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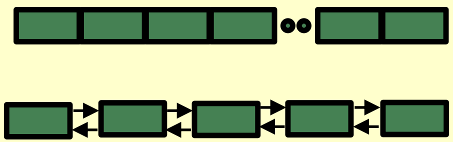
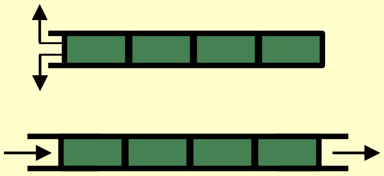
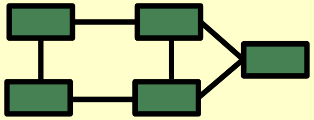
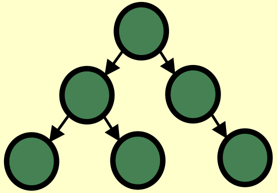
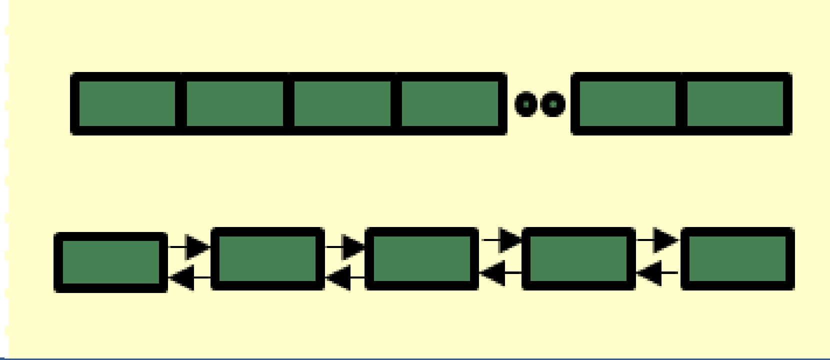
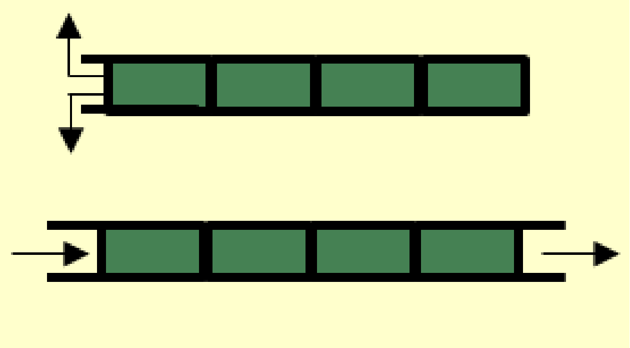
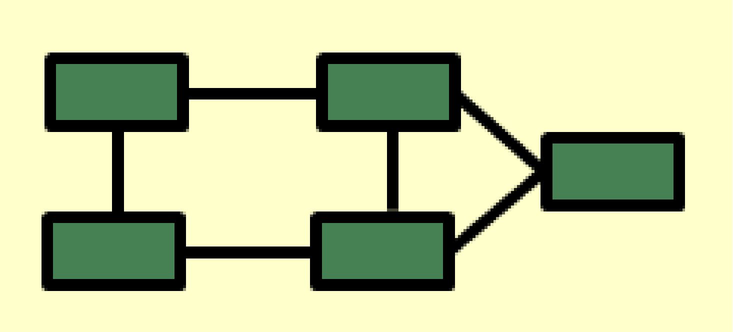
Data Structures

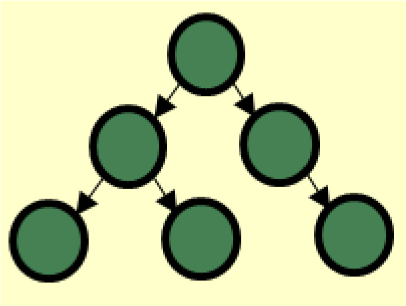









Introduction to Data Structures & Algorithms





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Why DSA?

We are surrounded by information which is to be stored in form of data !

