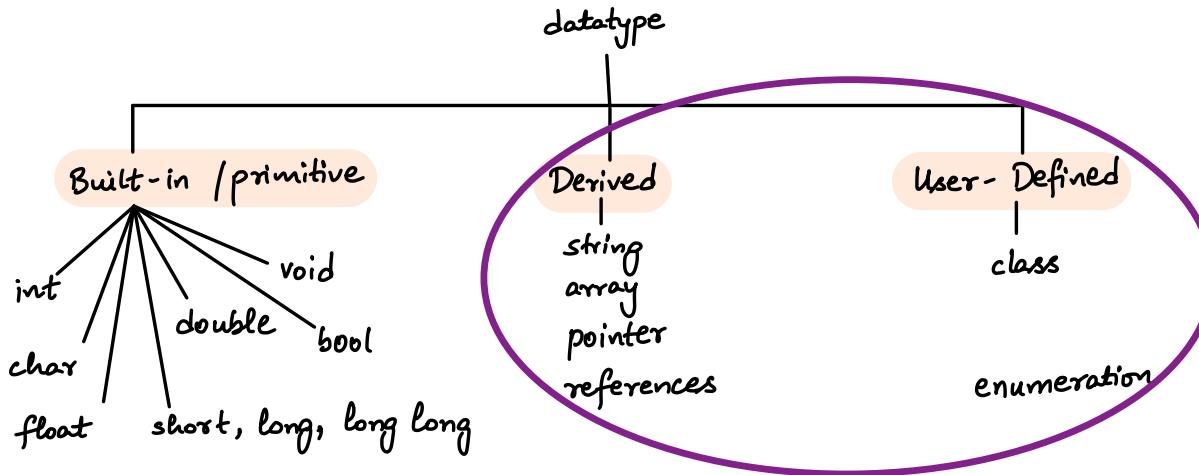
named memory location

datatype      variable      name

value

# Datatypes

type of data



int - 4 byte - 32 bits in memory

→  $-2^{31}$  to  $2^{31}-1$  in signed int

→ 0 to  $2^{32}-1$  in unsigned int

char - 1 byte - 8 bits in memory

↳  $2^8$  different chars.

## ASCII

↳ char maps with numerical ASCII value

char  $\leftrightarrow$  ASCII value  $\rightarrow$  store in memory

bool  $\rightarrow$  1 byte  $\rightarrow$  8 bits

true - 1

false - 0

↳ because minimum addressable memory is 1 byte

1 byte

We cannot address 1 bit in memory

float  $\rightarrow$  4 byte  $\rightarrow$  32 bits

double  $\rightarrow$  8 byte  $\rightarrow$  64 bits

long long  $\rightarrow$  8 byte  $\rightarrow$  64 bits

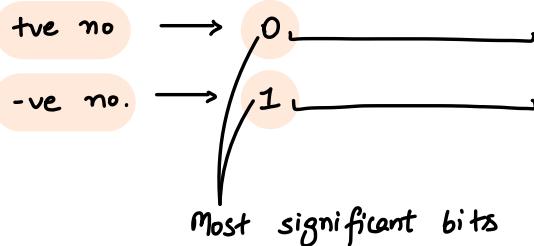
short  $\rightarrow$  2 byte  $\rightarrow$  16 bits

long  $\rightarrow$  4 byte  $\rightarrow$  32 bits

## How data is stored

int a=5;

↳ 32 bits  $\underbrace{0 \dots 00}_{29 \text{ bits}} 101$



### How -ve number is stored in memory

In 2's complement form

→ 1's complement + 1

→ reverse all bits

int a = -7;

7 → 0.....00111 } 32 bits

ignore -ve sign  
find binary equivalent

1's (7) → 1.....11000

find 2's complement

2's (7) → 1.....11001

→ this is how -7 will be stored in memory

### How to read -ve no. present in memory

→ take 2's complement

1.....11001

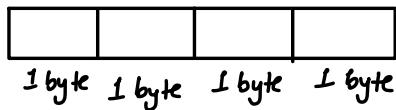
→ 1's complement → 0...00110

2's complement → 0...00111

→ + 7

-7

## Interesting problem



how computer know these are 4 chars or a single integer

↳ Using datatype

↳ tell 2 things

- ↳ type of data used
- ↳ space used in memory

## Signed vs Unsigned

↓  
↳ 0, +ve  
+ve, -ve, 0

↳ by default

int - 4 byte - 32 bits in memory

↳ total no. of combinations -  $2^{32}$

signed int

$-2^{31}$  to  $2^{31}-1$

unsigned int

0 to  $2^{32}-1$

} range

(10...0)

$2^{15} \rightarrow \underline{10...0} \rightarrow -2^{31}$

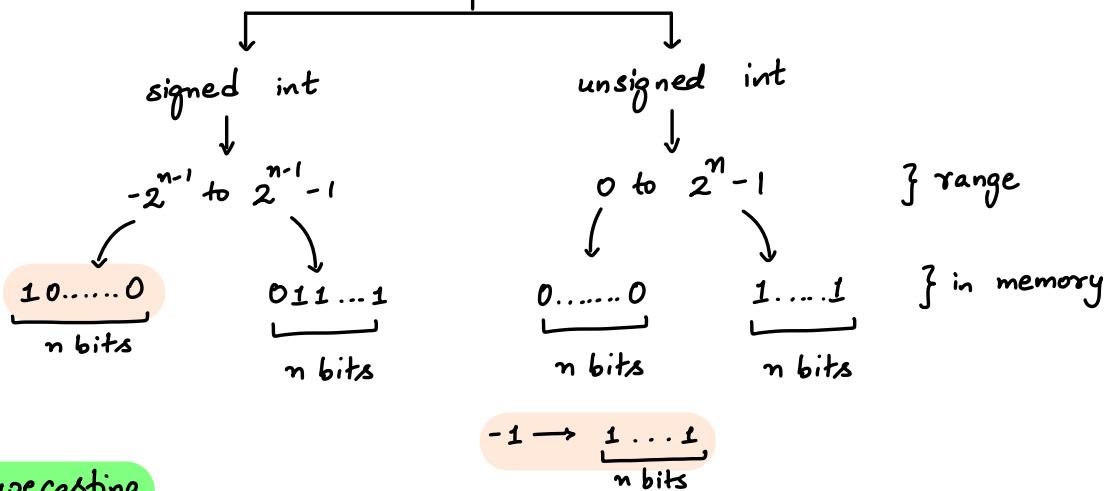
0.....0

1.....1

} in memory

## General Formula

$n$  bits in memory  
↳ total no. of combinations -  $2^n$



## Typecasting

↳ convert one type of data to another

### implicit typecasting

ex- `char ch = 97;`  
`cout << ch;` → (a)

### explicit typecasting

ex- `char ch = (char) 97;`  
`cout << ch;` → (a)

overflow ex- `char ch = 9999;`  
`cout << ch;`

$9999 \xrightarrow{\text{binary conversion}} 100111\underbrace{00001111}_{\text{stores only last 8 bits}}$

so  $ch$  stores 00001111 in memory

↓  
7  
↓  
acc. to ASCII table

## Operators -

### Arithmetic Operator

→ +, -, \*, /, %

int op int → int

float op int }  
int op float } float

float op float }

bool op bool → int

bool act as 0 or 1

double op int }  
int op double } double  
double op double }  
float op double }  
double op float }

3 → int → by default → cout << sizeof(3.0);  
3.0 → float / double not int

⑧

### Relational Operator

(a op b)

>, <, >=, <=, !=, ==

Output - 0 or 1

false ← ↗ true

these are different things

## Assignment Operators

=

## Logical Operators

↳ when you have multiple conditions

$(a \& \& b)$  → and → true if both are true

$(a || b)$  → or → true if any one is true

$(!a)$  → not → negate the result

Output - 0 or 1  
false ↕ true

$(\text{cond1} \& \& \text{cond2} \& \& \text{cond3})$

if cond1 is false

compiler will not check further  
as ans will already false

$(\text{cond1} || \text{cond2} || \text{cond3})$

if cond1 is true

compiler will not check further  
as ans will already true

## Conditions

if (cond.){  
execute  
}

if

if (cond.){  
execute 1  
}

else {  
execute 2  
}

if - else

**W1-L3**

if (cond1)  
execute 1  
else if (cond2)  
execute 2

if - else if

```

if (cond 1)
    execute 1
else if (cond 2)
    execute 2
else if (... )
else
    execute n
if - else if - else

```

```

if (cond 1)
    execute 1
else {
    if () { }
    else () { }
}

```

nesting if - else

## Loops

↳ to do something repeatedly

for - loop

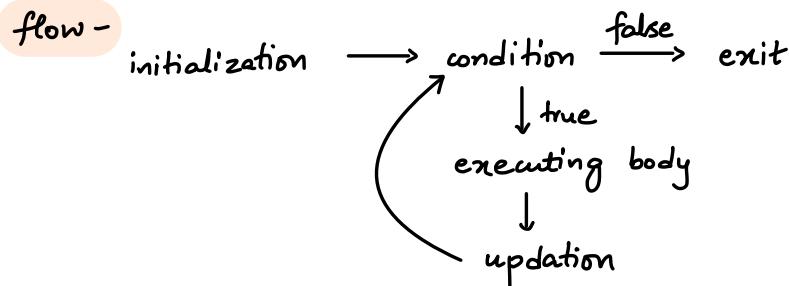
```

for( int i=0 ; i<5 ; i=i+1 ) {
    cout << "Love" ;
}

```

initialization      condition      updation

executing body



initialization  
condition  
updation

none is mandatory  
one or multiple    i, c, u can be added

multiple c → i>5, i<10;      i>5 & i<10

patterns -

$$\rightarrow a \text{ op } = b \longrightarrow a = a \text{ op } b$$

Op → +, -, \*, /, |, <<, >>

cin in if( )

```
int num;  
if (cin >> num) {  
    cout << "Hello";  
}  
else {  
    cout << "Hi";  
}
```

it will not give error

output -  
hello

for all input values of num

0, tue, -ve

out in if()

```
int num = 0;  
if (cout << num << endl) {  
    cout << "Hello";  
}  
else {  
    cout << "Hi";  
}  
}
```

it will not give error

output -  
0  
hello

for all values of `num`

0, tue, -ve

HLL - High level language

↳ human readable and user friendly

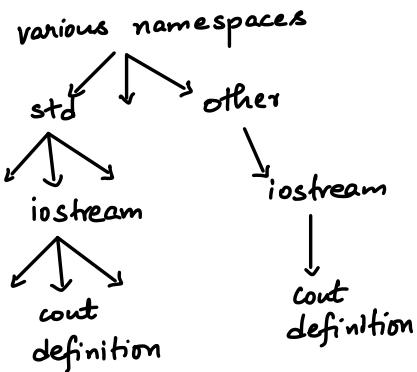
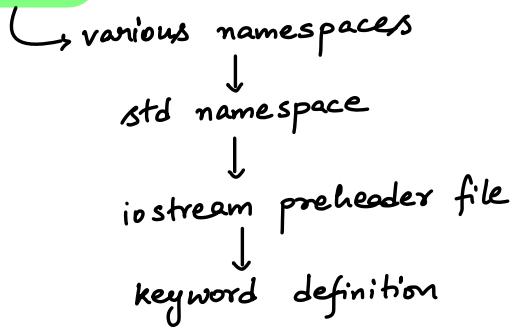
W1-L4

C++, C - Middle Level language

namespace → to avoid collision

↓  
multiple definitions of a single keyword

hierarchy



float f = 2.0 + 100;

cout << f; → output -

102 or 102.0  
compiler dependent

float f = 2.7;

int n = 157;

int diff = n - f;  
cout << diff;

output -

154

explanation -

$$n - f = 157 - 2.7 = 154.3$$

int diff = n - f

diff = 154

## ternary operator -

W1-HW

↳ syntax

variable = (condition) ? expression2 : expression3

(condition)? variable = expression2 : variable = expression3

2 and 3 cant be statements, they must be exp.

ex- `return (a > b) ? a : b;` → CORRECT

`(a > b) ? return a : return b;` → WRONG  
ERROR

these are statements, not expression

## by default -

`cout << sizeof(2.3);` → 8

↳ float

`cout << sizeof(a);` → 4 → int

↳  $-(2^{31}-1)$  to  $2^{31}-1$

`cout << sizeof(-2^{31});` → 8

↳ long long

↳ how to think

→ finding formula for rows and cols

$n=5$

row	stars
0	0
1	0
2	1
3	2
4	3

→ formula -

0 to  $< n-1$

$n-1$

-1

0

1

2

3

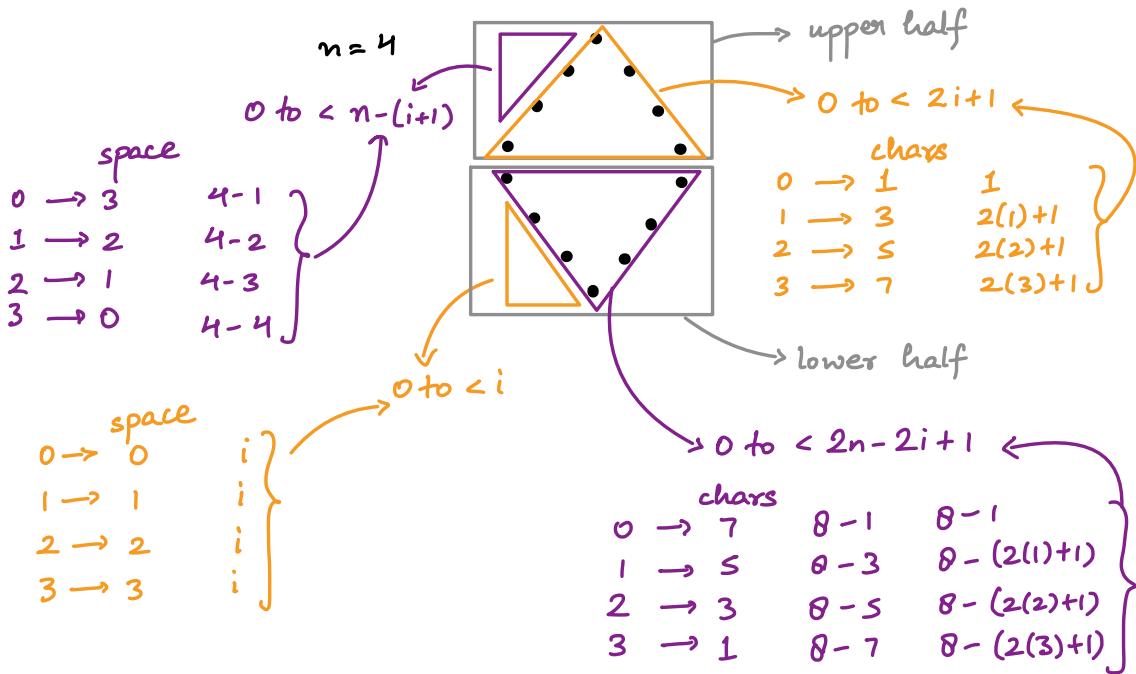
no. of times loop runs

as condition fails ( $0 < -1$ )

→ to do anything  $n$  times

↳ `for(i=0; i<n; i++) {}`

→ break the complex patterns



## Bitwise Operators

## W2-L2

→ use on bit level

And  $(a \& b)$  1 if both bits are 1

Or  $(a | b)$  1 if any or both bits are 1

not  $(\sim a)$  negate the result

nor  $(a ^ b)$  same values  $\rightarrow 0$   
diff. values  $\rightarrow 1$

$\sim 5$

→  $s \rightarrow 0 \dots 0101$

$\sim 5 \rightarrow 1 \dots 1010$

→ how compiler read this

→ 2's complement

$0 \dots 0101 \rightarrow 1$ 's complement

$0 \dots 0110 \rightarrow 2$ 's complement

-6

So  $\sim 5 = -6$

## Left and right shift operators

<<

shift all bits to left

\* by 2 (not in every case)

→ if MSB is 1 and

2nd MSB is 0

>>

shift all bits to right

/ by 2 (not in every case)

→ in -1

$a = a \ll b$  a left shifts, b times  $\rightarrow$  result  $\rightarrow a \times 2^b$

$a = a \gg b$  a right shifts, b times  $\rightarrow$  result  $\rightarrow \frac{a}{2^b}$   
b cant be -ve

↳ in case of -ve

$a = 5;$

↳ gives 8<sup>v</sup>

$a = a \ll 1;$   $a = 10$

$a = 5;$

in left shift  $\rightarrow$  filled with 0

$a = a \ll 2;$   $a = 20$

in right shift  $\rightarrow$  filled with

in +ve no.  $\leftarrow$  0 or 1  
in -ve no.  $\leftarrow$

right shift in -ve number

-ve no. in memory  $\rightarrow 1 \dots$

↓ right shift

1 1 ...

↳ signed bit is used to fill  
the vacant bit

ex-

$s \rightarrow 0 \dots 0 101$

$-s \rightarrow 1 \dots 1 011$

$-s \gg 1 \rightarrow 1 \dots 1 01 \rightarrow -3$

$-1 \gg 1 \rightarrow -1$

left shift in number where MSB is 1

and 2nd MSB is 0

no.  $\rightarrow 1 0 \dots \rightarrow$  -ve no.

left shift  $\rightarrow 0 \dots$

$\rightarrow$  +ve no.

## Pre- Post $\rightarrow$ Increment / Decrement Operator

### pre- increment

$\hookrightarrow ++a$

$\hookrightarrow$  first increment by 1, then use

### post- increment

$\hookrightarrow a++$

$\hookrightarrow$  first use then increment by 1

### pre- decrement

$\hookrightarrow --a$

$\hookrightarrow$  first decrement by 1, then use

### post- decrement

$\hookrightarrow a--$

$\hookrightarrow$  first use then decrement by 1

int a = 5;

cout  $\ll$  (++a) \* (++a);

output -

49

$\hookrightarrow$  due to operator precedence

$\rightarrow$  links.txt in repo

## break and continue

### break

$\hookrightarrow$  exit from that loop

### continue

$\hookrightarrow$  skip that iteration

## Variable Scoping -

```
int g= 25;           -----> global variable
int main(){
    int a;           -----> declaration
    int b= 5;         -----> initialization
    b= 10;           -----> updation
    //int b= 15;      -----> redefinition is not allowed
    int c= 7;
    g= 30;
    cout << g;      -----> 30

    if (true){
        int b= 15;
        cout << b;      -----> 15
        cout << c;      -----> 7
        g= 50;
        cout << g;      -----> 50
    }

    cout << a;      -----> gv
    cout << b;      -----> 10
    cout << c;      -----> 7
    cout << g;      -----> 50
}
```

Making global variable is very **BAD PRACTICE**

## Operator Precedence

- order of priority of operator
- no need to remember
- use brackets properly

## Switch Case

```
switch (expression) {
```

```
    case value1 :
```

executing body 1

break;

```
    case value2 :
```

executing body 2

break;

:

```
    case value n :
```

executing body n

break;

```
    default :
```

executing body

}

can also have  
nested switch  
case

not  
mandatory

without break

→ all below executing body will also execute

→ continue cannot be used in switch case

→ can only use in loops

## Function -

## W2-L3

- program linked with well defined task
- why
  - reusable
  - readable
- without
  - bulky
  - lengthy
  - buggy if mistake in any place

### syntax -

```
return type function name (input parameters){  
    executing body  
}
```

void → empty / no value      void x; → ERROR

cout << sizeof(int) → 4

cout << sizeof(void) → ERROR

```
int main(){  
    return 0; → 0 is used as means of  
}
```

returns 0 to Operating System

successful execution

- a cpp file can't have more than 1 main functions
- main can't have return type other than int in offline compiler

## Function Call Stack

function call  $\leftrightarrow$  function invoke

Stack

↳ Last In First Out

- ↳ tells what functions are active
- ↳ which function calls which
- ↳ local variables of function
- ↳ return type of function

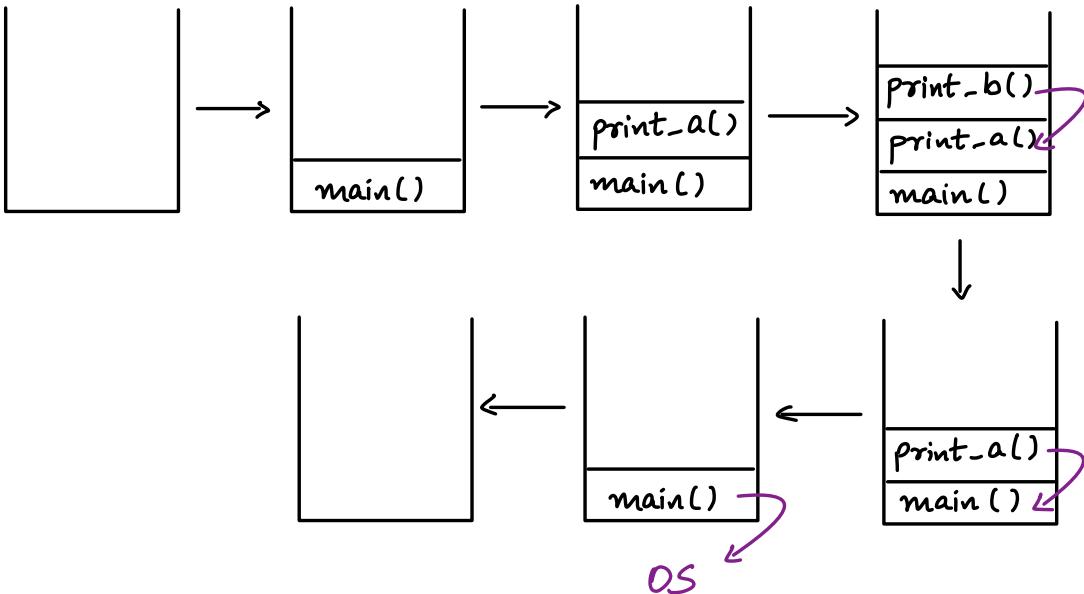
ex -

```
int main() {  
    int a=5;  
    print_a(a)  
    return 0;  
}  
} return to OS
```

```
void print_a(int a){  
    cout << a;  
    int b=3;  
    print_b(b);  
}
```

```
void print_b(int b){  
    cout << b;  
}
```