Storing is not only important. Fetching / Retrieving and Processing has to be efficient

Data has to be properly structured

List, Stack, Tree, Graph

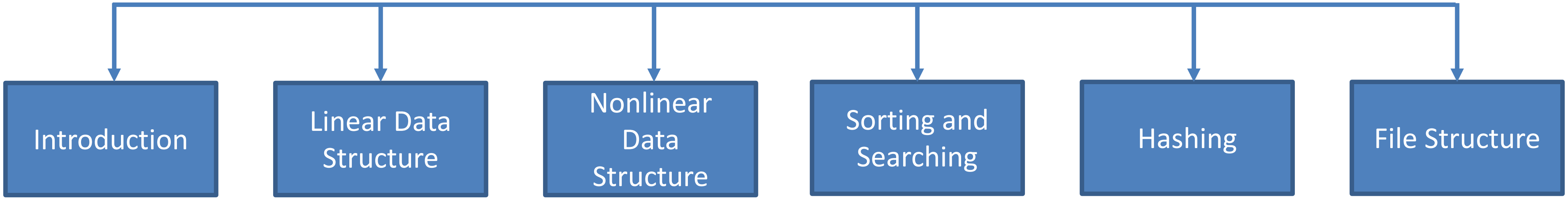
Implementation in C, C++, Java etc

GATE, Job Interview

Big data, AI, Machine Learning

"Data Structure" and "Algorithms" are two different words

Data Structures & Algorithms (DSA)



DSA: Introduction

- Introduction
- Linear Data Structure
- Nonlinear Data Structure
- Sorting and Searching
- Hashing
- File Structure

Introduction

- Elementary Data Organizations
- Data Structure Operations: insertion, deletion, traversal
- Data Management concepts
- Types of Data structures
- Data types: primitive and non-primitive.

DSA: Introduction

What is a data structure?

Structuring the data

Organizing the data

Why do I need to organize data?

To efficiently manage the data

What do you mean by efficiently manage data?

So that the data can be stored, retrieved and updated in a faster way

DSA: Introduction

What is a data structure?

Source: Wikipedia

In computer science, a data structure is a data organization, management, and storage format that enables efficient access and modification.

More precisely, a data structure is a collection of data values, the relationships among them, and the functions or operations that can be applied to the data.

It makes the algorithm (and in turn code) easy to understand and manage.

Concerns

Efficiency

Scalability

DSA: Introduction

Abstract Data Types (ADT)

Source: Wikipedia

In computer science, an abstract data type (ADT) is a mathematical model for data types.

ADT	Implementation in DS
List	Array, Linked List
Queue	Array, Linked List
Stack	Array, Linked List
Map	Tree, Graph