Output - 5 3

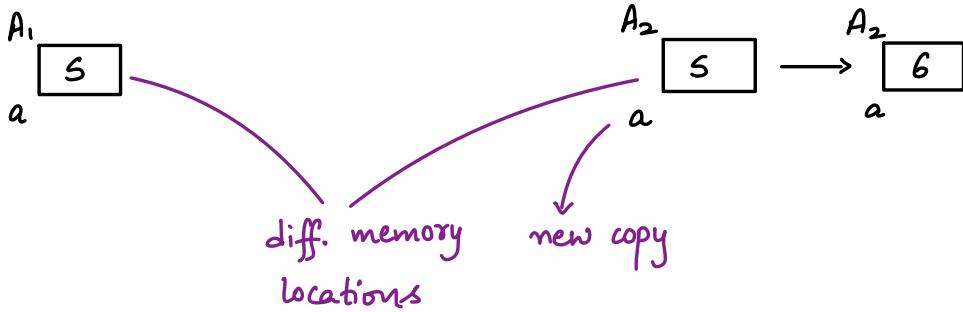


Pass by value  $\rightarrow$  value is passed to another variable

$\hookrightarrow$  a copy will be created of variables

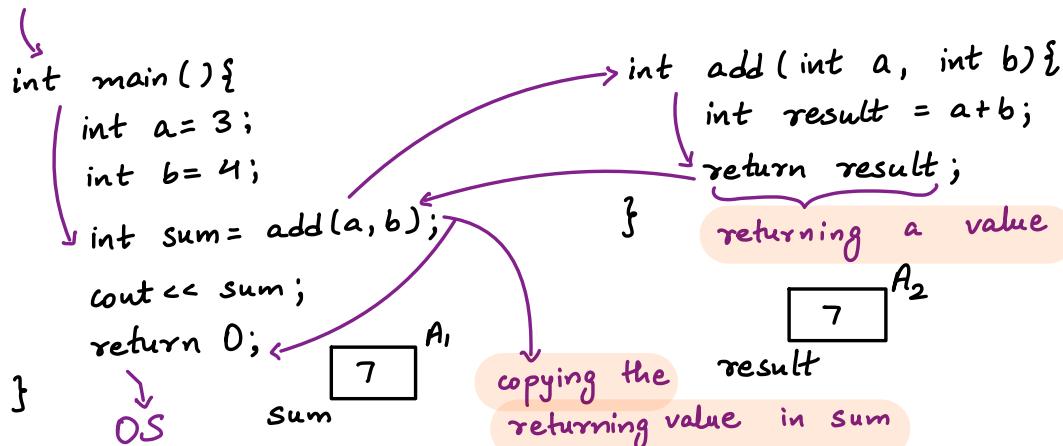
```
int main() {  
    int a=5;  
    printNumber(a);  
    cout << a;  
}
```

parameter  $\hookrightarrow$   
void printNumber(int a){  
 cout << a;  $\rightarrow 5$   
 a++;  
 cout << a;  $\rightarrow 6$   
}



## Address Of Operator &

```
int n=5;  
cout << &n;  $\xrightarrow{\text{output - address of } n}$ 
```



## Function Order

### Order 1

```
int add (int a, int b) {  
    return a+b;  
}  
  
int main () {  
    int a= 3;  
    int b = 5;  
    int sum= add (a, b);  
    cout << sum;  
    return 0;  
}
```

function  
declaration  
and  
definition

### Order 2

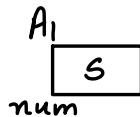
```
function declaration  
{  
int add (int a, int b);  
  
int main () {  
    int a= 3;  
    int b = 5;  
    int sum= add (a, b);  
    cout << sum;  
    return 0;  
}  
  
int add (int a, int b) {  
    return a+b;  
}
```

% operator → heavy operator

↳ so try to use it less

```
int num=5;
```

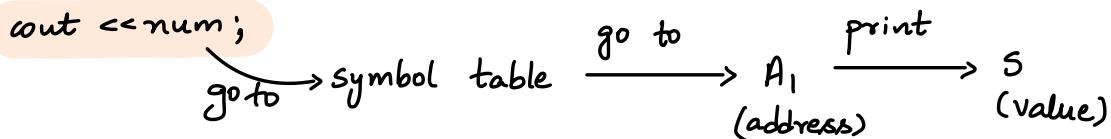
### Symbol table



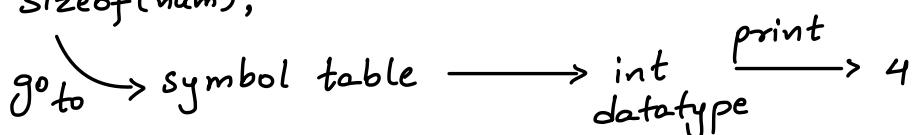
int num  $\longleftrightarrow$  A<sub>1</sub>  
 ↓  
 datatype      variable name

memory location of variable

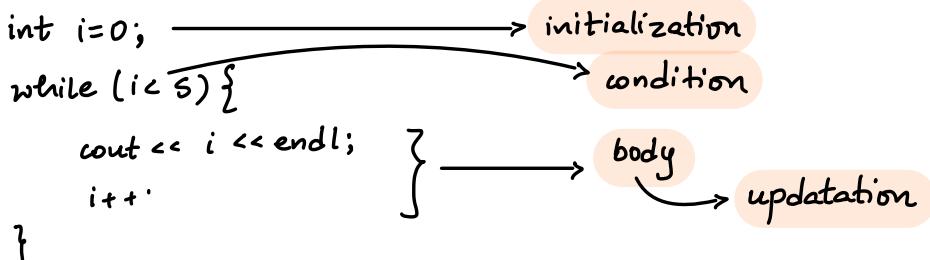
variable address mapping is stored



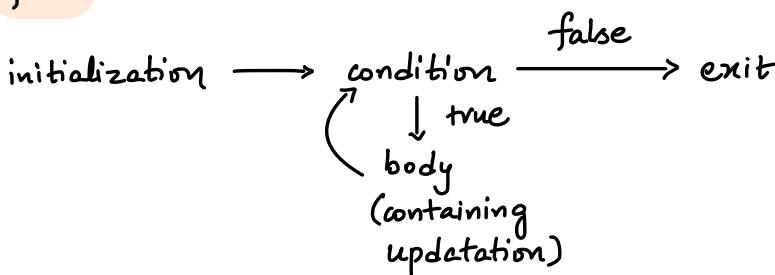
cout << sizeof(num);



### while loop



### flow



## left and right shift operators

int a = 2;

$a \ll 1;$   $\rightarrow$  no change

$\text{cout} \ll a;$   $\rightarrow 2$

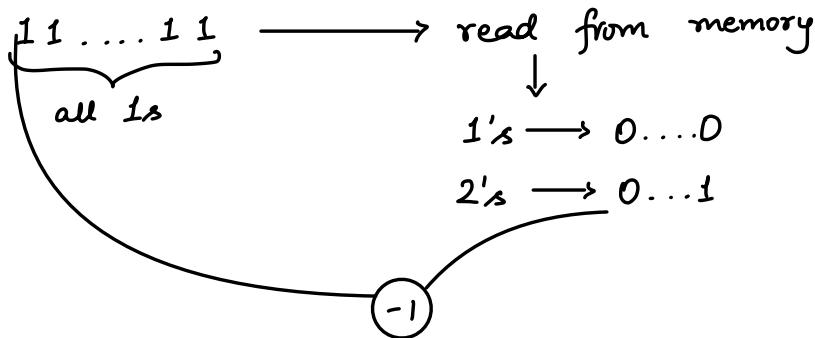
$a = a \ll 1;$   $\rightarrow$  change  $\rightarrow$  left shift by 1

$\text{cout} \ll a;$   $\rightarrow 4$

## right shift in -ve no.

$\hookrightarrow$  link in links.txt in repo

## How $-1$ is stored in memory -



$$\sim a = -(a+1) \quad \text{and} \quad \sim(\sim a) = a$$

ex -  $a = 5; \rightarrow 0\ \dots\ 0\ 101$

$a = \sim a; \rightarrow 1\ \dots\ 1010 \rightarrow -6 \rightarrow -(5+1)$

$a = -6;$

$\hookrightarrow 1\ \dots\ 1010$

$\hookrightarrow$  read

$-6$

$a = \sim a; \rightarrow 0\ \dots\ 0\ 101$

$\hookrightarrow 5 \rightarrow -(-6+1)$

## Number System

W2-R

↳ method to represent numeric values using digits

### Decimal Number System

↳ base 10

↳ digits → 0 to 9

### Binary Number System

→ base 2

↳ digits → 0, 1

→ used in CPU, memory, computer

→ 0 → power off

→ 1 → power on

→ number, images, all files & folder are in binary

### Decimal to Binary

→ divide no. by 2

→ store remainder

→ repeat above steps until no. is 0 or 1

→ reverse the bits so obtained

## Binary to Decimal

- multiply each bit with its place value
  - ↳ base  $i$
- add all products
  - ↳  $2^i$

## Time & Space Complexity

W3-R

### Time Complexity

- amount of time taken by an algo as a function of length of input
- not actual time
- it defines CPU operations
- use case -
  - to make efficient programs
  - ask by interviewer after every sol. you give

### Space Complexity

- amount of space taken by an algo as a function of length of input

## Units to represent Complexity

Big O  $\longrightarrow$  upper bound  $\longrightarrow$  worst case

Theta  $\Theta$  ————— average case

Omega  $\Omega$   $\longrightarrow$  lower bound  $\longrightarrow$  best case

## Big O Complexities

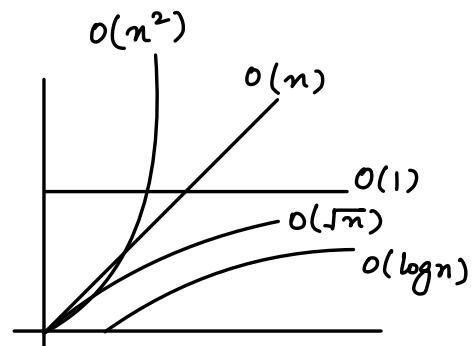
$O(1)$   $\longrightarrow$  Constant time

$O(n)$   $\longrightarrow$  Linear time

$O(\log_2 n)$   $\longrightarrow$  Logarithmic time

$O(n^2)$   $\longrightarrow$  Quadratic time

$O(n^3)$  ————— Cubic time



nesting → multiply → { }  
 in sequence → add → { } { }  
 → { }

$$f(n) = 4n^4 + \frac{n^3}{5} + \log n + n \log n \longrightarrow O(n^4)$$

## Complexity Order

$$O(1) < O(\log_2 n) < O(\sqrt{n}) < O(n) < O(n \log_2 n) < O(n^2)$$

$$< O(n^3) < O(2^n) < O(n!) < O(n^n)$$

# ARRAY

W3-L1

- Data structure to store similar items
  - ↳ same datatype
- Continuous memory location
- use case
  - ↳ for multiple same kind of data

int a[30000]; → 30000 variables are ready

## continuous memory allocation

↳ memory wastage  
if needable memory is present but not in continuous way

int a = 5;

A



a

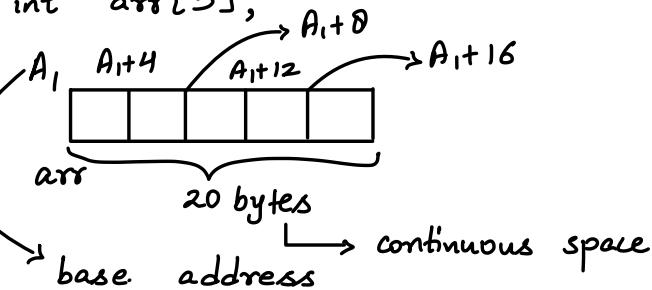
## symbol table

int a ↔ A

int arr ↔ A<sub>1</sub>

## Declaration

int arr[5];



`cout << arr ;`  $\longrightarrow A_1$   $\longrightarrow$  address of first index of array  
address of integer

`cout << &arr ;`  $\longrightarrow A_1$   $\longrightarrow$  base address of array arr  
address of array

Initialization

diff. things

`int arr [] = { 2, 4, 6, 8, 10 } ;`

`int arr2 [5] = { 2, 4, 6, 8, 10 } ;`

`int arr3 [10] = { 2, 4, 6, 8, 10 } ;`  $\longrightarrow$  remaining 5 will be 0

`//int arr4 [4] = { 2, 4, 6, 8, 10 } ;`  $\longrightarrow$  ERROR

`int arr5 [10] = { 0 } ;`  $\longrightarrow$  initializing all values with 0

Making array at runtime

`int n ;`

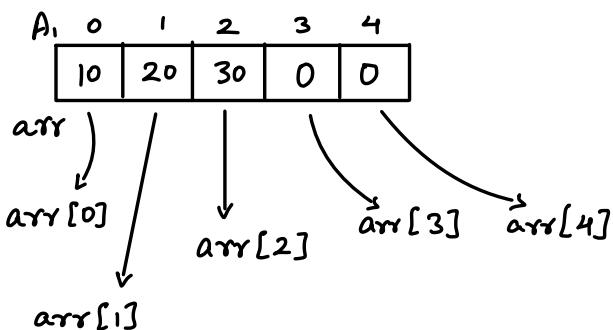
`cin >> n ;`

`int arr [n] ;`  $\longrightarrow$  BAD PRACTICE

Index and Access in memory

`int arr [5] = { 10, 20, 30 } ;`  $\longrightarrow$  0<sup>th</sup> based indexing

$\hookrightarrow$  0 to n-1



$\text{arr}[i] \longrightarrow \text{value at address } [A_1 + (i \times 4)]$

BA  
index  
due to int (datatype size)

that's why 0 based indexing

taking input in array

$\hookrightarrow \text{cin} \gg \text{arr}[i];$

## Arrays and Function

$\hookrightarrow \text{func ( int arr[], int size) } \{$   
}

arr here is not an array, it is pointer pointing to first index of array (will learn ahead)

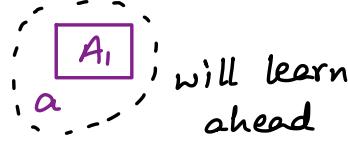
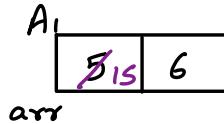
array is passed by reference because pointer is passed by value

updation in actual array

always pass size alongwith arr

```
int main() {
    int arr[] = {5, 6};
    int size = 2;
    func (arr, size);
    return 0;
}
```

```
void func ( int a[], int size) {
    a[0] = a[0] + 10;
}
```



`sizeof( int );` → 4 → in bytes

`int arr [5];`

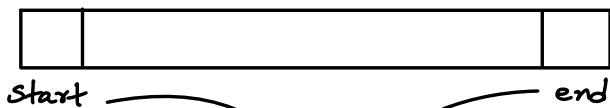
`sizeof( arr );` → 20 → in bytes  
→ not 8 ( size of pointer )

linear search in array

INT\_MIN and INT\_MAX

- to find max. , start ans with INT\_MIN
- to find min. , start ans with INT\_MAX

2 pointer approach



use of 2 variables as extreme points

To find size of array

`int arr [ ] = { 1, 2, 3, 4 };`

`int size = sizeof( arr ) / sizeof( int );`

→ datatype

## Vector

## W3-L2

- Data structure
- Same as array but dynamic
  - size not fixed
- default size → 0
- if gets full and new items are inserted
  - size gets doubled
- pass by value in functions

### Initialization

- vector <int> arr {10, 20, 30}; → 

10	20	30
----	----	----
- vector <int> arr (5); → 

0	0	0	0	0
---	---	---	---	---
- vector <int> arr (5, -2); → 

-2	-2	-2	-2	-2
----	----	----	----	----

  - int n; size → value
- cin >> n; → let n = 5
- vector <int> arr(n); → 

0	0	0	0	0
---	---	---	---	---
- vector <int> arr (n, 10); → 

10	10	10	10	10
----	----	----	----	----

### Insertion -

arr.push\_back (5);

### Remove

arr.pop\_back();

### Size -

arr.size();

→ no. of elements it stores

### declaration

vector <int> arr;

→ arr.size() → 0

→ arr.capacity() → 0

## Empty or Not

arr. empty ();  $\longrightarrow$  true if empty

## Capacity -

arr. capacity ();  $\longrightarrow$  \* by 2 if arr gets fully filled  
and a new element is inserted

→ no. of elements it can store

→ in initialization, capacity = size in all methods of initialization

sizeof (arr);  $\longrightarrow$  compiler dependent  
initially

cout << arr ;  $\longrightarrow$  give ERROR

→ Xor  $\longrightarrow$  cancels out same element

$$0 \wedge \text{ans} = \text{ans} \quad \begin{cases} 0 \wedge 1 = 1 \\ 0 \wedge 0 = 0 \end{cases}$$

## for each loop

```
for (auto val: arr){  
    cout << val << ' ';  
}
```

## 2D Arrays

## W3-L3

→ array of arrays  
→ use case

→ to work on multiple rows and columns

### Declaration -

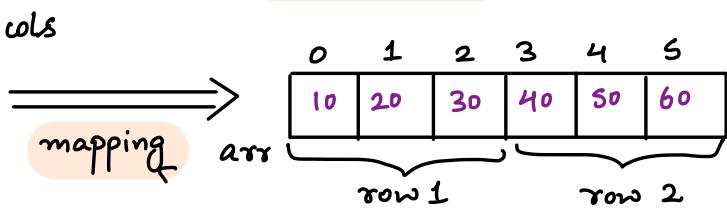
int arr [m][n]; →  $m \times n$  elements  
cols → 0 to  $n-1$   
rows → 0 to  $m-1$

int arr [2][3];

### visualize -

	cols		
0	10	20	30
1	40	50	60
rows	0	1	2

### in memory -



### Access -

arr [i][j];  
→ col index  $0 \leq j \leq n$   
→ row index  $0 \leq i \leq m$

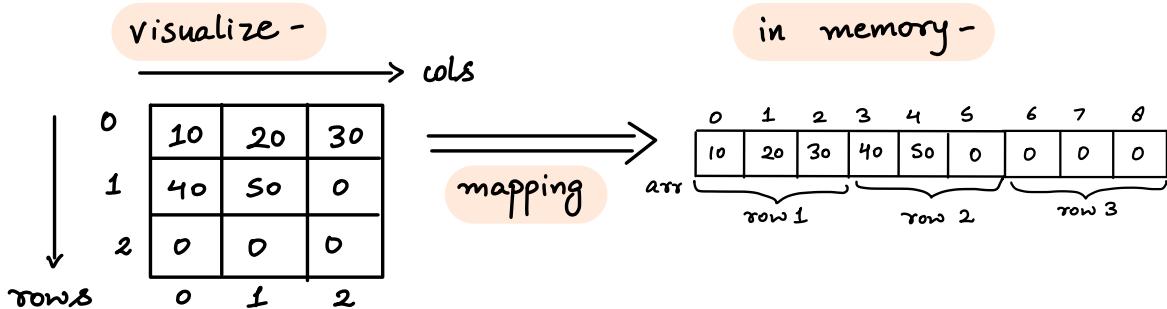
### Mapping -

linear\_index = c \* i + j  
no. of cols  
row index  
col index

$$i = \text{linear\_index} / c$$
$$j = \text{Linear\_index \% c}$$

## Initialization -

int arr[3][3] = {{10, 20, 30}, {40, 50}}; same  
int arr[3][3] = {10, 20, 30, 40, 50};



## 2D Arrays and function -

→ pass by reference

func (arr[ ][500], int rows, int cols)

actually arr  
here is  
int (\*[500]  
(array of pointers),  
not a 2D array

→ cannot leave blank  
why if dont know, put large value  
500 tells size of array of pointers

→ this value and no. of cols  
in array passed in function  
call should be same

## 2D Array -

→ not an array of pointers

→ array of arrays

```
func( int a [ ] [ 3 ], int rows , int cols ) {
```

```
    cout << & a ; —> add. of a —> A4
```

```
    cout << a ; —> A1
```

```
    cout << a [ 0 ] ;
```

```
    cout << & a [ 0 ] ;
```

```
    cout << & a [ 0 ] [ 0 ] ; —> 10
```

```
    cout << sizeof( a ) ; —> 4
```

```
    cout << sizeof( a [ 0 ] ) ; —> 12
```

```
}
```

```
int main () {
```

```
    int arr [ 2 ] [ 3 ] = { 10, 20, 30, 40, 50 } ;
```

```
    func( arr, 2, 3 );
```

```
    return 0;
```

```
}
```