DSA: Introduction

Computational Complexity

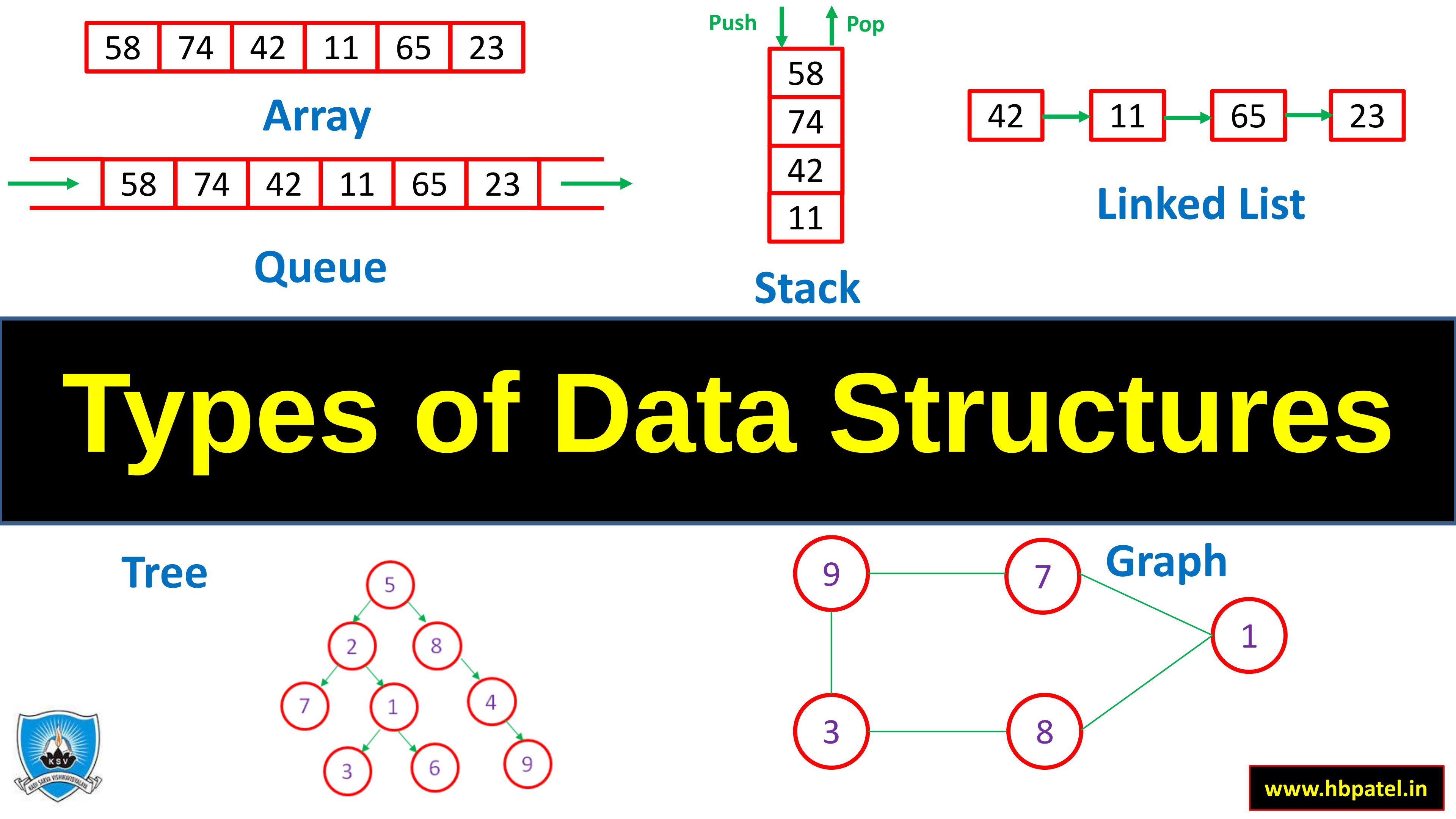
- To understand the performance of the data structure or algorithm
- How much time does an algorithm need to complete?
- How much memory (space) does an algorithm require for its computation?

Upper bound and Lower bound

- Big-O Notation (O) – Worst case scenario
- Omega Notation (Ω) – Best case scenario
- Theta Notation (θ) – Average case scenario

Thank You

Next: Types of Data Structure


58 74 42 11 65 23
Array
58 74 42 11 65 23
Queue
Push
Pop
58
74
42
11
Stack
42 11 65 23
Linked List
Types of Data Structures
Tree
5
2
8
7
1
4
3
6
9
Graph
9
7
1
3
8
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Types of Data Structures

Types of Data Structures

- Primitive Vs. Non-primitive data structures
- Linear Vs. Non-linear data structures
- Static Vs. Dynamic data structure

Primitive Vs. Non-primitive Data Structures

Primitive Data Structure

- Fundamental data structure available for programming
- Example: int, float, char, pointer
- Can store only single data value

Non-primitive Data Structure

- User defined data structure
- Classified into: linear and non-linear data structure
- Example of linear data structure: array, stack, queue, linked list
- Example of non-linear data structure: tree, graph
- Can store multiple data values

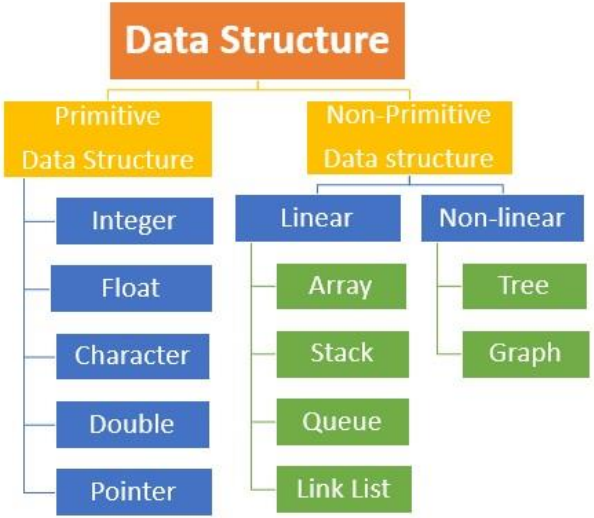
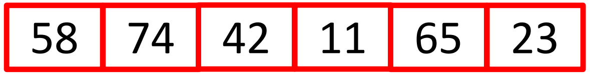
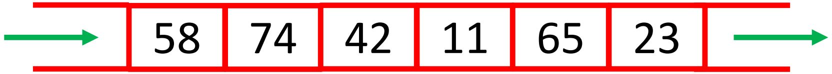