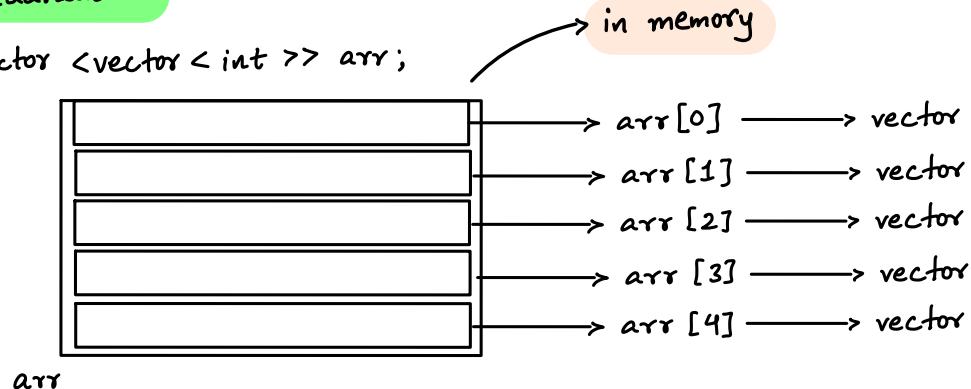
	$A_1$	$A_2$	$A_3$
$A_1$	10	20	30
$A_2$	40	50	0
$A_3$	0	0	0

$A_4$	$A_1$	$A_2$	$A_3$
$a$			

## 2D Vector

## Declaration -

```
vector<vector<int>> arr;
```



## Declaration -

vector<vector<int>> arr; → no. of rows

```
vector<vector<int>> arr (m);
```

Number of rows

arr. size()

Number of cols

arr[i].size()

→ in  $i$ th row  
→ size of  $i$ th row

## Initialization

```
vector<vector<int>> arr (rows, (vector<int>(cols, value));
```

rows → no. of rows in arr

cols  $\rightarrow$  no. of cols in arr  
 $\rightarrow$  size of 1D vector

value  $\longrightarrow$  initial value in all elements

initialization of 1D  
vectors in arr

```
vector<vector<int>> arr(2, vector<int>(4, 101));
```



101	101	101	101
101	101	101	101

arr

### auto keyword -

→ automatically replace with required data type

```
int arr [4]
```

```
for( auto i = 0; i < 4; i++)  
    cout << arr [i];
```

### : Operator

→ belongs to operator

→ generally used for sequential access

→ map, set, array, vector

```
ex - vector<int> arr {1, 2, 3};
```

```
for( int i: arr)  
    cout << i;           → 1 2 3
```

```
for( auto i: mapping)  
    cout << i;
```

```
for( auto i: sett)  
    cout << i;
```

## Searching

## Linear Search

```

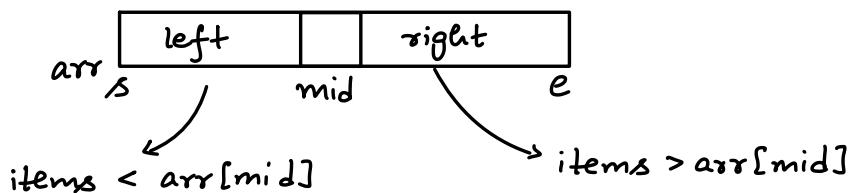
int linearSearch ( vector <int> arr, int target ) {
    int n = arr.size();
    for( int i=0; i<n ; i++ ){
        if ( target == arr[i] )
            return i;
    }
    return -1;
}

```

T. C -  $O(n)$ S.C. -  $O(1)$ 

## Binary Search -

→ condition → sorted order → monotonic function  
 → binary → 2 → left and right search



```

int binarySearch ( int arr[], int n, int target ){

    int s= 0, e=n-1;

    int mid = s+(e-s)/2;

    while( s<=e ){

        int element = arr[mid];

        if (target == element)
            return mid;

        else if ( target < element)
            e=mid-1; —→ search in left subarray

        else
            s= mid +1; —→ search in right
                           subarray

        mid = s + (e-s)/2;
    }

    return -1;
}

```

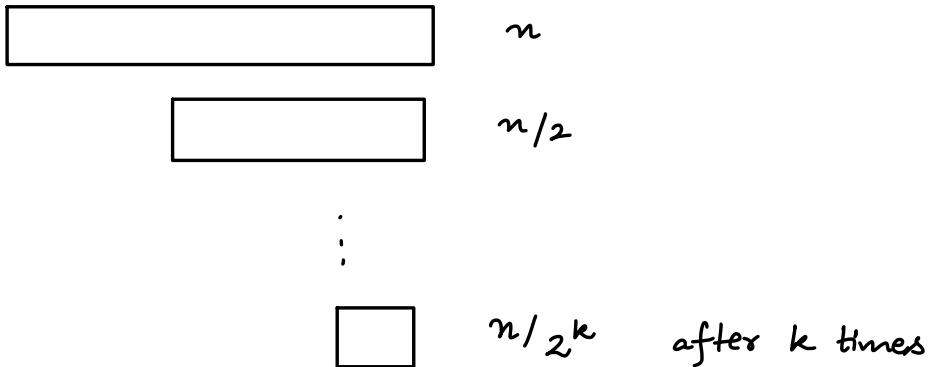
issue in  $mid = \frac{s+e}{2}$  ; —→ int overflow  
 if  $s+e > \text{INT\_MAX}$

so use  $mid = s + \frac{e-s}{2}$  ;

T.C -  $O(\log_2 n)$

S.C. -  $O(1)$

## T.C. of binary Search



at last  $\frac{n}{2^k} = 1$

$$k = \log_2 n$$

So loop runs  $\log_2 n$  times

$$\text{T.C.} = O(\log_2 n)$$

W4-L2

→ Search Space

    └ find range of search space (start & end)  
        in ques of. Binary Search

→ store mid in ans if needed

## → In binary search questions

```
while (s <= e) {  
    ans = mid;  
    s = mid + 1;  
    left search ← e = mid - 1;  
}  
right search
```

convert  
ans = mid, s = mid + 1

```
while (s < e) {  
    s = mid; → right search  
    left search ← e = mid - 1;  
}  
OR  
s = mid + 1 → right search  
left search ← e = mid;
```

convert  
ans = mid, e = mid - 1

cout << (int)(-3.74);

W4-L3

→ - [ int (3.74) ]

→ - (3) → - 3

cout << (-22)/7; → - 3

cout << 22/(-7); → - 3

Types of ques in binary search

→ 1<sup>st</sup> type → classic questions

→ lower bound

upper bound

peak in mountain array

can also find array is sorted or not

→ pivot in sorted rotated array

search in sorted rotated array

↓ pivot index = n-1

→ 2<sup>nd</sup> type → find in search space (range)

- predicate function
- sqrt of a no.
- divide 2 numbers

logic to decide either left or right

### Advance Binary Search Problems

→ Book allocation

Painters Partition

Aggressive Cows

Roti / Paratha Spoj

Eko Spoj

→ 3<sup>rd</sup> type → observation in index

- missing element in sorted array
- add appearing element in array

### Sorting

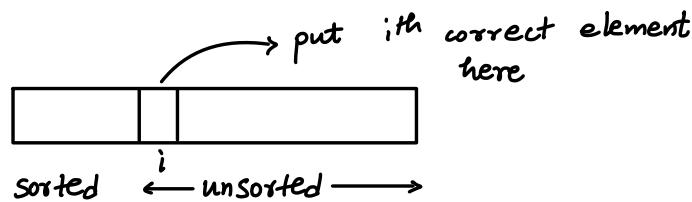
### W4-L5

- putting all elements either in increasing order or decreasing order

## Selection Sort -

- select minimum element and put it in its right position
- select correct element for  $i^{\text{th}}$  index
  - $i^{\text{th}}$  minimum element

```
void selectionSort ( int arr[], int n){  
    for( int i=0; i<n-1; i++) {  
        mini = i;  
        for( int j=i+1; j<n; j++) {  
            if ( arr[mini] > arr[j] )  
                mini = j;  
        }  
        swap (arr[i], arr[mini]);  
    }  
}
```



T.C.  $O(n^2)$

S.C.  $O(1)$

Use Case - for small size array

- put  $i^{\text{th}}$  lowest element to its correct position

## Bubble Sort -

→ in  $i$ th round put  $i$ th largest element to its correct position using adjacent comparisions

```
void bubbleSort ( int arr[], int n){  
    for( int i=0 ; i<n-1 ; i++) {  
        bool swapping = false;  
        for( int j= 0 ; j<n-i-1 ; j++) {  
            if (arr[j] > arr[j+1]) {  
                swap ( arr[j], arr[j+1]);  
                swapping = true;  
            }  
        }  
        if ( swapping == false)  
            break;  
    }  
}
```

T. C. -  $O(n^2)$  → reverse sorted  
Worst and average case

$O(n)$  → best case → already sorted

S.C. -  $O(1)$

Use Case - To put  $i$ th largest element to its correct position

## Insertion Sort -

→ take an element and insert it on its correct position by shifting

```
void insertionSort ( int arr [ ], int n ) {  
    for ( int i = 1 ; i < n ; i ++ ) {  
        int curr = arr [ i ] ;  
        int j = i - 1 ;  
        for ( ; j >= 0 ; j -- ) {  
            if ( arr [ j ] > curr )  
                arr [ j + 1 ] = arr [ j ] ; // shifting  
            else  
                break ;  
        }  
        arr [ j + 1 ] = curr ; // inserting  
    }  
}
```

T.C. -  $O(n^2)$  → worst & average case

$O(n)$  → best case

S.C. -  $O(1)$

Use Case - When array is small or when array is partially sorted

## Inbuilt sort function

- `sort (arr.begin(), arr.end());`
- algo used is Intro sort
  - hybrid of quick sort, heap sort, insertion sort
- min. time than any of other sort

T. C. -  $O(n \log n)$

S. C. - Not Defined

## Stable and Unstable Algorithm

Stable → order preserve after sorting

                  → of same values

### Stable Sorting Algo

2 1 **2** 2 3

↓  
after sorting

1 2 **2** 2 3

if  $A[i] = A[j]$  ,  $i < j$

then  $A[i]$  comes first before  
 $A[j]$  after sorting too

Stable - Bubble Sort, Insertion Sort, Merge Sort,  
Count Sort

Other (unstable) sorting algorithms can be made stable  
by some changes

# T.C. and S.C Sorting Algorithm Table

Algo	S. C.	Worst T.C.	Avg. T.C.	Best T.C.
Selection	$O(1)$	$O(n^2)$	$O(n^2)$	$O(n^2)$
Bubble	$O(1)$	$O(n^2)$	$O(n^2)$	$O(n)$
Insertion	$O(1)$	$O(n^2)$	$O(n^2)$	$O(n)$
sort func. (intro sort)	not defined	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$
merge	$O(n)$	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$
quick	$O(n)$	$O(n \log n)$	$O(n \log n)$	$O(n^2)$

# CHAR ARRAYS & STRING

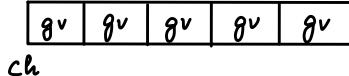
W5-L1

Char Arrays -

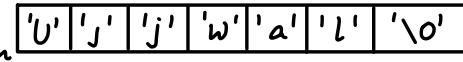
→ Data structure → used to store data

Not Data type → tells type of data

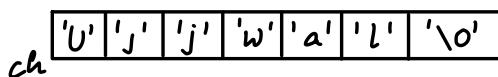
char ch[5];



char ch[] = {'U', 'j', 'j', 'w', 'a', 'l'} ch



char ch[] = "Ujjwal";



Taking input in char array

char ch[7];

cin >> ch[i];

cin >> ch; → by default NULL char will

insert at end

→ '\0'



NULL char refers string termination

→ cin reads until it gets any white space

→ space ' '

tab '\t'

endl '\n'

cout << ch; → cout print until it gets delimiter

```
char ch [10];
```

cin >> ch ;  $\longrightarrow$  Ujjwal

store in buffer memory

'U'	'j'	'j'	'w'	'a'	'l'	'\0'
-----	-----	-----	-----	-----	-----	------

buffer

copy in memory of ch

'U'	'j'	'j'	'w'	'a'	'l'	'\0'	gv	gv	gv
-----	-----	-----	-----	-----	-----	------	----	----	----

ch 0 1 2 3 4 5 6 7 8 9

cout << ch ;  $\longrightarrow$  Ujjwal  $\longrightarrow$  stops after 'l'  
because of '\0' char

### Overflow -

```
char ch [4];
```

cin >> ch ;  $\longrightarrow$  Ujjwal

cout << ch ;  $\longrightarrow$  Compiler Dependent

### sizeof (char array)

```
char ch [] = "Ujjwal";
```

cout << sizeof (ch) ;  $\longrightarrow$  7

$\downarrow$   
 $6 + 1$

$\downarrow$   
NULL char

## get line

`cin.getline (char array, max char to write, delimiter);`

char where taking input stops  
↓  
by default '\n' → enter

ex- `cin.getline (ch, 50);`

`cin.getline (ch, 50, '');`

## Char arrays and function

→ pass by reference

`func (char ch[]){`

`}`

Size of char array →  $\frac{\text{size of (ch)}}{\text{size of (char)}}$  → 1

## Some inbuilt functions of char array

`strlen (ch);`

`strcmp (ch1, ch2);`

`strcpy (ch1, ch2);`

## String 8

- Datatype
- Not Data Structure
- Dynamic char array
- NULL char at last of string

string str; → empty string created

cin >> str; → Ujjwal

'U'	'j'	'j'	'w'	'a'	'l'	'l'	'\0'
-----	-----	-----	-----	-----	-----	-----	------

cout << str; → Ujjwal str

cout << str.length(); → 6, not 7

## getline -

string str;

getline (cin, str);

## char array

char ch [ ] = "B\_abba-r";

cout << ch; → B\_abba-r

cout << arr.size () → 9

ch [1] = '\0';

ch [6] = '\0';

cout ch; → B

stops just as it gets NULL char

## string

string str = "B\_abba-r";

cout << str; → B\_abba-r

cout << str.length () → 8

cout << str.size () → 8

str [1] = '\0';

str [6] = '\0';

cout << str; → Babbar

Runs till the length of string

## Sort function in strings -

W5-L3

string str = "babbar";

sort (str.begin(), str.end());  $\longrightarrow$  aabbbr

sort (str.begin(), str.end(), greater<char>());

$\longrightarrow$  rbbbbaa

## Custom Comparator -

bool cmp (char a, char b) {

    return a < b;  $\longrightarrow$  can be any function  
    according to need

}

bool cmp2 (char a, char b) {

    return a > b;

}

int main () {

    string str = "babbar";

    sort (str.begin(), str.end(), cmp);

    cout << str;  $\longrightarrow$  aabbbr

    string str2 = "babbar";

    sort (str.begin(), str.end(), cmp2);

    cout << str2;  $\longrightarrow$  rbbbbaa

    return 0;

}

# Hash Map → WILL LEARN LATER

→ Data structure

→ data stored in key-value pair

## Initialization

`map<key datatype, value datatype> map-name;`

`map<int, char> m;` → ordered map

`m[0] = 'a';`

`m[1] = 'b';`

`m[25] = 'z';`

`cout << m[0];` → 'a'

`cout << m[25];` → 'z'

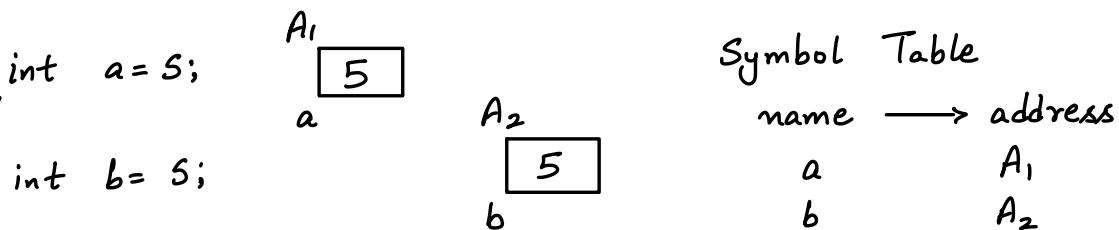
`cout << m[20];` → " → NULL char

`cout << (int) m[20];` → 0

# SYMBOL TABLE

W6-L1

- Data Structure
- Stores mapping of variable name, datatype & memory location address → Done by OS
- entries in symbol table can't be changed



→ entry of a in symbol table is made

cout << a; → 5

## & Address Of Operator

cout << &a; →  $A_1$  → address of

cout << &b; →  $A_2$

hexadecimal  
↑  
variable a in  
memory

Not 100%  
Sure

$A_2 = A_1 \pm 4$  → because of consecutive  
variables in memory  
↓  
int datatype  
of a and b

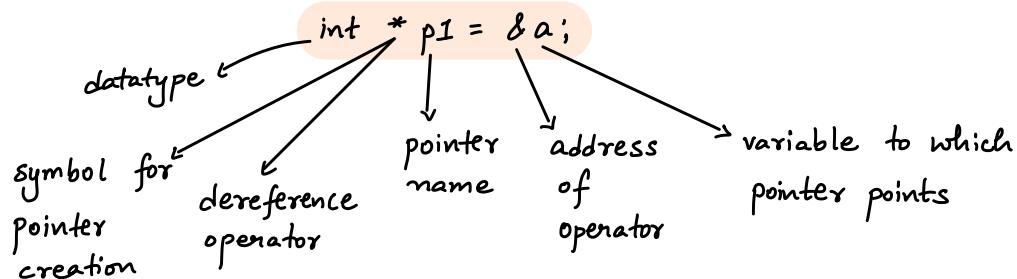
# POINTERS

→ stores address

→ NOT a datatype, just a variable  
storing address of another variable

```
int a = 5;
```

int \* p1 = &a; p1 is a pointer to integer datatype



```
string s = "Ujjwal 2327";
```

string \* ptr = &s → ptr is a pointer to string datatype

```
int a = 5;
```

```
int * ptr = &a;
```

```
cout << a; → 5
```

```
cout << * a; → ERROR
```

```
cout << &a; → A1
```

```
cout << ptr; → A1
```

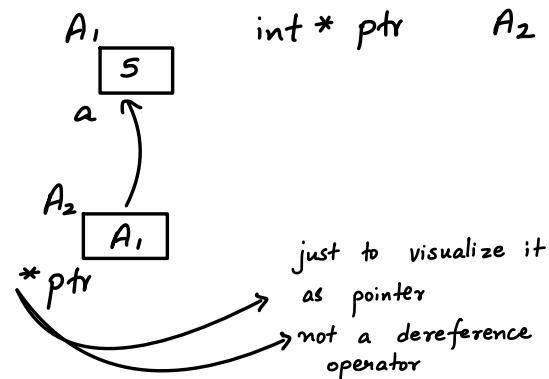
```
cout << * ptr; → 5
```

```
cout << &ptr; → A2
```

symbol table

int a A1

int \* ptr A2



$^*$  ptr  $\longrightarrow$  value at (address stored in ptr)  
 $\longrightarrow$  dereference operator

$\&$  ptr  $\longrightarrow$  address of ptr

size of pointer

$\text{sizeof}(\text{ptr}); \longrightarrow 8$   $\longrightarrow$  Always  
depends on  
architecture  
compiler implementation  
memory organization  
64 bit architecture  
it stores address,  
datatype does not matters

Use case of pointer

- dynamic memory allocation
- memory management
- pointer arithmetic
  - ↳ go from one location to other
- pass by reference in array
- to create pointer to function
  - ↳ passing a function inside another function as an argument

int \* ptr;  
cout << ptr;  $\longrightarrow$  **VERY BAD PRACTICE**  
Segmentation fault

A1  
 $*\text{ptr}$   
gv

ptr points to a memory location that may not be of its program

Segmentation fault -

→ using other's memory

NULL Pointer

```
int * ptr = 0;
```

```
int * ptr2 = NULL;
```

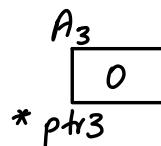
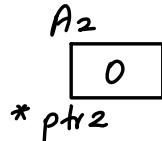
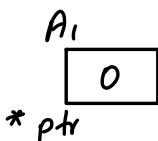
```
int * ptr3 = nullptr;
```

```
cout << ptr; → 0
```

```
cout << *ptr; → ERROR
```

```
cout << &ptr; → A1
```

same



Segmentation fault

Arithmetic Operations In Pointers

```
int a = 5;
```

```
a++;
```

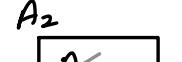
```
int * ptr = &a;
```

```
*ptr++;
```

```
ptr++;
```



a



\*ptr

A<sub>1</sub> to A<sub>1</sub> + 3 has already be taken by integer a, so next address will be A<sub>1</sub> + 4

```
int a = 10;
```

```
int *ptr = &a;
```

a 10

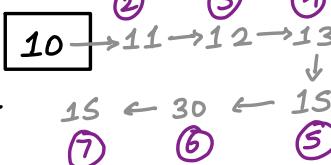
&a A<sub>1</sub>

ptr A<sub>1</sub>

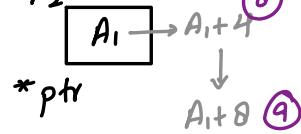
\*ptr 10

&ptr A<sub>2</sub>

A<sub>1</sub>



A<sub>2</sub>



① \*ptr \* 2

20

② (\*ptr) ++

10

③ ++ (\*ptr)

12

④ a = a + 1

13

⑤ \*ptr = \*ptr + 2

15

⑥ \*ptr = \*ptr \* 2

30

⑦ \*ptr = \*ptr / 2

15

⑧ \*(ptr++)

15

⑨ \*(++ptr)

9v

```
int a = 5;
```

```
int *ptr = a; -----> ERROR
```

### Copying a pointer

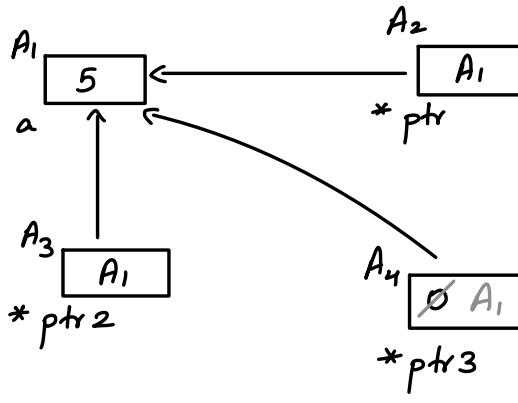
```
int a = 5;
```

```
int *ptr = &a;
```

```
{ int *ptr2 = ptr;
```

```
{ int *ptr3 = 0;
```

```
{ ptr3 = ptr;
```