Image source: https://msatechnosoft.in/

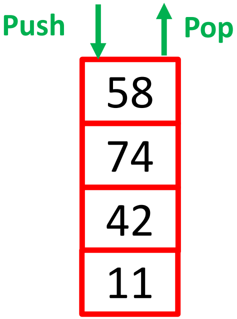
Linear Data Structures



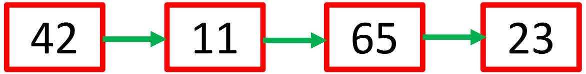
Array



Queue

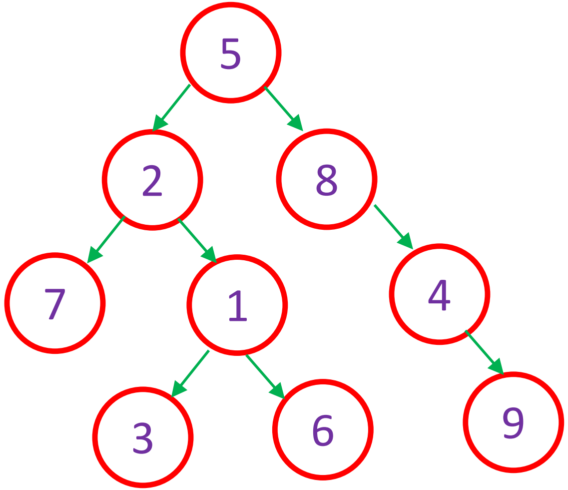


Stack

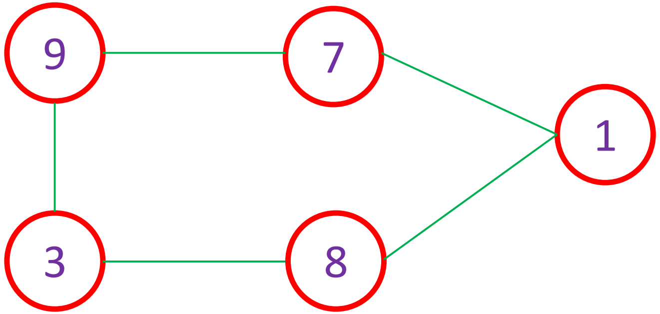


Linked List

Non-linear Data Structures



Tree



Graph

Linear Vs. Non-Linear DS

Linear Data Structure

- It arranges the data in orderly manner where the elements are attached adjacently
- Level: Single
- Implementation: Easier
- Example: Array, Stack, Linked List, Queue

Non-linear Data Structure

- It arranges the data in sorted order, creating a relationship among the data element
- Level: Multiple
- Implementation: Difficult
- Example: Tree, Graph

Static Vs Dynamic DS

Static Data Structure

- Memory is allocated at compile time (before running/execution).
- Maximum size is fixed
- Example: Array
- Advantage: Fast access. Disadvantage: Slower insertion/deletion, memory waste

Dynamic Data Structure

- Memory is allocated at run time
- Maximum size is flexible (can be increased/reduced)
- Example: Linked list
- Advantage: Faster insertion/deletion, Memory save Disadvantage: Slow access, Computation overhead

Operations on DS

- Search

42	23	74	11	65	58

11?

- Sort

11	23	42	58	65	74

- Insert

11	23	42	58	65	74

49?