# ARRAYS & POINTERS

W6-L2

```
int arr[] = {10, 20, 30, 40, 50};
```

CONSTANT pointer to the first element of array

cannot change

also does not have separate memory

arr[i] → element at index i

& arr[i] → address of arr[i]

cout << arr[0]; → 10

cout << &arr[0]; → A<sub>1</sub>

{ cout << arr; → A<sub>1</sub>

cout << &arr; → A<sub>1</sub>

same address unlike pointers

```
int *ptr = arr;
```

cout << \*ptr; → 10

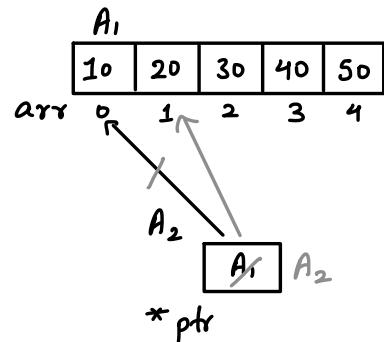
cout << ptr; → A<sub>1</sub>

cout << &ptr; → A<sub>2</sub>

cout << \*arr; → 10

cout << \*(&arr); → 10

cout << \*(&arr[0]); → 10



Symbol table

type	name	address
------	------	---------

int(*)[5]	arr	A <sub>1</sub>
-----------	-----	----------------

int*	ptr	A <sub>2</sub>
------	-----	----------------

cout << \*arr +1;  $\longrightarrow$  11

cout << \*(arr + 1);  $\longrightarrow$  20

cout << \*(arr + 2);  $\longrightarrow$  30

cout << arr [2];  $\longrightarrow$  30

cout << 2[arr];  $\longrightarrow$  30

arr [i]  $\longleftrightarrow$  \*(arr + i)  $\longleftrightarrow$  i[arr]

arr ++;  $\longrightarrow$  ERROR  $\longrightarrow$  Entry in symbol table

ptr ++;  $\longrightarrow$  A<sub>1</sub> + 4  $\longrightarrow$  cant be change

→ You can access subpart of an array using pointers

int \*ptr = arr;

cout << \*(ptr + 2);  $\longrightarrow$  40

cout << \*(ptr + 100);  $\longrightarrow$  gv / segmentation fault /  
out of bound error

Arrays / Array pointers

int arr [] = {10, 20, 30};

① cout << arr;  $\longrightarrow$  A<sub>1</sub> }<sub>same</sub>  
cout << &arr;  $\longrightarrow$  A<sub>1</sub>

Pointers / Normal pointers

int \*ptr = arr;

① cout << ptr;  $\longrightarrow$  A<sub>1</sub> }<sub>diff.</sub>  
cout << &ptr  $\longrightarrow$  A<sub>4</sub>

② arr ++;  $\longrightarrow$  ERROR

② ptr ++;  $\longrightarrow$  VALID

③ sizeof(arr);  $\longrightarrow$  3\*4 = 12

③ sizeof(ptr)  $\longrightarrow$  8  
↓  
size of address

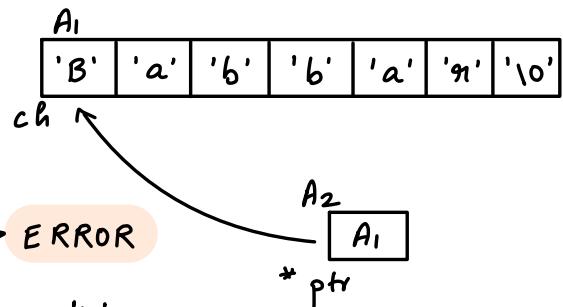
```
int * p1 = arr;
```

```
int * p2 = &arr; -----> ERROR
```

```
int * p3 = &arr[0];
```

## CHAR ARRAYS & POINTERS

```
char ch [] = "Babbar";
```



```
char * ptr = ch;
```

```
char * p = &ch; -----> ERROR
```

```
char * p2 = &ch[0]; -----> valid
```

```
cout << ch; -----> Babbar
```

not an address

```
cout << ptr; -----> Babbar
```

not an address

whole string from that  
location until NULL char

cout implementation

is diff. in char

pointers and char arrays

```
cout << &ch; -----> A1
```

```
cout << ch[0]; -----> B
```

```
cout << &ch[0]; -----> Babbar
```

```
cout << *ptr; -----> B
```

```
cout << &ptr; -----> A2
```

$$ch[i] \longleftrightarrow * (ch + i) \longleftrightarrow i[ch]$$

→  $ch$ ,  $\&ch[0]$ , and  $ptr$  values are addresses but due to diff. cout implementation in char pointers and char arrays,  
 $cout \ll ch$ ,  $cout \ll \&ch[0]$  and  $cout \ll ptr$  will give Babbar

`char ch[] = "Sherbano";`

`char *ptr = ch;`

`cout << ch ;` → Sherbano

`cout << *ch ;` → S

`cout << &ch ;` → A<sub>1</sub>

`cout << *(ch + 3);` → n

`cout << ptr ;` → Sherbano

`cout << &ptr ;` → A<sub>2</sub>

`cout << *(ptr + 3);` → n

`cout << ptr + 2;` → erbano

`cout << *ptr ;` → S

`cout << ptr + 8;` → " → NULL char

`cout << ptr + 9;` → gv

cout << ch[0];  $\longrightarrow$  S

cout << & ch[0];  $\longrightarrow$  Sherban

cout << &(\* ch);  $\longrightarrow$  Sherban

## CHAR AND POINTER

char ch = 'k';

char \* ptr = &ch;

cout << ch;  $\longrightarrow$  k

cout << & ch;  $\longrightarrow$  k.....

$\begin{cases} \rightarrow \text{gv} \\ \rightarrow \text{print until it gets '\0'} \end{cases}$

cout << ptr;  $\longrightarrow$  k.....

cout << & ptr;  $\longrightarrow$  A<sub>2</sub>  $\begin{cases} \rightarrow \text{gv} \\ \rightarrow \text{print until it gets '\0'} \end{cases}$

cout << \* ptr;  $\longrightarrow$  k

## Behind The Scenes

char ch[10] = "Babber";

$\longrightarrow$  2 step process

① 

'B'	'a'	'b'	'b'	'a'	'r'	'\0'
-----	-----	-----	-----	-----	-----	------

temp memory  $\downarrow$  copy

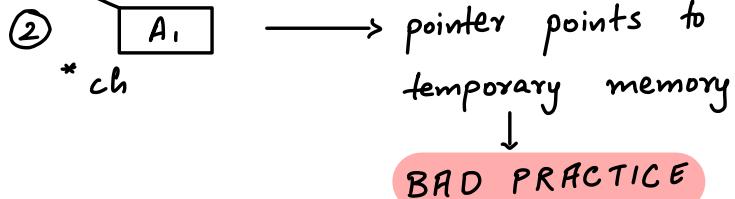
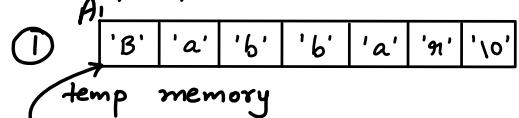
② 

'B'	'a'	'b'	'b'	'a'	'r'	'\0'	gv	gv	gv
-----	-----	-----	-----	-----	-----	------	----	----	----

ch

char \* ch = "Babbar"

→ 2 step process



## POINTERS WITH FUNCTIONS

→ pass by value

a copy of pointer is made

→ but simulates pass by reference

→ as in case of arrays & functions

→ pointer is passed

int func ( int arr[]){

cout << arr; → A1

cout << \*arr; → 10

cout << &arr; → A2

cout << sizeof(arr); → 8

A2  
A1  
\*arr

copy of pointer  
is created

```
int func2 ( int * arr ) {
```

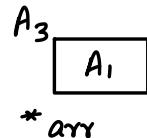
→ pointer is passed

```
cout << arr; → A1
```

```
cout << * arr; → 10
```

```
cout << &arr; → A3
```

```
cout << sizeof(arr); → 8
```



copy of pointer  
is created

```
}
```

```
int main() {
```

```
int arr [ 5 ] = { 10, 20 }; arr
```

```
cout << arr; → A1
```

```
cout << * arr; → 10
```

```
cout << &arr; → A1
```

```
cout << sizeof(arr); → 5 * 4 = 20
```

```
func ( arr );
```

```
func ( arr 2 );
```

```
return 0;
```

```
}
```



→ whole array will not pass

→ only array pointer / base address will pass

→ pass by reference for array

→ copy of pointer pointing to base address will be created

```

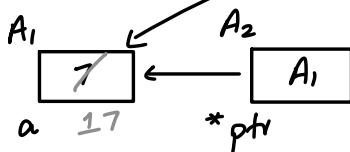
int main() {
    int a = 7;
    int * ptr = &a;
    update (ptr);
    return 0;
}

```

```

void update ( int * p ) {
    ① * p = * p + 10;
    ② p++;
}

```



$$\begin{aligned}
 *p &= A_3 \\
 *A_1 &= *A_1 + 10 \\
 *A_1 &= 7 + 10 = 17 \\
 a &= 17
 \end{aligned}$$

## Function to Pointers in HW

### Basic Mathematics for DSA

W6-L3 R

### Sieve of Eratosthenes Theorem

→ to find no. of prime numbers between 1 &  $n$

Steps-

- make an array of size  $n$  and mark them all as primes from 2 to  $n$
- Start from 2 till end, mark all no.  $> 2$  comes in the table of 2 as non prime
- Do above step for numbers 2 to  $< n$  if they are marked prime
- Count all remaining marked prime numbers

seive

```

int countPrimes ( int n) {
    if (n <= 1)
        return 0;
    vector <int> isPrime (n, true);
    isPrime [0] = isPrime [1] = 0; // making both 0

```

```
int ans = 0;
```

```
for( int i=2 ; i<n ; i++) {
```

```
    if ( isPrime [i]) {
```

```
        ans ++;
```

```
        for( int j= 2*i ; j<n ; j+= i)
```

```
            isPrime [j] = false;
```

```
}
```

```
}
```

```
return ans;
```

```
}
```

$i \neq i < n$

→ to optimize T.C.  
as  $2i$  to  $(i-1)*i$  are  
already marked when  
 $i = 2$  to  $(i-1)$

TC -  $O(n * \log(\log n))$

SC -  $O(n)$

$$n \left[ \frac{n}{2} + \frac{n}{3} + \frac{n}{5} + \frac{n}{7} + \frac{n}{11} + \dots \right]$$

$$n^2 \left[ \frac{1}{2} + \frac{1}{3} + \frac{1}{5} + \frac{1}{7} + \frac{1}{11} + \dots \right]$$

$$n \log(\log n)$$

Same with **segmented sieve** → having high & low

## GCD/HCF and LCM

→ Greatest Common Divisor

$$\rightarrow \text{gcd}(a, b) = \text{gcd}(a - b, b) \quad a > b$$

$$\text{gcd}(a, b) = \text{gcd}(b - a, a) \quad b > a$$

$$\text{gcd}(a, b) = \text{gcd}(a \% b, b) \quad a > b$$

$$\text{gcd}(a, b) = \text{gcd}(b \% a, a) \quad b > a$$

takes more time bcz of \% op.

Use first method as \% is heavy operator and computer takes more time

→ Euclid Algorithm

Apply above formula till one of the parameter becomes 0

And other one will be GCD

```
int gcd( int a, int b ) {
```

```
    if (a == 0)
```

```
        return b;
```

```
    else if (b == 0)
```

```
        return a;
```

```
    while (a > 0 & & b > 0) {
```

```
        if (a > b)
```

```
            a = a - b;
```

```
        else
```

```
            b = b - a;
```

```
}
```

```
}
```

```
    return (a == 0) ? b : a;
```

TC -  $O(\min(a, b))$

## LCM

$$\text{lcm} * \text{gcd} = a * b$$

$$\text{lcm} = \frac{a * b}{\text{gcd}}$$

## Modulo Arithmetic

$$\rightarrow a \% n \rightarrow [0, n)$$

$$\rightarrow (a + b) \% n = (a \% n) + (b \% n)$$

$$(a - b) \% n = (a \% n) - (b \% n)$$

$$(a * b) \% n = (a \% n) * (b \% n)$$

$$(\dots ((a \% n) \% n) \dots \% n) = a \% n$$

## Fast Exponentiation

$$\rightarrow a^b = a^{b/2} * a^{b/2} , \quad b \text{ is even}$$

$$a^b = [a^{b/2} * a^{b/2}] * a , \quad b \text{ is odd}$$

```
int fastExponentiation ( int a, int b){  
    int ans = 1;  
    while (b){  
        if (b & 1)  
            ans = ans * a;  
        a = a * a;  
        b >>= 1; // b = b >> 1 or b = b / 2  
    }  
    return ans  
}
```

dry run code on  $2^5$ , if confusion

T.C. -  $O(\log n)$

Learn wild, void and dangling pointers from dashboard  
after learning dynamic allocation

# MULTI LEVEL POINTER

W6-L4

int a = 5;

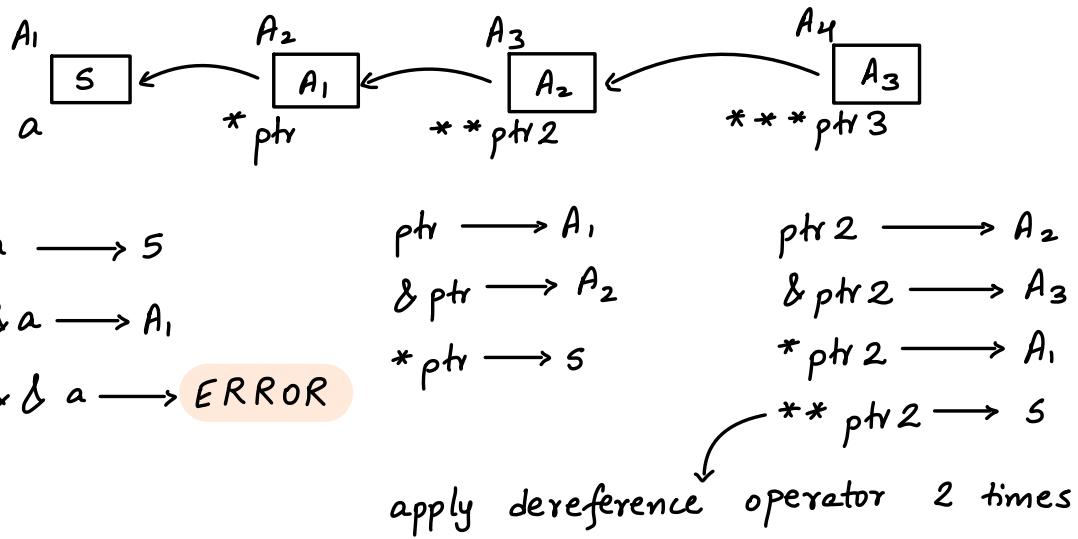
int \*ptr = &a;

int \*\*ptr2 = &ptr  $\longrightarrow$  double pointer

$\longrightarrow$  ptr2 is a pointer to int \* data

int \*\*\*ptr3 = &ptr2;

$\longrightarrow$  ptr3 is a pointer to int \*\* data



ptr3  $\longrightarrow$  A3

\*\*\*ptr3  $\longrightarrow$  A1

&ptr3  $\longrightarrow$  A4

\*\*\*ptr3  $\longrightarrow$  5

\*ptr3  $\longrightarrow$  A2

```

int main(){
    int a = 5;
    int * ptr = &a;
    int ** ptr2 = &ptr;
    func( ptr2 );
    return 0;
}

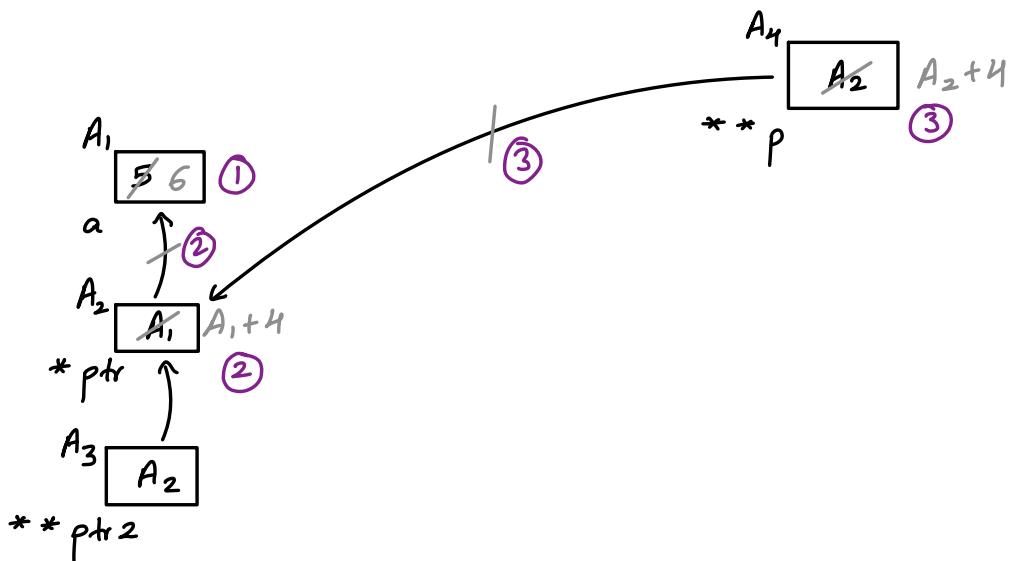
```

```

void func( int ** p ){
    ① (** p) ++ ;
    ② (* p) ++ ;
    ③ p ++ ;
}

```

both are same



```

int a = 5;
int * p = &a;
int ** q = p; -----> ERROR

```

## REFERENCE VARIABLE

- alternate of pointers
- diff. names of same variable
  - same memory location
- only new entry in symbol table,  
no other memory will allocate
- can access a variable by diff. names

int a = 5;

int &b = a;

A<sub>1</sub>

5

a, b

Symbol Table

a	A <sub>1</sub>
b	A <sub>1</sub>

## Use Case

- reference variable can't be set to NULL  
pointers can be set to NULL  
So more safety in reference variable  
Always points to valid object / variable
- pointers are difficult to understand,  
more readability in reference variable
- generally used to implement **PASS BY**  
**REFERENCE** concept

# PASS BY REFERENCE

- reference variable passes in function
- does not create copy

```
int main () {  
    int a = 5;  
    update (a);  
    update2 (&a);  
    int *ptr = &a;  
    //update3 (&a); → ERROR  
    update3 (ptr);  
    return 0;  
}
```

```
void update( int &x){
```

①  $x++$ ;

}

PASS BY  
REFERENCE

```
void update2( int * p){
```

②  $(*p)++$ ;

}

PASS BY  
VALUE

$A_2$

$A_1$

$*p$

$A_1$

5

$a, x$

1

6 → 7 → 8  
2 3

$A_3$

$A_1$

$*ptr$

```
void update3( int * &pt){
```

③  $(*pt)++$ ;

}

$A_4$

$A_1$

$*pt$

```

vector<int> func( vector<int> &arr) {
    for (int i=0; i < arr.size(); i++)
        arr[i]++;
    return arr;
}

```

int solve ( int & arr ) { this is reference variable of type int

```

} int solve (int & arr[ ])

```

```

int main () {

```

```

vector<int> arr { 1, 2, 3, 4 };

```

```

vector<int> ans = func(arr);

```

```

for ( auto i: ans)

```

```

    cout << i; —————> 2 3 4 5

```

array of reference is not allowed

solv1( arr ); —————> ERROR vector != int

```

int arr2 [ ] = { 1, 2, 3 };

```

solve( arr2 ); —————> ERROR int[3] != int

```

return 0;
}

```

# RETURN BY REFERENCE

→ return a variable, not a value

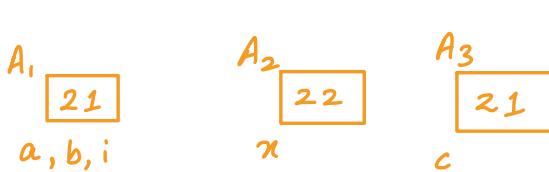
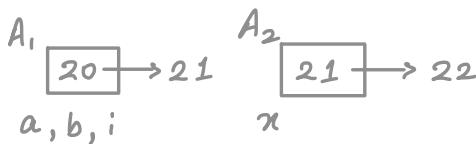
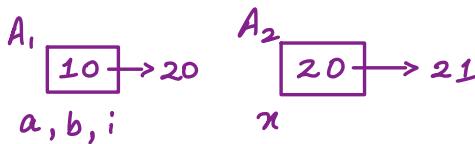
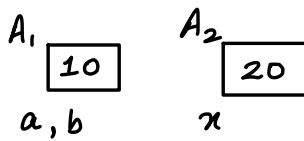
→ To implement atleast 1 of 2 conditions must be true.