11	23	42	49	58	65	74

- Delete

11	23	42	58	65	74

23

11	42	58	65	74

- Update

11	23	42	58	65	74

58->59

11	23	42	59	65	74

Thank You

Next: Linear Data Structure (Sparse Matrix)

DSA: Linear Data Structure

- Introduction
- **Linear Data Structure**
  - Array — Sparse Matrix
  - Stack — Push, Pop, Peep, Change, Overflow, Underflow, Applications
  - Queue — Normal, Circular, Priority, Double ended
  - Linked List — Singly, Doubly, Circular
- Nonlinear Data Structure
- Sorting and Searching
- Hashing
- File Structure

Sparse Matrix

$$\begin{bmatrix} 0 & 0 & 5 & 2 \\ 0 & 0 & 0 & 6 \\ 9 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 \end{bmatrix} \Rightarrow$$

Row	Column	Value
0	2	5
0	3	2
1	3	6
2	0	9
3	0	7

Sparse Matrix

- **Majority of elements are ZERO**

$$\begin{bmatrix} 0 & 0 & 5 & 2 \\ 0 & 0 & 0 & 6 \\ 9 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 \end{bmatrix}$$

- **How do we implement/represent sparse matrix?**

  - Arrays

  - Linked List

- **Why Sparse matrix?**

  - Storage [Only non-zero elements are stored in a triple <row, col, value>]

  - Computation power [Only non-zero elements are traversed]

Sparse Matrix

- **Array representation of a sparse matrix**

- 2D array can be represented using three rows. First row indicating row of non-zero element, second row representing column of non-zero element and third row depicting the non-zero value.

- **Example**

$$\begin{bmatrix} 0 & 0 & 5 & 2 \\ 0 & 0 & 0 & 6 \\ 9 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 \end{bmatrix}$$

Row	0	0	1	2	3
Column	2	3	3	0	0
Value	5	2	6	9	7

Row	Column	Value
0	2	5
0	3	2
1	3	6
2	0	9
3	0	7

Sparse Matrix

- **Assignment 1: Write a program to check whether the given matrix is sparse matrix or not.**
- Hint: Number of ZEROs should be more than half of the total elements in the matrix

```
int isSparse(int A[row][col])
{
int i,j, count=0;
for(i=0; i<row; ++i)
{for(j=0; j<col; ++j)
          if(A[i][j]==0)count++;
}
if(count>=(row*col)/2)return count;
else return -1;
}
```

```
/* sparse matrix */
#include<stdio.h>
#define row 4
#define col 3
int main()
{
   int S[row][col]={0,5,0,0,0,8,0,0,0,1,0,0},status;
   status = isSparse(S);
   if(status==-1)printf("Not a sparse matrix");
   else printf("Sparse matrix: With %d zero elements
from total %d elements", status, row*col);
   return 0;
}
```

OUTPUT

```
Sparse matrix: With 9 zero elements from total 12 elements
```

https://github.com/hbpatel1976/Data-Structure/blob/master/sparse1.c

Sparse Matrix

- **Assignment 2: Write a program to convert the given matrix into sparse matrix.**

```
/* sparse matrix */
#include<stdio.h>
#define row 4
#define col 3
#define max 10
void main()
{   int original[row][col]={0,5,0,0,0,8,0,0,0,1,0,0}, sparse[max][3], i,j,count=0;
    for(i=0; i<row; ++i)
    {for(j=0; j<col; ++j)
           {if(original[i][j]!=0)
              {sparse[count][0]=i;
              sparse[count][1]=j;
              sparse[count][2]=original[i][j];
              count++;
              }
           }
    }
    for(i=0; i<count; ++i) printf("%d\t%d\t%d\n",sparse[i][0],sparse[i][1],sparse[i][2]);
}
```