1. passing a reference variable
2. passing a global variable

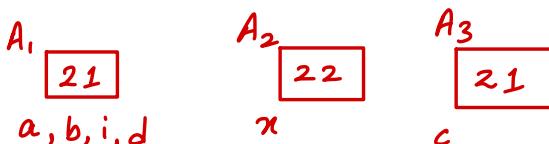
passing a reference variable

```
int main (){  
    int a = 10;  
    int & b = a;  
    int x = 20;  
    ref(a) = x;  
    x++;  
    ref(b) = x;  
    x++;  
    int c = ref(a);  
    int &d = ref(a);  
    return 0;  
}
```

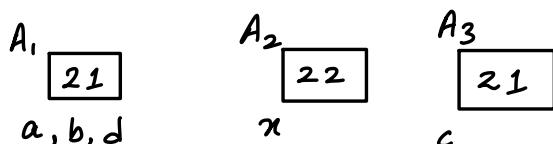
```
int & ref( int & i){  
    return i;  
}
```



`int c = ref(a) = i;`  
`int c = 21;`



`int &d = ref(a) = i;`  
`int &d = i;`



## passing a global variable

```
int x = 5;
```

```
int main () {
```

```
    ref () = 10;
```

$x = 10$

```
    ref2 () = 20; → ERROR
```

```
    return 0;
```

```
}
```

```
int & ref () {
```

```
    return x;
```

```
}
```

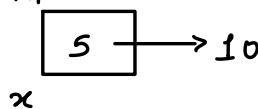
```
int ref2 () {
```

```
    return x;
```

```
}
```

returning a value, not variable

A,



$10 = 20$ ;

↳ that's why ERROR

## pass by value but return by reference

```
int main () {
```

```
    int a = 10;
```

BAD PRACTICE

```
    int & b = a;
```

```
    int x = 20;
```

```
    ref (a) = x;
```

```
    x++;
```

```
    ref (b) = x;
```

```
    x++;
```

```
int & ref ( int temp ) {
```

```
    return temp;
```

```
}
```

returning a variable stored  
in temporary memory

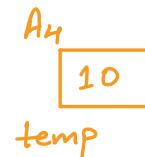
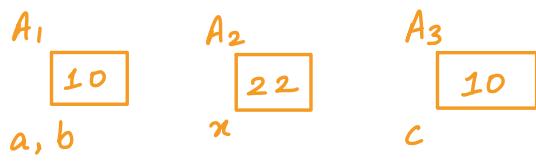
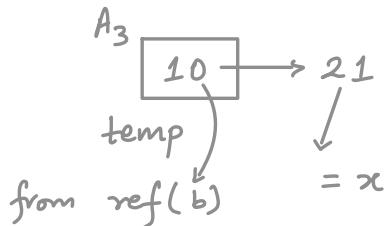
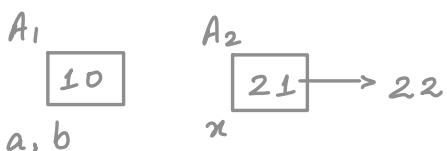
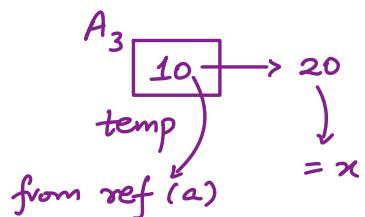
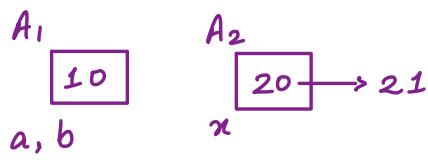
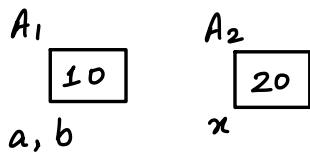
ERROR

```

int c = ref(a);
int &d = ref(a);
return 0;
}

```

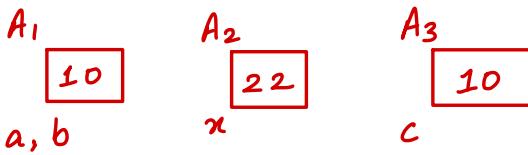
lets assume it will run, then this would happen



```

int c = ref(a) = temp;
int c = temp;
int c = 10

```



d (variable of main function refers to  
a temporary memory

→ BAD PRACTICE

DON'T DO THIS  
AT HOME

Have similarity

IMP QUESTION

```
int main () {
    int * ptr = solve ();
    return 0;
}
```

A2

A1

\* ptr

```
int * solve () {
    int a=5;
    int * p = &a;
    return p;
}
```

A1

a

A3

A1

\*p

pointing to a temp  
memory, 'a' variable  
will finished outside  
solve function so value  
of 'a' can be change with time

→ BAD PRACTICE

## Some Important Questions

W6-A

→ `int *ptr = 0;`  
`int a = 10;`  
`*ptr = a; -----> runtime ERROR`  
`cout << *ptr;`

→ `char *ch = 'a';`  
`char *ptr = &a;`  
`ch++;`  
`cout << *ptr; -----> 'b'`

→ `int a[] = {1, 2, 3, 4, 5};`

`int *p = a++; -----> ERROR`

`cout << *p;`

→ pointer of static variables  
are constant pointers

→ pointer of dynamic  
memory allocation variables  
can be change

→ `char ch = "hello";`  
`cout << ch; -----> hello`  
`ch++; -----> ERROR`  
`cout << ch;`

name of array refers  
to base address

→ double arr [] = { 2.5, 7.9, 50.25 } ;

double \* ptr = arr ;

ptr = ptr + 0.25 ; → ERROR

cout << ptr ;

→ pointer arithmetic op-  
can only be done  
using integers

→ int arr [] = { 1, 2, 3, 4, 5 } ;

int \* ptr1 = arr ;

int \* ptr2 = arr + 3 ;

cout << ptr2 - ptr1 ; → 3, NOT 12

→ int a = 5 ;

int \* ptr = &a ;

int \*\* ptr2 = &ptr ;

ptr2 = &a ; → ERROR → int \*\* cant convert

cout << \*ptr2 ; to int \*

→ int a = 5 ;

int \* p = &a ;

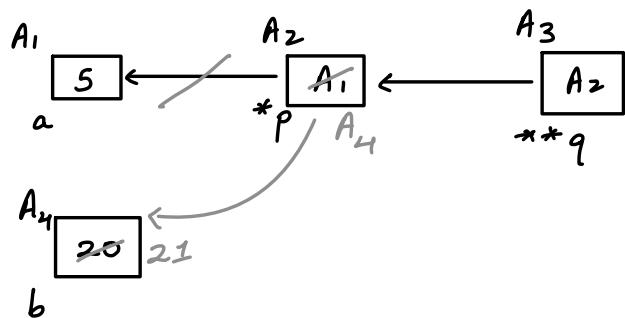
int \*\* q = &p ;

int b = 20 ;

\* q = &b ;

(\*p)++ ;

cout << a << ' ' << b ; → 5 21



→ int a = 5;

int \* ptr = &a;

int \*\* ptr2 = &ptr;

int \*\* ptr3 = &(&a); → ERROR

cout << \*\* ptr3;

address of (address in  
memory location)

(doesn't make any sense)

W6-L5

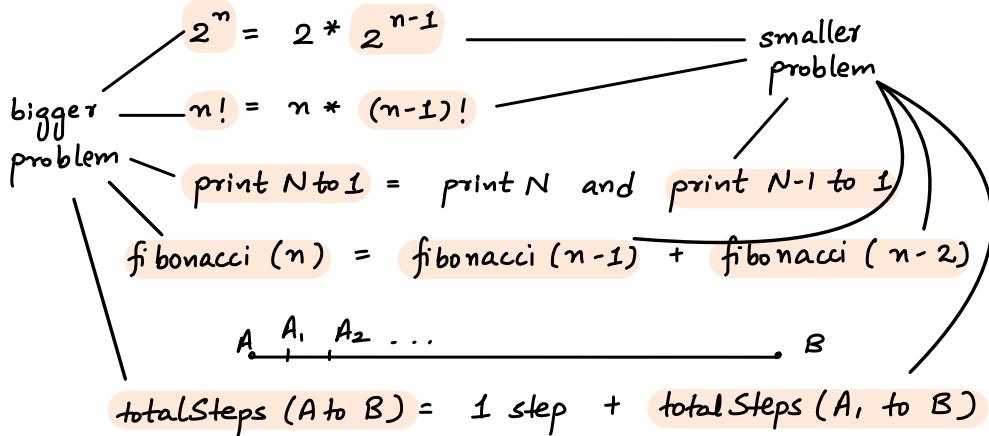
POITER IMP DOUBT

(IN DASH BOARD)

# RECURSION

W7-L1

- When a function calls itself
- When sol. of bigger problem depends on similar smaller problem (s)



## Components of Recursion

- Base Case / Stopping cond. → return statement
- Recurrence Relation (recursive call)
- Processing → optional

## Head Recursion

- recurrence relation before processing

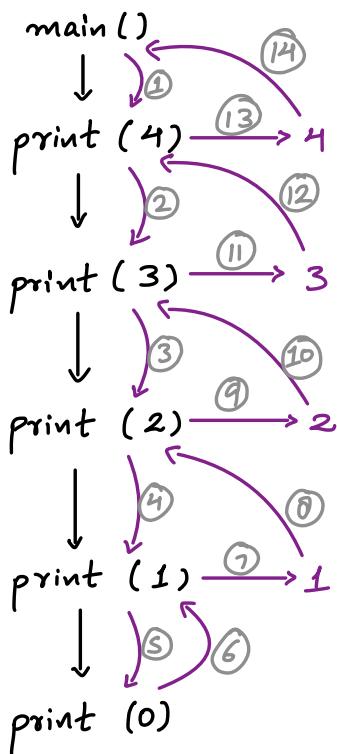
## Tail Recursion

- recurrence relation after processing

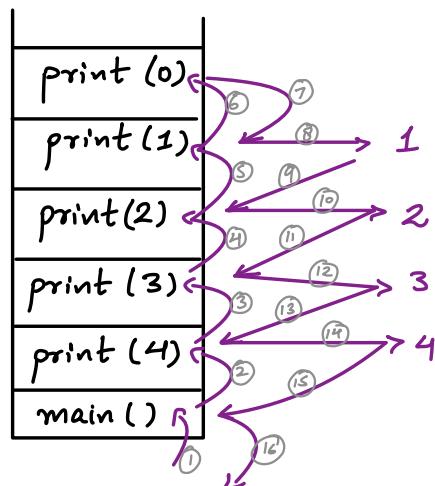
```
int main () {
    int n = 4;
    print (n);
    return 0;
}
```

```
void print ( int n) {
    // base condition
    if ( n == 0)
        return;
    // recurrence relation
    print (n-1);
    // processing
    cout << n;
}
```

### Recursion Tree



### Call Stack



Output - 1 2 3 4

```

int main(){
    int n = 4,
    int ans = fib(n);
    cout << ans;
    return 0;
}

```

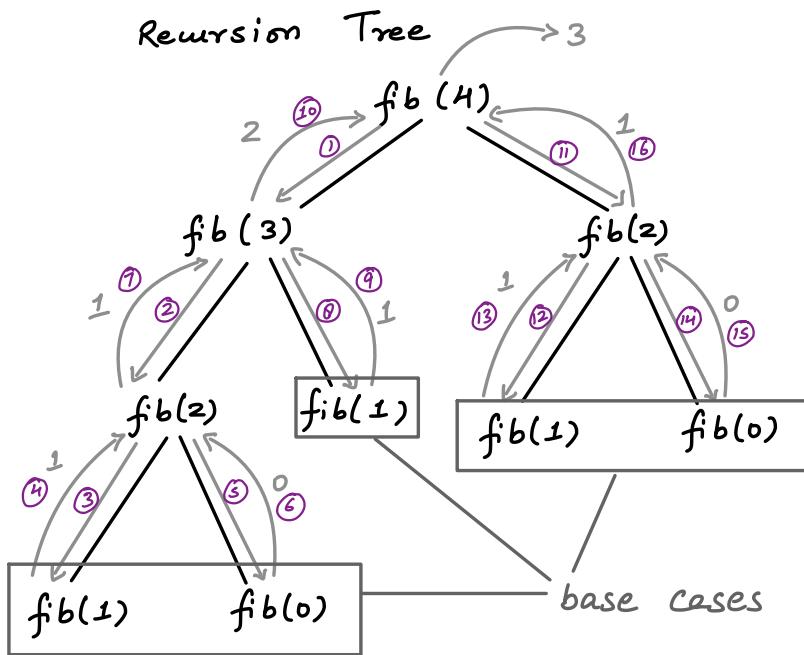
```

int fib( int n){
    if( n == 0 || n == 1)
        return n;
    return fib(n-1) + fib(n-2);
}

```

$n \rightarrow 0 \ 1 \ 2 \ 3 \ 4$

$\text{fib}(n) \rightarrow 0 \ 1 \ 1 \ 2 \ 3$



Magical line for Recursion

Ek case solve krdo, baaki recursion sambhal lega

Just believe on it, dont doubt on recursion

→ func ( vector <int> arr, int i, int &ans)

W7-L2

pass by reference

if we want to retain value of ans after function call

→ Try to pass everything by reference IF POSSIBLE

└→ SC Yes

TC Yes (no copying of variables again & again)

→ to reverse answer, you can use recursion

Integer literal with a leading 0

`n = 0100;` → interpreted as an octal number

`cout << n;` → 64 → convert 0100 octal to decimal

`cin >> n;` → (0100)

`cout << n;` → 100 → no conversion as  
cin reads 0100 as 100

Entry in function call stack

W7-L3

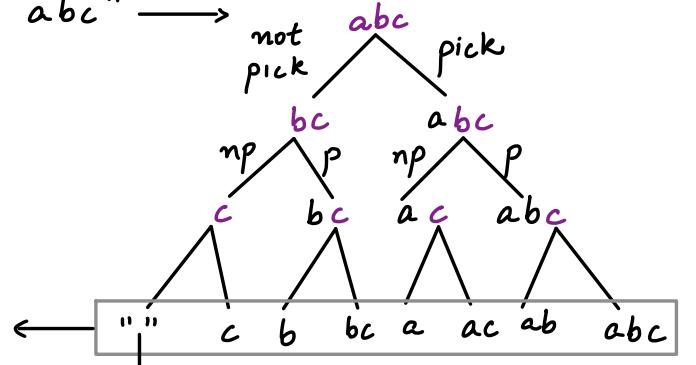
└→ Computer has track of variables of that function about their memory location and all in symbol table

→ Expression can't be pass by reference

## Subsequences

→ Made by either including or excluding every element, but order remains same

→ ex- "abc" →



subsequences of string "abc"

→  $2^n$ ,  $n \rightarrow$  length of string

## Arithmetic Operations on Strings

`s1 = "Ujjwal";`

`s2 = "2327";`

`cout << "Ujjwal" + "2327";` → ERROR

`s1 = s1 + s2;`

`cout << s1;` → "Ujjwal2327" → Concatenate

`-, *, /, %` → NOT VALID in strings

## Coin change problem

W7-L4

→ find min. coins equivalent to given amount

```
int coinChange( vector<int> arr, int amount) {  
    if (amount == 0)  
        return 0;  
    if (amount < 0)  
        return INT_MAX; // means INVALID or  
                           // cant be changed  
    int mini = INT_MAX;  
    for (int i=0; i<arr.size(); i++) {  
        mini = min (mini, coinChange (arr, target - arr[i]));  
    }  
    // now min. coins req. has been found  
    if (mini == INT_MAX)  
        return INT_MAX; // means INVALID or  
                           // cant be changed  
    else  
        return mini + 1;  
}
```

Type 1: inclusion exclusion pattern → for using  
either this or that subsequence questions

Type 2 - for loop in recursion

→ If the recursion ques seems tough, use void function and pass ans by reference in function

## TC & SC of Recursive Solutions

W7-R

T.C. → Can be found by recursive relation or recursive tree

S.C. → found using max depth of function call stack  
└→ max space used in any particular time instant in function call stack

### Linear Search

$$f(n) = k + f(n-1) \quad \text{Base case} \rightarrow \text{for } n=0$$

Recursive Relation Method -

$$T(n) = k + T(n-1)$$

$$T(n-1) = k + T(n-2)$$

.

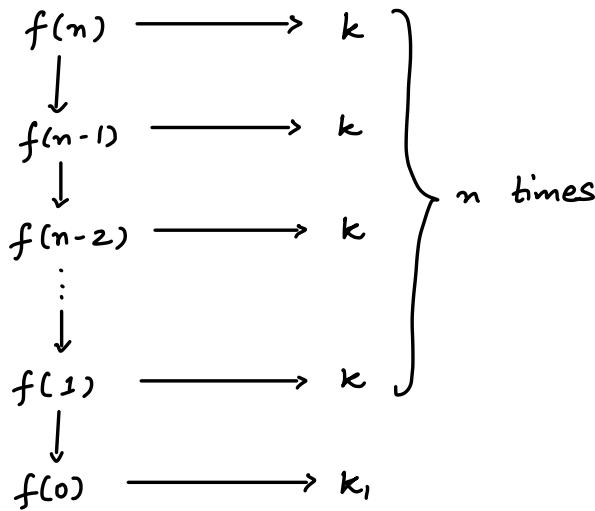
$$T(0) = k,$$

$$T(n) = nk + k,$$

$$T(n) = O(n)$$

T.C -  $O(n)$

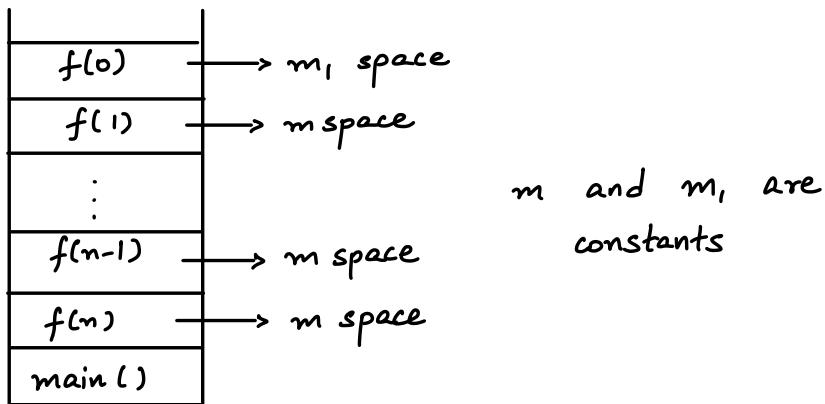
## Recursive Tree Method - Best method



$$T(n) = nk + k_1$$

$$T(n) = O(n)$$

## Space Complexity -



$$SC = mn + m_1$$

$$SC = O(n)$$

→ max depth

## Binary Search

$$f(n) = k + f(n/2); \quad \text{base case} \rightarrow \text{for } n=0$$

## Recursive Relation Method

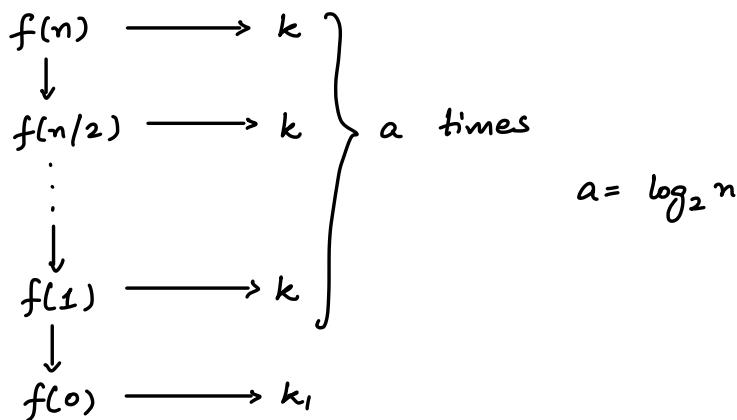
$$\begin{aligned} T(n) &= k + T(n/2) \\ T(n/2) &= k + T(n/4) \\ &\vdots \\ T(1) &= k + T(0) \\ T(0) &= k_1 \end{aligned} \quad \left. \begin{array}{l} \\ \\ \\ \end{array} \right\} a \text{ times} \quad a = \log_2 n$$

$$T(n) = a k + k_1$$

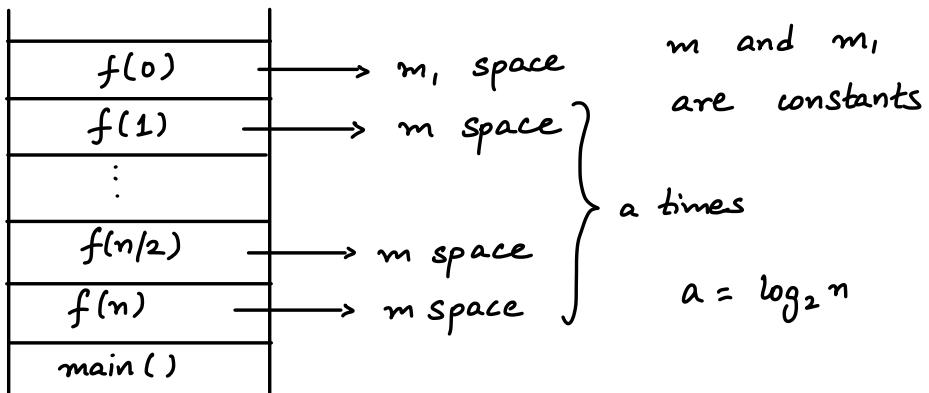
$$T(n) = k \log_2 n + k_1$$

$$T(n) = O(\log_2 n)$$

## Recursive Tree Method



## Space Complexity -



$$SC = m \log_2 n + m_1$$

$$SC = O(\log_2 n)$$

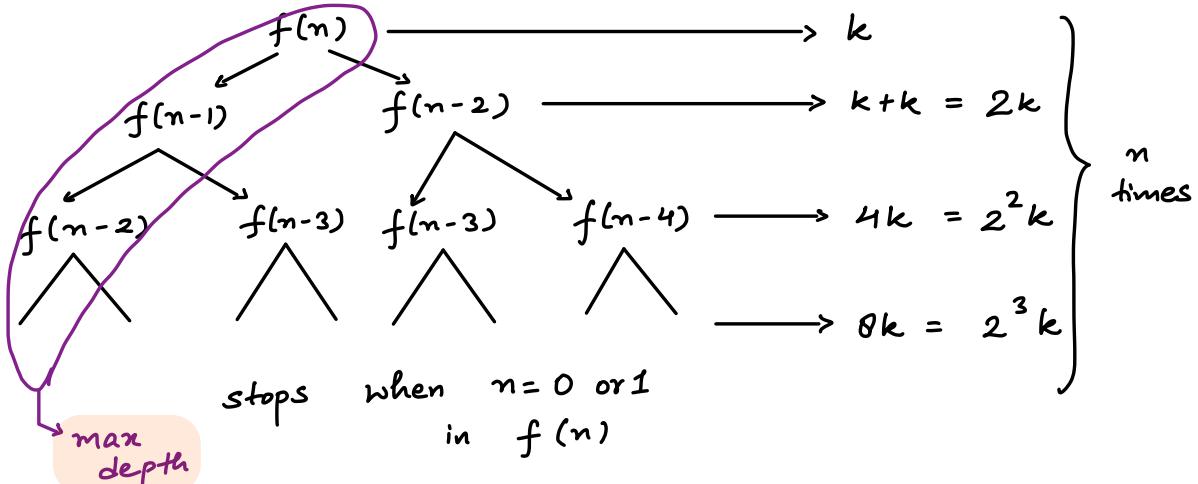
max depth

## Fibonacci Series

$$f(n) = k + f(n-1) + f(n-2)$$

base case  $\rightarrow$  for  $n=0$  or  $1$

## Recursive Tree Method



$$T.C \leq [k + 2k + 2^2k + \dots + 2^{n-1}k]$$

$$T.C. \leq k * [1 + 2 + 2^2 + \dots + 2^{n-1}]$$

$$T.C \leq k * (2^n - 1)$$

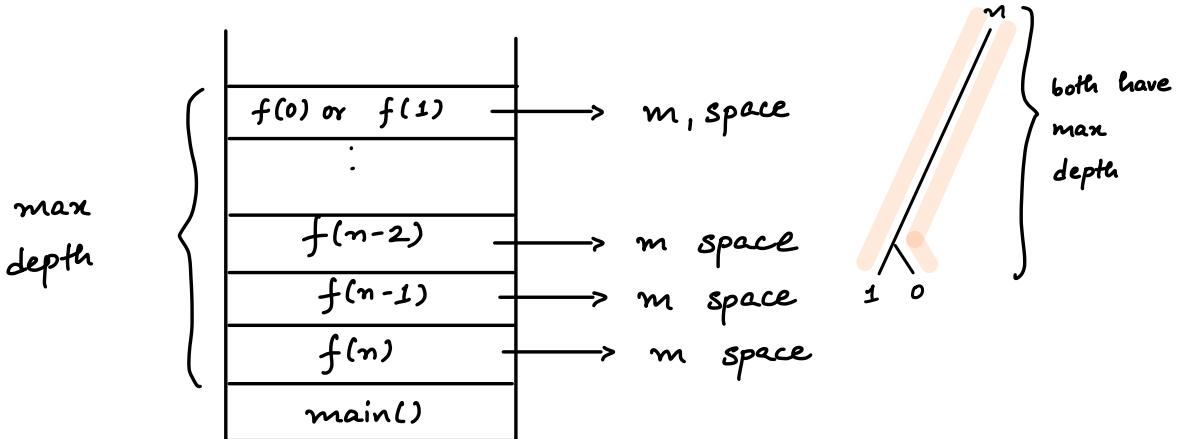
$$T.C = O(2^n)$$

assume  
for simplicity  
and for large  
numbers

→ exponential TC

→ very bad

## Space Complexity



$$SC = m(n-1) + m,$$

$$SC = O(n)$$

→ max depth

if this is such a case

fun(0)	→ $n^3$ space / time
fun(1)	→ $n^2$ space / time
:	
fun(n-1)	→ $n$ space / time
fun(n)	→ $k$ space / time
main()	

$$S.C. - n * n^3$$

↳ max SC in any call

$$T.C. - n * n^3$$

↳ max T.C. in any call

## Divide & Conquer

→ using recursion

W8-L1

## Merge Sort

- Divide the array in 2 halves
- Sort them
- Merge those 2 sorted subarrays

## Standard Merge Sort

```
void merge( vector <int> &arr, int s, int e) {  
    int mid = e - (s + e) / 2;  
    int len1 = s - mid + 1;  
    int len2 = e - mid;  
    vector <int> left (len1);  
    vector <int> right (len2);  
    int i = 0, j = 0, k = s;  
    while (i < len1)  
        left [i++] = arr [k++];  
    while (j < len2)  
        right [j++] = arr [k++];  
    i = 0, j = 0, k = s;
```

```

while ( i < len1 & & j < len2 ) {
    if ( left [ i ] <= right [ j ] )
        arr [ k ++ ] = left [ i ++ ];
    else
        arr [ k ++ ] = right [ j ++ ];
}
while ( i < len1 )
    arr [ k ++ ] = left [ i ++ ];
while ( j < len2 )
    arr [ k ++ ] = right [ j ++ ];
}
void mergeSort ( vector < int > & arr, int s, int e ) {
    if ( s >= e )
        return ;
    int mid = s + ( e - s ) / 2 ;
    mergeSort ( arr, s, mid );
    mergeSort ( arr, mid + 1, e );
    merge ( arr, s, e );
}

```

due to copy in every level

→ in best case too →

T.C. -  $O(n \log n)$  → number of levels

S.C. -  $O(n)$  →  $(n + \frac{n}{2} + \frac{n}{4} + \frac{n}{8} + \dots \text{ till } 1)$

IMPLEMENT MERGE SORT - GFG

## Quick Sort

## W8-L2

→ Partition

Choose one element named pivot and put it on its correct position

Put elements less than pivot in left subarray and otherwise in right subarray

→ Sort left & right subarrays recursively

```
int partition( vector <int> &arr, int s, int e){  
    int pivotIndex = s; —————> This is one way  
    int pivot = arr[s]; Other ways - choose last  
- choose random  
    int cnt = 0; ↓  
randomised  
quick sort  
    for( int i=s+1; i<=e ; i++ ) {  
        if( arr[i] > pivot )  
            cnt++;  
    }  
    int correctPosition = s + cnt;  
    swap( arr[pivotIndex], arr[correctPosition] );  
    pivotIndex = correctPosition
```

```

int i=s, j=e;
while( i < correctPosition && j > correctPosition) {
    while( arr[i] < pivot)
        i++;
    while( arr[j] >= pivot)
        j--;
    if( i < correctIndex && j > correctIndex)
        swap( arr[i++], arr[j--]);
}
return correctPosition;
}

void quickSort( vector <int> &arr, int s, int e) {
if( s >= e)
    return;
int p = partition( arr, s, e);
quickSort( arr, s, p-1);
quickSort( arr, p+1, e);
}

```

T.C. -  $O(n \log n)$   $\longrightarrow$  log<sub>n</sub> number of function calls

$O(n^2)$   $\longrightarrow$  for both ascending & descending sort

S.C. -  $O(n)$   $\longrightarrow$   $n$  number of function calls

## Backtracking

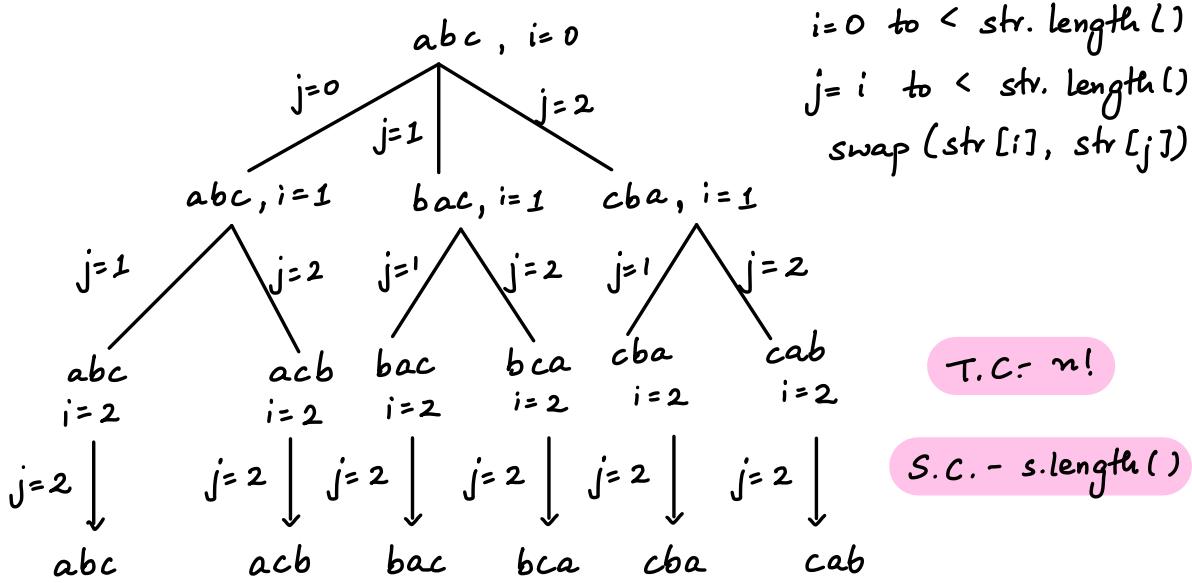
- specific form of recursion
  - explore all possible solutions and
  - don't check the solution you have already discarded
  - brute force
  - used for reference variables passed in functions

## Permutation in a string

$s = "abc"$  permutations -  $abc, acb, bac, bca,$

permutations -  $abc, acb, bac, bca,$   
|  $cab, cba$

$\rightarrow$  total -  $n!$



## Time Complexity

W8-L7

- max time required by an algorithm as a function of input
  - for worst case
- number of calls \* T.C. - time in 1 call
- T.C. - total time in 1 level \* number of levels

## Space Complexity -

- max space taken by an algorithm at any particular instant
- S.C. - space in 1 call \* max depth

→ Remember min space and time can be  $O(1)$  not  $O(0)$

## Type 1 Linear Tree

fun (n) {

    Base Case

    Processing

    fun (n-1)

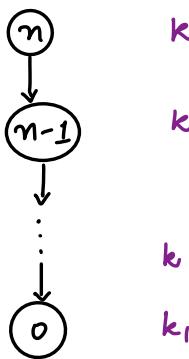
}

$k_1$   
 $k_2$

$\} k$

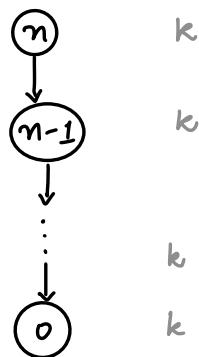
→ pass by value  
1 variable  $n$  is created

→ pass by reference  
min space is constant



T.C. -  $nk + k$ ,

T.C. -  $O(n)$

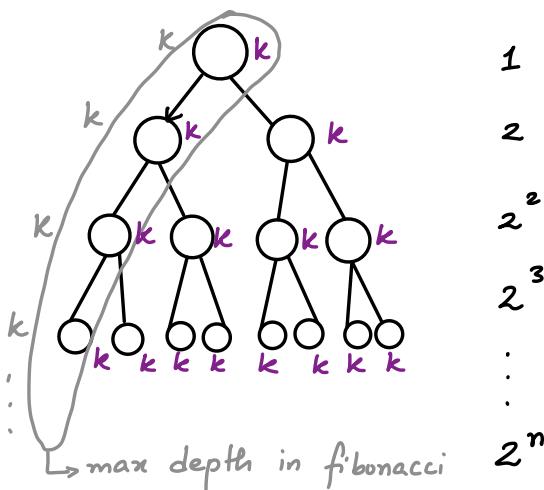


S.C. -  $(n+1)k$

S.C. -  $O(n)$

Counting  
factorial  
power of 2  
check sorted  
max in array  
min in array

## Type 2 Non Linear Tree



$$T.C. = k + 2k + 4k + \dots + 2^n k$$

T.C. =  $O(2^n)$

S.C. =  $nk$

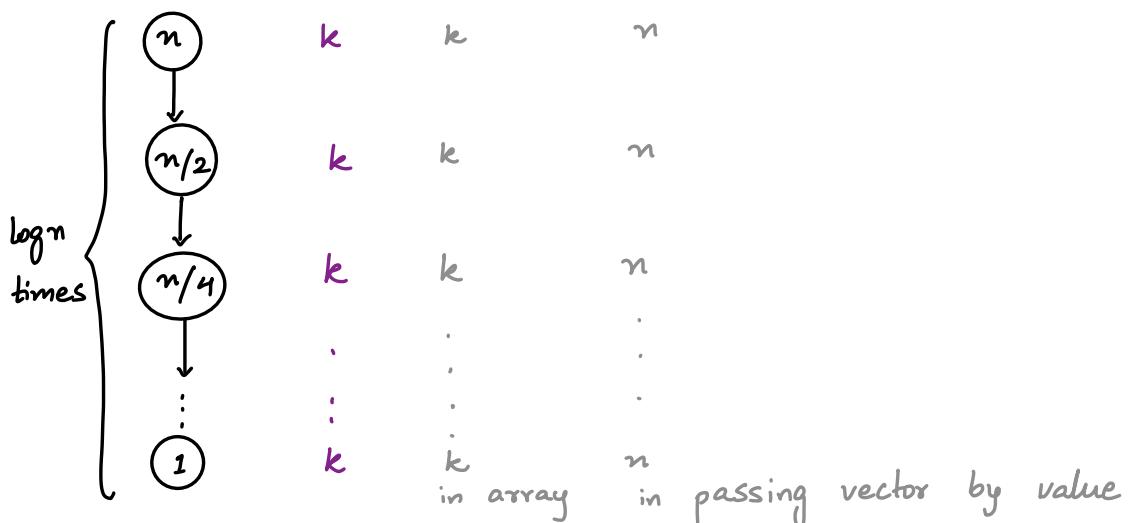
S.C. =  $O(n)$

fibonacci

jump stairs

subsequences

### Type 3 Logarithmic



T.C. =  $\log n * k$

S.C. =  $\log n * k$

S.C. =  $\log n * n$

T.C. =  $O(\log n)$

S.C. =  $O(\log n)$

S.C. =  $n \log n$

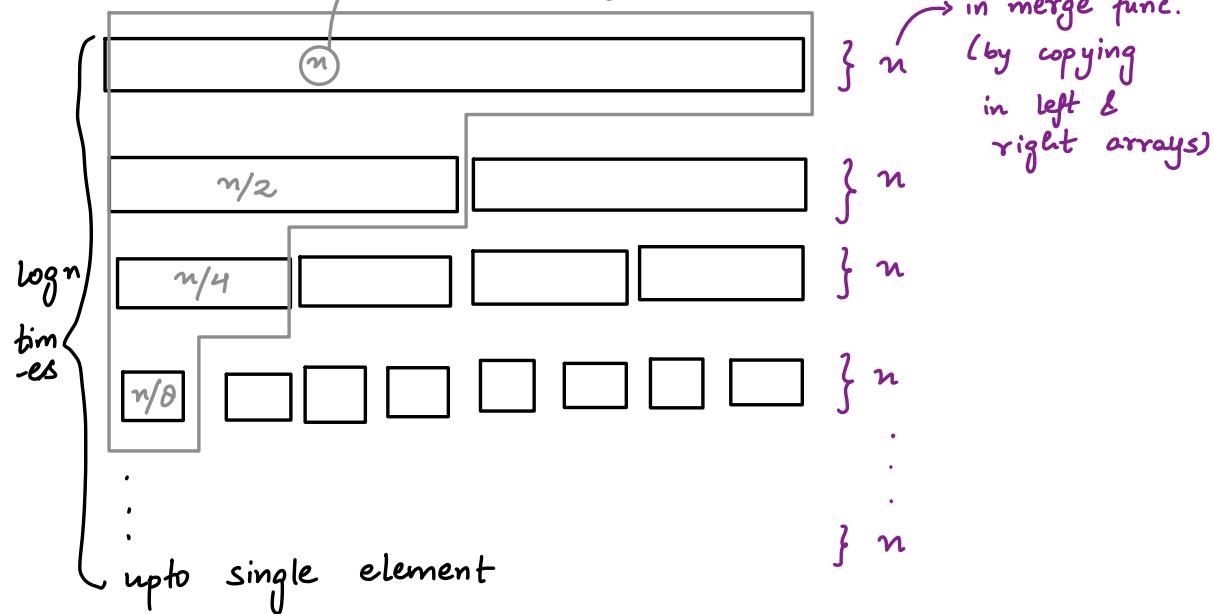
binary search

array / vector  
pass by reference

vector pass  
by value

## Merge Sort

in merge func. (in copying in left & right arrays)



T.C - time in 1 level \* number of levels

T.C. -  $n * \log n$

T.C. -  $O(n \log n)$

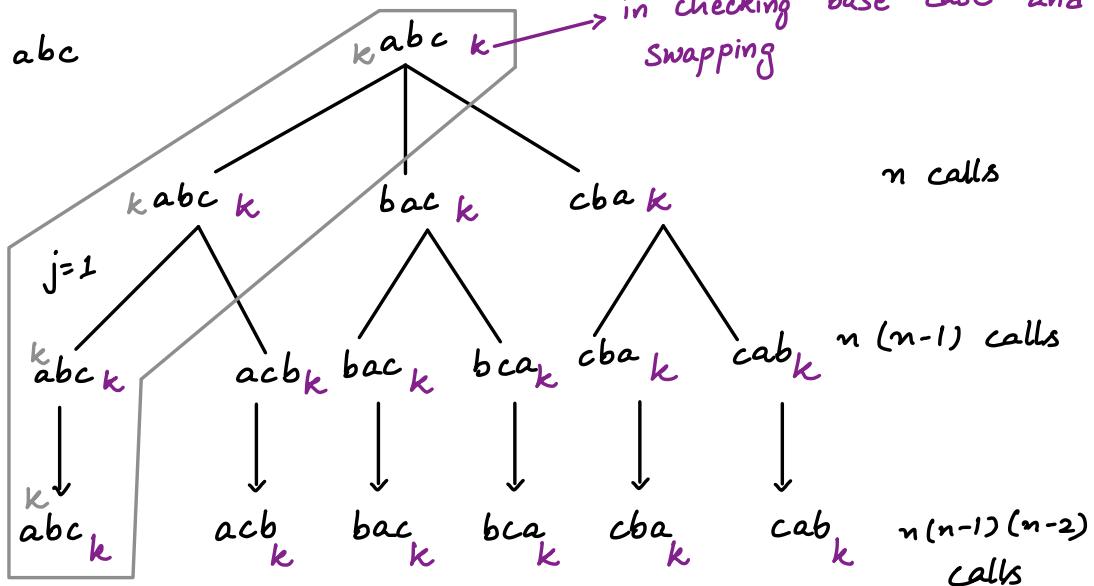
S.C. -  $n + \frac{n}{2} + \frac{n}{4} + \dots + 2$

S.C. -  $O(n)$

## Backtracking Questions

### Permutations of a String

$s = abc$



$$T.C. - k + nk + n(n-1)k + n(n-1)(n-2)k + \dots + n!k$$

$$T.C. - O(n!)$$

$$S.C. - n^* k$$

$$S.C. - O(n)$$

## Rat in a maze

$m$  rows

$n$  cols

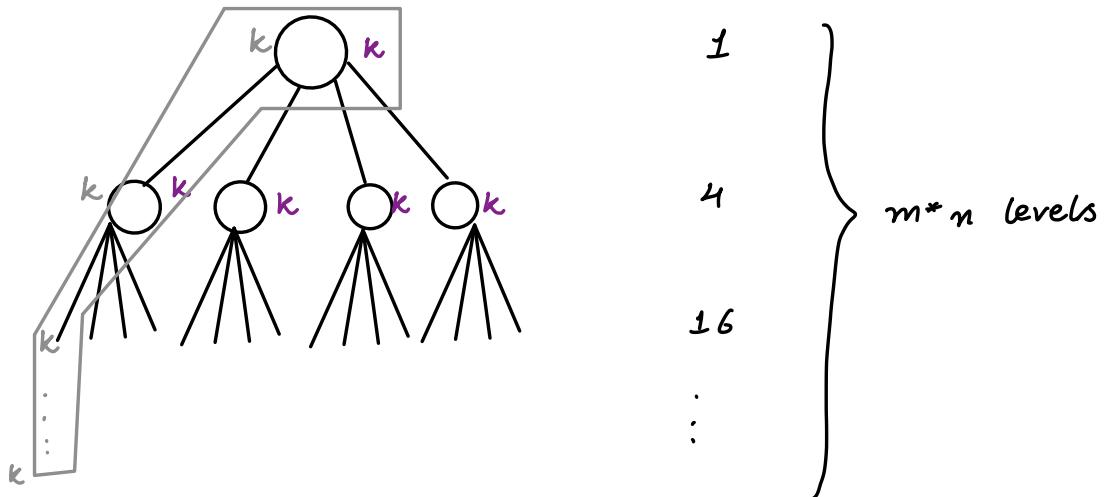
func( )

base case

4 recursive calls

↳ down, left, right, up

}



$$T.C. - k + 4k + 4^2k + \dots + 4^n k$$

$$T.C. - O(4^{mn})$$

S.C. -  $k * mn$   $\xrightarrow{\text{depth}}$  of visited 2D array &  $mn$   $\xrightarrow{\text{pass by reference}}$

$$S.C. - O(m * n)$$

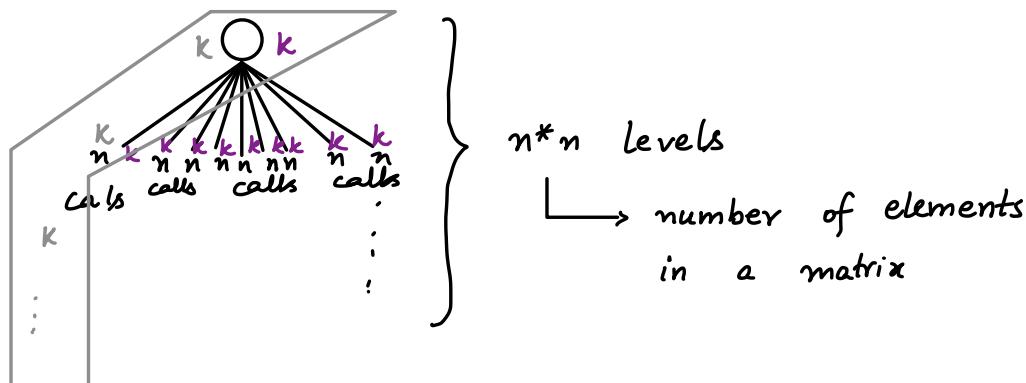
## Sudoku Solve

$n \times n$  matrix

standard

$$\hookrightarrow n = 9$$

```
func() {
    base case
    n recursive calls + isSafe func.
}
```



$$T.C. - k + kn + kn^2 + \dots kn^{n^2}$$

$$T.C. - O(n^{n^2})$$

$$S.C. - k * \overbrace{(n^2)}^{\text{depth}}$$

$$S.C. - O(n^2)$$

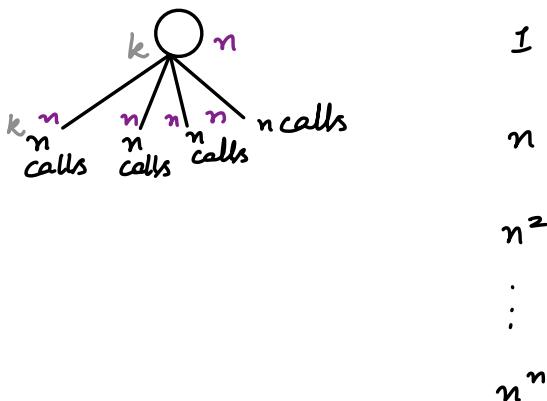
if  $n$  is already given 9,  $T.C - O(1)$  &  $S.C - O(1)$