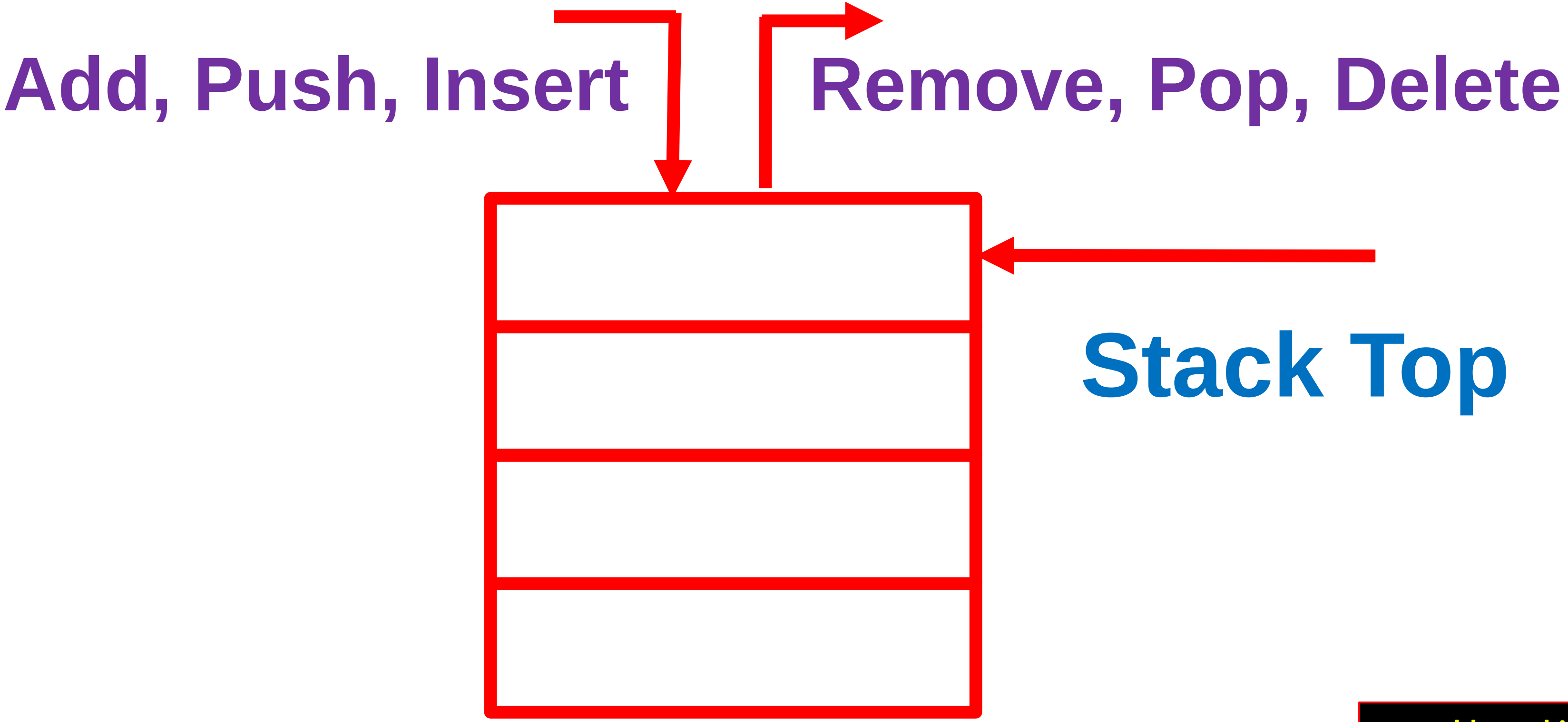
https://github.com/hbpatel1976/Data-Structure/blob/master/sparse2.c

OUTPUT		
0	1	5
1	2	8
3	0	1

Thank You

Next: Linear Data Structure (Stack)

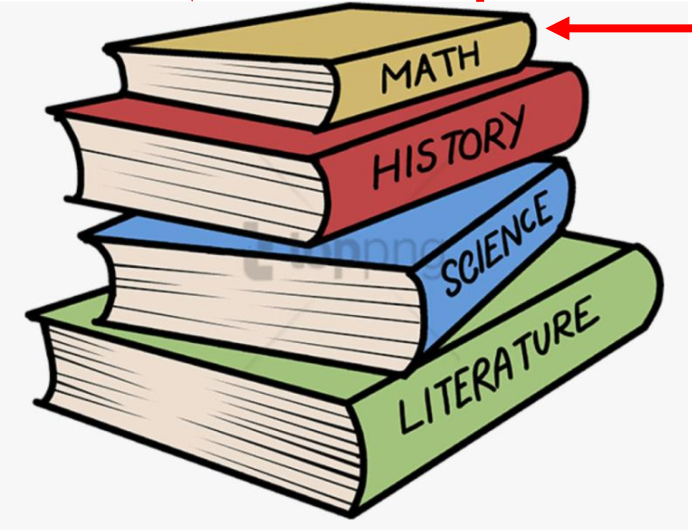
Stack



Stack

Add Book
(Push / Insertion)

Remove Book **(Pop / Deletion)**



Stack Top

Another Examples

Stack

Stack is a linear data structure (having similar data types)

Insertion (**push**ing an element) and deletion (**pop**ing an element) is possible from one end only, which is nothing but top of the stack.