## N Queens

func( )

$k$       base case  $\longrightarrow k$   
 $\left\{ \begin{array}{l} k_1 \\ k_2 \end{array} \right.$        $n$  is safe function  $\longrightarrow O(n)$   
 $n$  recursive calls

}



$$T.C. - n(1) + n(n) + n(n^2) + \dots + n(n^n)$$

T.C. -  $O(n^n)$   $\longrightarrow$  worst case

T.C. -  $O(n!)$   $\longrightarrow$  average case

$$S.C. - k^* n$$

$$S.C. - O(n)$$

S.C. -  $k^* n + n$   $\xrightarrow{\text{in optimized sol for creating 3 maps}}$

$$S.C. - O(n)$$

→  $n^* n!$  can be written as  $n!$

→  $n^* 2^n$  can be written as  $2^n$

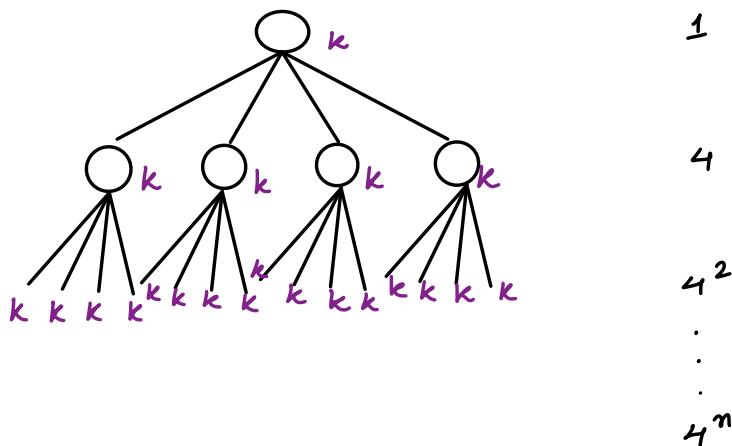
## Phone Keypad Problem

1	2	3
abc	def	
4	5	6
ghi	jkl	mno
7	8	9
pqrs	tuv	wxyz

```

fun ( ) {
    base case k
    ↳ store output in ans array
    at max 4 recursive calls
}

```



$$T.C. = k + 4k + 4^2k + \dots + 4^n k$$

T.C. =  $O(4^n)$

in max depth      length of 1 output string

$$S.C. = (k + 2k + \dots + nk) + (4^n * n)$$

↑                      ↑

store output in base case      no. of strings stored in ans array

S.C. =  $O(4^n)$

- Object Oriented Programming
- programming technique in which everything revolves around objects
  - creation
  - interaction
  - access
  - changes
- 2 things
  - property / state → variables
  - behaviour / method → functions
- why ?
  - readable
  - reusable
  - easily maintain
  - easily to understand

## Class

- to make user defined / custom datatype
- has structure definition

class - design / blueprint / idea

object - actual entity

↳ instance of class

→ has existence

→ Class and Object both take memory

### Creating a class

```
class className {  
    // states  
    string name;  
  
    // method  
    void sleep(){  
    }  
};
```

### sizeof (class) -

```
class animal {
```

```
};
```

cout << sizeof (animal); → 1 to give existence  
for identifying this class, so min.

```
class animal {
```

```
    int age;
```

```
};
```

possible memory is  
allocated

cout << sizeof (animal); → 4

```
class animal {  
    string name;  
};
```

```
cout << sizeof (animal);
```

24

Why?

```
class animal {  
    int age;  
    char ch;  
};
```

```
cout << sizeof (animal);
```

↳ due to padding  
and greedy alignment

```
class animal {
```

```
    string name;  
    string age;
```

```
    void sleep () {
```

```
        cout << name << " is sleeping ";
```

```
}
```

```
};
```

} states / properties / data members

} method /  
behaviour /  
member  
function

## Static Object Creation

animal ramesh ;

Accessing state and method of object  
object Name state : not class

object Name. method( parameters );

ex- ramesh. age ;

ramesh . sleep();

## Access Modifiers

→ defines access scope of state / method

3 types

public

can access that

state / behaviour

inside as well as

outside the class

private (by default)

can access that

state / behaviour

only inside the  
class, not outside  
the class

protected

same as

private but

can be

## access

inside

```
class animal {  
    public : —————> after marking,  
    string name; all below state /  
    string age; behaviour will be of  
    void sleep () { that type  
        cout << name;  
    }  
    private :  
    void eat () {  
    }  
};
```

To access private member outside class

↳ use public methods getter and setter

```
class animal {  
    string name;  
    public :  
    string getName () { getter  
        return name;  
    }  
};
```

```

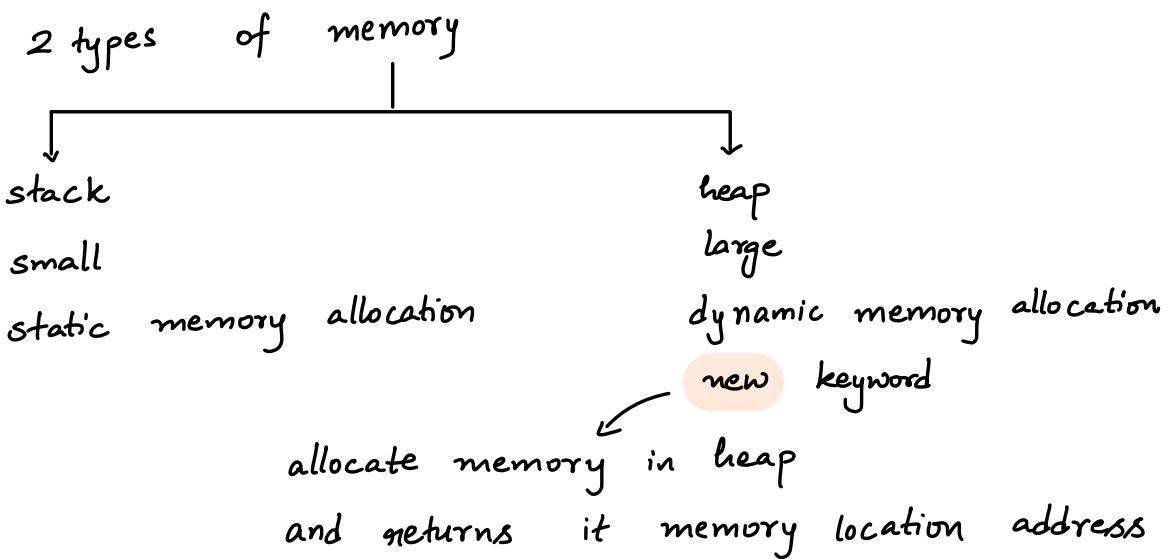
void setName ( string newName){    setter
    name = newName;
}

};

int main( ){
    animal ramesh;
    cout << ramesh. name; -----> ERROR
    cout << ramesh. getName(); -----> gu
    ramesh. setName ("Lion ");
    cout << ramesh. getName(); -----> Lion

```

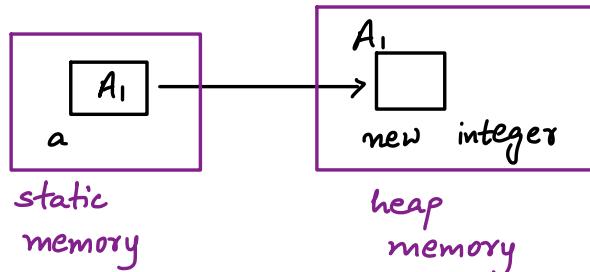
## Dynamic Memory Allocation



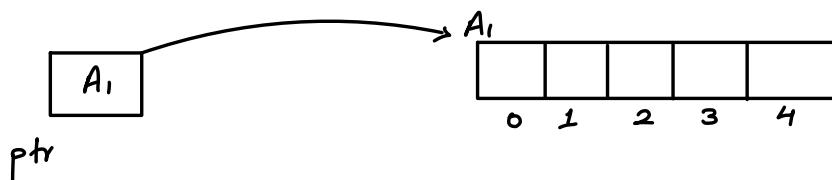
```
int a = 5;
```



```
int * a = new int
```



```
int * ptr = new int [5];
```



- space allocated in heap memory, cannot be cleaned automatically even after finishing of func.
- there is no garbage collector in C++

Allocation

```
int * a = new int;
```

```
int * arr = new int [5];
```

De allocation

```
delete a;
```

```
delete arr [ ];
```

# Object Creation using dynamic memory allocation

```
animal * suresh = new animal;
```

suresh.name;  $\longrightarrow$  ERROR as suresh is a pointer, \*suresh is object

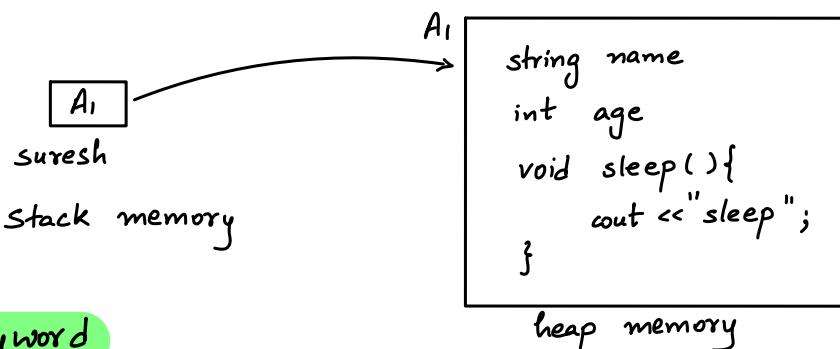
(\*suresh).name; } 1<sup>st</sup> way of access

(\*suresh).sleep();

suresh  $\rightarrow$  name;

suresh  $\rightarrow$  sleep();

} 2<sup>nd</sup> way of access



## this keyword

$\hookrightarrow$  pointer to current object

```
class animal {
```

```
    int age;
```

```
public:
```

```
    void setAge ( int age) {
```

```
        this  $\rightarrow$  age = age;
```

```
        // (*this).age = age;
```

```
}
```

```
};
```

} both are correct

## Object Creation

→ Constructor Call (in both static and dynamic allocation)

- initialize the object
- function with no return type
- its name is same as class
- created by default

```
class animal {
```

```
    int age;
```

```
    int weight;
```

// default constructor

```
animal () {
```

```
    cout << "Constructor Called";
```

```
    this->age = 10;
```

```
    this->weight = 20;
```

```
}
```

} now built-in  
constructor does not  
called, it will be  
called

→ accessing members and methods

using this keyword is **GOOD PRACTICE**

// parameterised constructor

```
animal ( int age) {
```

```
    this->age = age;
```

```
    cout << "Parameterised constructor called";
```

```
}
```

// parameterised constructor 2

```
animal ( int age, int weight){
```

```
    this->age = age;
```

```
    this->weight = weight;
```

```
    cout << "Parameterised constructor 2 called";
```

```
}
```

// copy constructor (wrong way)

```
animal (animal obj) {
```

```
    this->age = obj.age;
```

```
    this->weight = obj.weight;
```

```
    cout << "Copy Constructor Called";
```

```
}
```

animal a;

animal b = new animal;

animal c = a;

animal d (a);

animal e = \* b;

animal f (\* b);

)

↳ copy constructor call

↳ pass by value

↓  
infinite loop

// copy constructor (right way)

```
animal (animal & obj) {
```

```
    this->age = obj.age;
```

```
    this->weight = obj.weight;
```

```
    cout << "Copy Constructor Called";
```

```
}
```

```
}
```

## Destructor

- free memory
- for static object creation,  
destructor gets called automatically  
where object's scope ends
- for dynamic object creation,  
you have to do it manually using  
`delete objName;`
- no return type
- no input parameter

```
class animal {  
    int age;  
    int weight;
```

// destructor

```
~animal () {  
    cout << "destructor called";  
}
```

}

- Encapsulation
- Inheritance
- Polymorphism
- Abstraction (Pitaji of all OOPs pillars)

### Encapsulation

- Wrap data members and member functions in one parent entity (class)
- Objective → Data Hiding
  - security
  - privacy
  - can make readonly
  - can decide what to hide and what to show
  - work with parent entity is simple

Objective of class → Encapsulation

Perfect / Full / 100% Encapsulation

- when all data members are marked private and access them using getter and setter

## Inheritance

- inherit some properties (data members and data functions) from parent / super / base class to sub / child / derived class
- Objective → Reusability
- is a relationship
- Syntax
  - class childName : mode1 parentName1, ... , modeN parentNameN {  
    // additional states and methods  
}

```
class Animal {  
    int age;  
    public:  
    int weight;  
    protected:  
    void eat () {  
        cout << "eating";  
    }  
};
```

```
class Dog : public Animal {  
};  
Dog is a Animal  
class cat : public Animal,  
protected Dog {  
};
```

Access Modifier of Base class	Mode of inheritance		
	Public	Protected	Private
Public	Public	Protected	Private
Protected	Protected	Protected	Private
Private	NA	NA	NA

NA → Not Accessible

↳ can't be inherited

### Protected

↳ Same as private access modifier

but can be inherited



can be accessed inside child class

### Private

↳ can access inside class but not outside

cannot be inherited

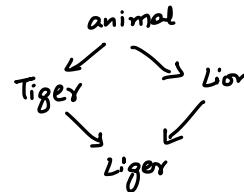


cannot be accessed inside child class

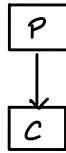
## Type of Inheritance

P- Parent      C- Child

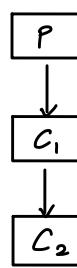
- Single
- Multilevel
- Multiple
- Heirarchical
- Hybrid → mixture of all above 4



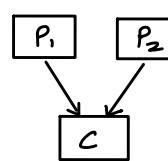
Single



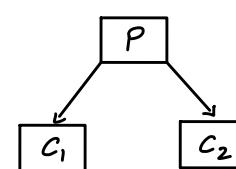
Multilevel



Multiple



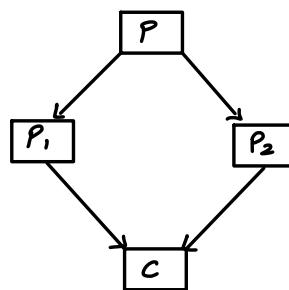
Heirarchical



## Diamond Problem / Inheritance Ambiguity Problem

→ If multiple parents have same property then how to access them

→ `objectName. Parent Class Name :: property ;`



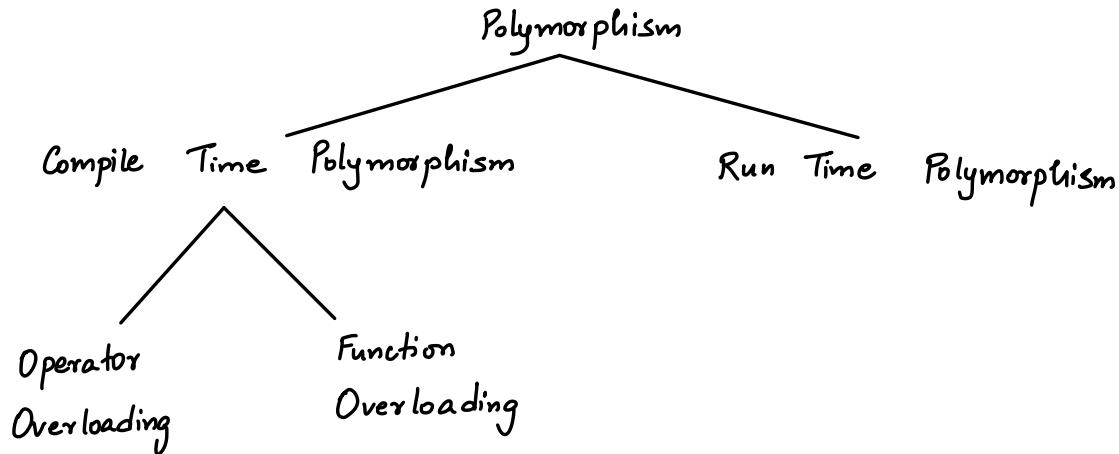
scope resolution operator

- If parent and child have same property, then parent property inside child class will get overwrite by child property
- Multiple inheritance is possible in C++, not in Java

## Polymorphism

↳ form

→ existed in many forms



## Function Overloading

↳ one function existing in multiple forms / signatures

→ Multiple Signatures

↳ diff. in either no. of parameters or type of parameters, not diff. in return type

→ 5.12 → double

5.12f → float

```
class Maths {  
public:  
    int sum (int a, int b){  
        return a+b;  
    }  
    float sum ( int a, double b){  
        return a+b;  
    }  
    int sum( int a, int b, int c){  
        return a+b+c;  
    }  
};  
int main () {  
    Maths m;  
    cout << m.sum (5, 2);  $\longrightarrow$  7  
    cout << m.sum (5, 2.5);  $\longrightarrow$  7.5  
    cout << m.sum (5, 2, 7);  $\longrightarrow$  14  
    return 0;  
}
```

## Operator Overloading -

→ to make new implementation of an operator

object1 op variable2

→ same as  
object 1. op (variable2);  
→ object 1 → current object  
→ op → method  
→ variable 2 → input parameter

```
class Para {
```

```
public:
```

```
int val;
```

```
Para (int val) {
```

```
    this → val = val;
```

```
}
```

```
int operator + (Para obj2) {
```

```
    return this → val - obj2. val;
```

```
}
```

```
int operator + (char ch) {
```

```
    cout << this → val + 10;
```

```
}
```

```
};
```

```

int main (){
Para a(5);
Para b(2);
cout << a + b; -----> same as a.+ (b)
                                ↳ 3
a + 'c'; -----> 15
a + '7' ; -----> 15
return 0;
}

```

→ "operator + " function must have exactly 1 parameter as + is binary operator

↓  
 2 operands  
 current object      ↗  
 input parameter

Run Time Polymorphism -

↳ polymorphism after execution

Function Overriding -

## Function / Method Over-riding

- when function of parent class is defined separately inside child class
- reusable + custom behaviour wherever you want

```
class Animal {
```

```
public:
```

```
void speak () {
```

```
    cout << "speak";
```

```
}
```

```
};
```

```
class Dog : public Animal {
```

```
public:
```

```
void speak () {
```

```
    cout << "bark";
```

```
}
```

```
};
```

```
int main () {
```

```
    Animal a;
```

```
    cout << a.speak();
```

```
    Dog d;
```

```
    cout << d.speak();
```

```
class Animal {
```

```
public:
```

// upcasting

Animal \* b = new Dog ;

cout << b. speak(); —————> speak → function of parent class called

Animal \* b = new Dog;

cout << b. speak(); —————> bark

// down casting

Dog \* c = new Animal ; —————> Compiler dependent (ERROR or not)

cout << c. speak(); —————> bark

Dog \* c = new Animal ;

OOPS Week is not completed

from my side

will complete in future

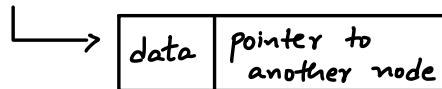
## Abstraction

- Objective → Implementation Hiding
- Talk about in a larger scale  
not focus on detail

# LINKED LIST

W10-L1

- Dynamic linear data structure to store similar data
- non-continuous memory allocation
- insertion and deletion is easy  
 $O(1)$  if you are standing on that node / pointer
- no concept of indexing,  
it has concept of addresses
- collection of nodes

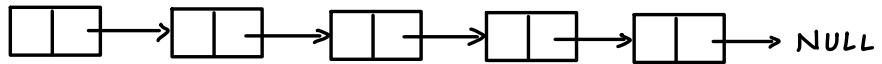


## node creation (simplest)

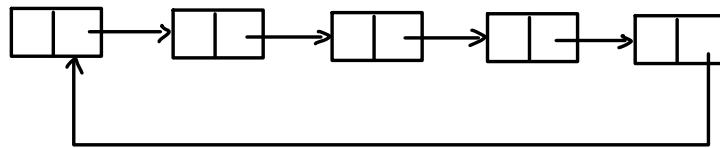
```
class node {  
public:  
    int data;  
    node * next;  
}
```

## Types of linked list

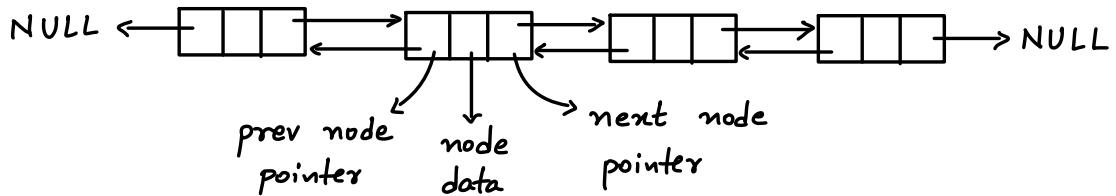
→ Singly LL



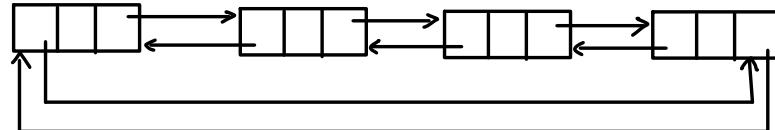
→ Circular LL



→ Doubly LL



→ Circular Doubly LL



→ LL is nothing but Hindi (any other language)

→ Linear Data Structure

└→ single descendent

→ In LL ques, there are high chances of error, so check edge cases (head, tail, size=1, not found, and more) before submit.

W10-L2

### Doubly Linked list

→ node creation

```
class node {  
public:  
    int data;  
    node * next;  
    node * prev;  
}
```

### Circular Linked List

→ no Head and Tail

→ insertion & deletion is only on the basis of value

→ Converting loop code to recursion code

→ Add parameters that are changing in loop

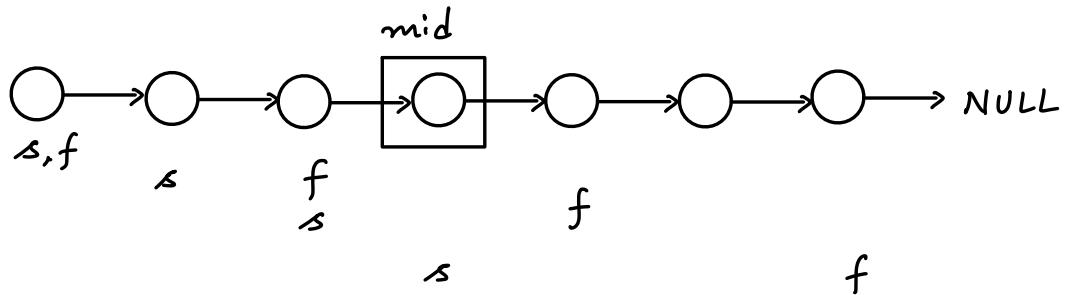
→ Stopping condition in loop acts as base case

## Tortoise Algorithm

## W10-L3

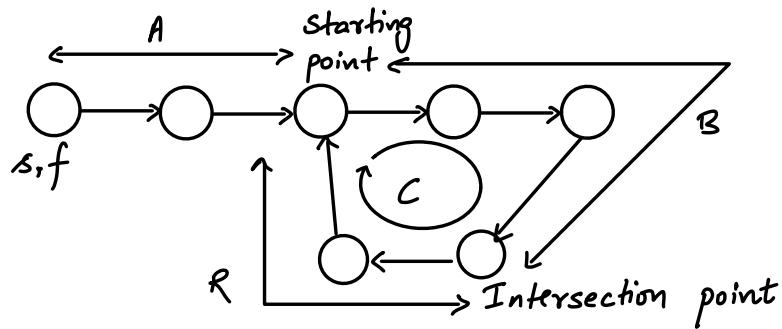
- fast and slow pointer approach
- get middle

```
int getMiddle ( node * head) {  
    if (head == NULL)  
        return -1;  
  
    node * fast = head;  
    node * slow = head;  
  
    while (fast != NULL){  
        fast = fast -> next;  
        if (fast != NULL){  
            fast = fast -> next;  
            slow = slow -> next;  
        }  
    }  
    return slow -> data;  
}
```



## Floyd's Cyclic Detection Algorithm

- to detect and delete loop in linked list
- detect the loop in linked list
- find starting point of loop in linked list
- delete the loop from linked list



$$\text{distance } (f) = 2 * \text{distance (slow)}$$

$$A + B + xC = 2(A + B + yC)$$

$$A + B = (x - y)C$$

$A + B$  made some cycles

$$B = (x - y)C - A$$

so after  $B$  steps from intersection point,  
some no. of cycles starting from starting  
point get completed

So intersection point + A  $\Rightarrow$  reach starting point

Also head + A  $\Rightarrow$  reach starting point

$$R + zC = A$$

```
162 // also works if loop starts from head
163 void removeLoop(node* &head){
164     if(head==NULL)
165         return;    node *&head
166
167     node* fast = head;    also works if loop starts from head
168     node* slow = head;
169     bool loopFound = false;
170
171     while(fast!=NULL){
172         fast = fast->next;
173         if(fast != NULL){
174             fast = fast->next;
175             slow = slow->next;
176         }
177
178         if(fast==slow){
179             loopFound = true;
180             break;
181         }
182     }
183
184     if(loopFound){
185         slow = head;
186         while(fast!=slow){
187             fast = fast->next;
188             slow = slow->next;
189         }
190
191         cout << "loop started from " << slow->data << '\n';
192         node*prev = slow;
193         while(prev->next!=slow){
194             prev = prev->next;
195         }
196         prev->next = NULL;
197
198     }
199     else{
200         cout << "no loop was present\n";
201     }
202 }
```

# STACKS

# W11-L1

→ Data Structure

→ LIFO (Last In First Out) Order

→ no index based accessing, only can access top

## initialization

```
stack <int> s;
```

## insertion

```
s. push ( 20 );
```

## deletion

```
s. pop ( );
```

## top element

```
s. top ( );
```

can only be use if we are sure that stack is non empty

## empty or not

```
s. empty ( );
```

## size

```
s. size ( );
```

→ If we pop a data set after pushing in stack, we get the answer in reverse order

So to reverse anything or to use LIFO order you can use stack

→ Stack can be implemented either by array (static or dynamic) or linked list

{ in implementation dont use vector as it is stl class }

### Copying a stack

W11-L2

```
stack <int> st 1;
```

```
stack <int> st 2 = st 1;
```

→ if we have to do something for every element of stack, generally we need to write 2 functions, first → for removing top, storing it and use recursion

second → for doing that something on a single element (top) of stack

ex - sort a stack

↳ insert top of stack in sorted stack

reverse a stack

↳ insert top of stack at the bottom

→ General format to solve standard stack question

void func (st)

if (st. empty ()) {

base case

processing

return;

}

int top = st. top ();

save top

st. pop ();

pop

func (st);

recursion call

processing

processing

}

Pair -

pair < int, char > p ; } initialize

p = make - pair ( 27, 'x' );

p. first = 27; p. second = 'x'; } insert

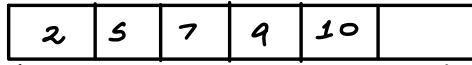
p = { 27, 'x' };

W11-L3

# QUEUE

W12-L1

→ Data structure in which data is stored in the form FIFO (first in first out) order



front  
deletion

first element of queue

q.front()  
q.back()

rear

insertion

place to insert next element

creation

```
queue <int> q;
```

rear always shows  
empty block

insertion -

```
q.push(10);
```

deletion -

```
q.pop();
```

front element

```
q.front();
```

back element

```
q.back();
```

### size

q. `size();`

### empty or not

q. `empty();`

- queue can be implemented using either by dynamic array or by linked list
- if `front == rear` → queue is empty
- element access through index is not possible
- if iterative and recursive, both have same complexities, then iterative sol. takes less time generally

### → queue patterns

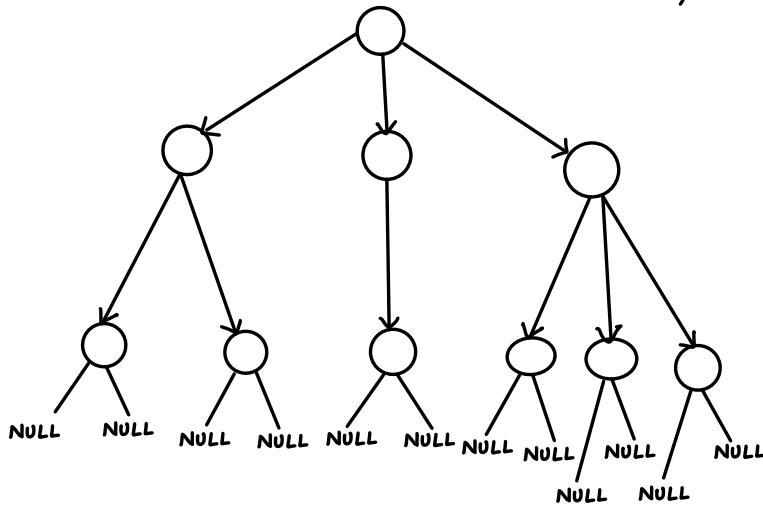
- queue / deque in sliding window
- traversals (trees and graph)
- use after sorting vector
- circular tour ques.

## sliding window

→ process first window

→ repeatedly remove first element of window &  
add next element in window to process  
next window

→ non linear data structure in which data is stored in hierarchical form



### Binary Tree

→ Tree having no. of children for each node is less than or equal to 2

### n-ary tree

→ Tree having no. of children for each node is less than or equal to  $n$

→ generic tree

## node

→ smallest unit of tree

for binary tree

```
class node {  
    int data;  
    node * left;  
    node * right;  
}
```

for many tree

```
class node {  
    int data;  
    vector<node*> child;  
}
```

## root node

→ top most / starting node of the tree  
→ only one in whole tree

## leaf node

→ node with no child

## non leaf node

→ node other than root and leaf nodes

## parent → child

→ parent of root node is either NULL or itself or anything else according to the ques

### ancestor

→ all nodes in the path from that node to root node

### descendent

→ all nodes in the path from that node to any no. of leaf nodes

### sibling

→ nodes that are children of same parent

### level

→ start from root as 0 and increase as we go below towards leaf by 1

### height of node

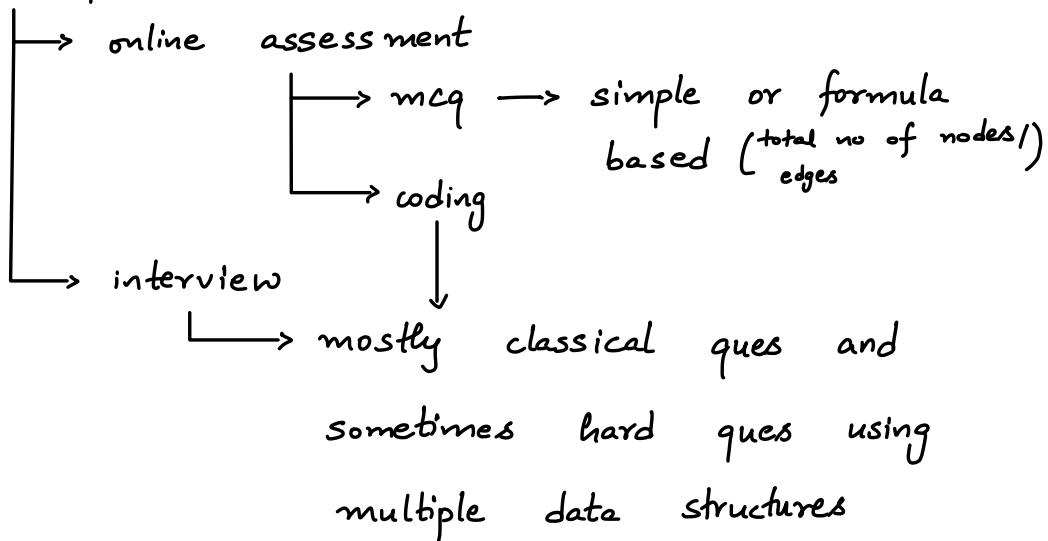
→ acc. to ques no. of nodes/edges from leaf to node in longest path

→ start from bottom most node as 1 and increase as we go upwards towards the root by 1

### height of tree

→ height of root node

## → trees questions



→ tree is aasaan if you know recursion

## Tree traversal algorithms

- level order traversal (BFS)
- spiral traversal (BFS)
- preorder, inorder, postorder traversal (DFS)
  - ↓
  - CLR
  - ↓
  - LCR
  - ↓
  - LCR
- C - process curr node      L - goto left      R - goto right
- moris traversal

→ there is no official algo to create tree from data

## skew tree

↳ tree in which each node has only left child  
or

tree in which each node has only right child

→ int main () {

// wrong way

node \* root = func();

// right way

node \* root = NULL;

root = func();

node \* func () {

return node;

}

gva

\*root

→

valid add.  
from func.

wrong  
way

0

\*root

→

valid add.  
from func.

}

→ if we have to store nodes, then store their  
pointers (node \*) as we know that node size  
can either be larger but node pointer will always  
of same size i.e. either 4 or 8 acc. to compiler  
Another reason is that multiple nodes can have  
same data but with diff. addresses

## Balanced Binary Tree

W13-L2

→ at every node the absolute diff. between heights of left and right subtree must be  $\leq 1$

## Perfect / Full Binary Tree

→ every node has either 0 or 2 children and only last level has leaf nodes

## Complete Binary Tree

→ tree in which nodes are created levelwise and from left to right  
→ all levels are completely filled except last one

## Sum Tree

→ replace every node value with sum of values of that node, left subtree sum, and right subtree su

→ if you don't find logic to solve tree question, just start running recursion in examples and you will find solution eventually

## W13-L4

→ There are only 2 approaches to solve any tree question

- use recursion in both left and right subtree
- OR
- find path from root to that node/leaf

- build tree from inorder and preorder (CLR)
- build tree from inorder and postorder (LRC)
- right recursion call before }  
left recursion call }

→ In ques. where we find views

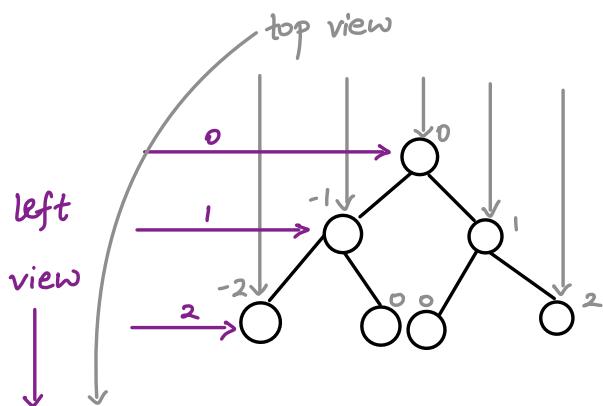
W13-L5

(like top / left/ bottom/ right view of the tree)

we use 3 concepts

→ map  
→ level order traversal  
→ horizontal distance

from root



store in map and not update if another found on the same level / horizontal distance

for bottom and right view store in map and update if another found on the same level / horizontal distance

left view & right view → 4 approaches

)

in github repo code

# BINARY SEARCH TREE

W14-L1

for every node, every data in left subtree should be smaller than node data and every data in right subtree should be greater than node data

→ inorder traversal of BST is always sorted  
    → store or use acc. to ques

→ in average case, height of tree is  $\log_2 n$   
    ↓  
    simple & BST both

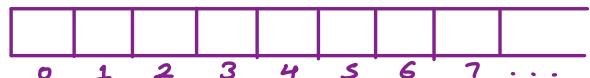
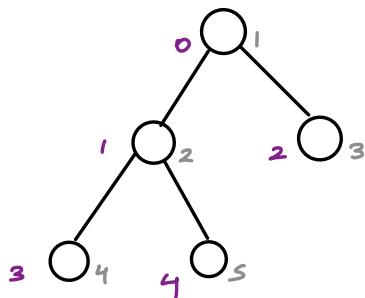
→ in interviews, there is very high chances of asking variation of deletion in BST

→ given a leaf node, find its successor and predecessor leaf node of that node

→ Data Structure that exists in the form of Complete Binary Tree and holds heap property

max heap - every parent value is greater than its children value

min heap - every parent value is less than its children value



$i^{\text{th}}$  node  $\rightarrow$  left child -  $2i+1$ , right child -  $2i+2$   
 $\rightarrow$  parent -  $(i-1)/2$

$i^{\text{th}}$  node  $\rightarrow$  left child -  $2i$ , right child -  $2i+1$   
 $\rightarrow$  parent -  $i/2$

→ We visualize heap as tree but create as array

### insertion and deletion

#### insertion

- insert at bottom
- rearrange the nodes if heap property is violated
  - compare node with its parent
- T.C. -  $O(n)$

#### deletion

- deletion is only done of top / root node
- replace last value with top node
- delete last node (reduce size by 1)
- rearrange the nodes if heap property is violated
  - compare node with both of its children
- T.C. -  $O(n)$

## Use Case of Heap

→ to find maximum & minimum element in  $O(1)$  time

## Heapify

→ process of rearranging a node to its correct position starting from that node as tree

→ same as deletion code

    ↳ rearrange the nodes if heap property

    is violated

    → compare node with both of its children

→ if there are  $n$  nodes in heap (CBT), then from  $(\frac{n}{2} + 1)^{th}$  to  $n^{th}$  nodes (in 1 based indexing) are leaf nodes and so are valid heap and there is no need to heapify those leaf nodes

## Build heap

- convert a given array to a heap
- use heapify function
- T. C. -  $O(n)$

## Heap Sort

- swap first node and last node
- reduce size by 1
- run heapify algo
- repeat these steps till size becomes 1
- T. C. -  $O(n \log n)$







# DYNAMIC PROGRAMMING

W17-L1

→ technique used to optimize sol.

key point

↳ those who forget the past are condemned to repeat it



don't compute the things, you have already completed



store all the distinct answers

you are getting within the process

## Phases of question solving

- Recursion
- Top Down Approach (Recursion + Memoisation)
- Bottom Up Approach (Iterative + Tabulation)
- Space Optimization

## 2 Conditions needed to apply DP

- overlapping subproblems
  - ↳ solving same problem again & again
- optimal substruture
  - ↳ optimal sol. of bigger problem can be calculated using optimal sol. of smaller problem

## Top Down (Recursion + Memoisation)

- create and initialize the dp array or map
  - store all the new answers in dp array and return that
  - check whether the ans is already exists in dp array
- write condition after base case
- if (dp array contains ans for given input)  
return ans;

## Bottom Up (Iterative + Tabulation)

- create and initialize dp array / map
- store base case answers in dp array
- find ans. from bottom to up (reverse of recursion) iteratively and store them in dp array.  
using loops
- add extra base case(s) if necessary

S.C. (bottom up) is better than S.C. (top down)

↓  
iterative

↓  
recursive

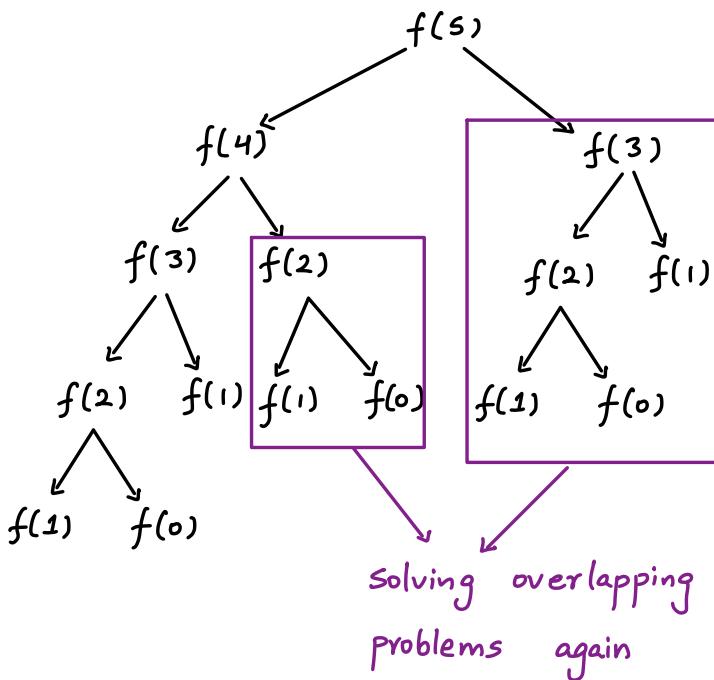
→ In majority cases size of dp array in bottom up is same as that of top down, but in some we have to change it

→ No. of dimensions of dp array (1D, 2D, etc) depends upon the no. of changing parameters in the ques

## Space Optimization Sol.

- check where the useless space is used and try to reduce it.
- Analyze the dp expression and findout to what parameters curr value is dependent and find out the pattern in those parameters

ex- fibonacci



DP can be used

recursion  
T.C. -  $O(2^n)$   
S.C. -  $O(n)$

top down  
T.C. -  $O(n)$   
S.C. -  $O(n+n)$

bottom up  
T.C. -  $O(n)$   
S.C. -  $O(n)$

space optimization  
T.C. -  $O(n)$   
S.C. -  $O(1)$

factorial