Last in first out (**LIFO**) [Or First in last out - FILO]

Last in first out (LIFO) [Or First in last out - FILO]

Stack is an ordered list

peep () – Return top of the stack without removing the element

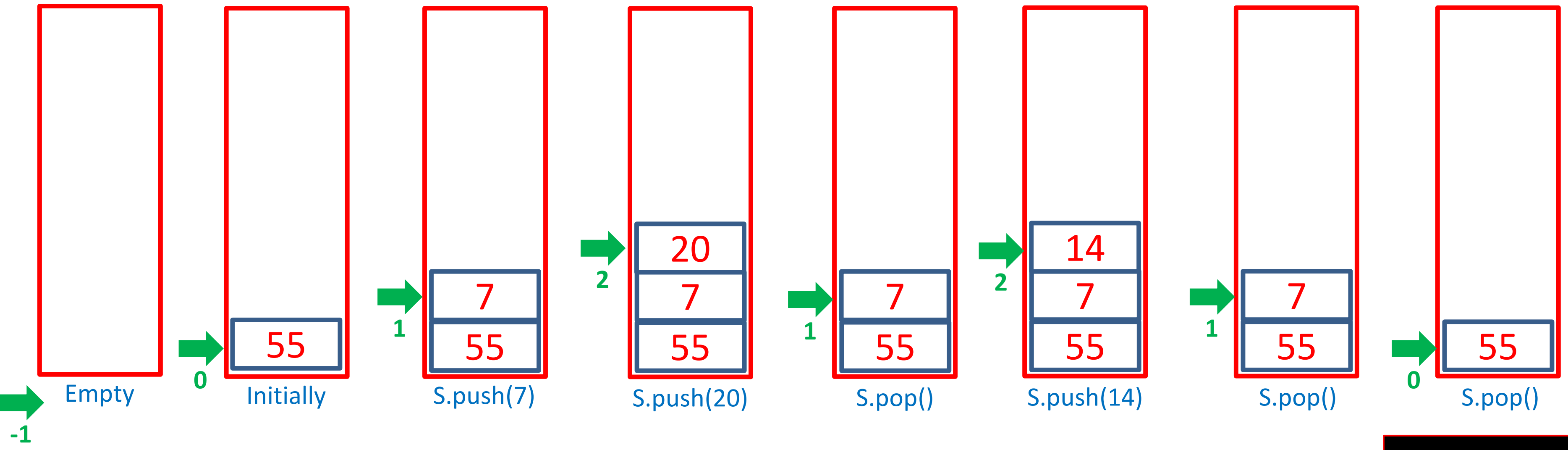
isEmpty () - Is the stack empty?

isFull () - Is the stack full?

Stack: Example

Let S is an instance of stack. Consider the following sequence of operations performed on S which initially contains element with 55 as top most elements. What will be the element at the top of the stack after the following sequence of operations?

`S.push(7), S.push(20), S.pop(), S.push(14), S.pop(), S.pop()`



Stack: Implementation

```
#include<stdio.h>
#define size 5
int S [size], top=-1;


int main()
{
push(50);
push(7);
push(20);
pop();
push(14);
pop();
pop();
printf("Stack top = %d",top);
return 0;
}
```

```
void push(int x)
{
if(top==size-1)
          {printf("Stack Overflow"); return;}
else      {
          top++;
          S[top]=x;
          printf("Element pushed : %d\n",S[top]);
          }
}
```

```
void pop(void)
{
if(top==-1)
{printf("Stack Underflow"); return;}
else
{printf("Element popped : %d\n",S[top]);top--}
}
```

OUTPUT
Element pushed : 50
Element pushed : 7
Element pushed : 20
Element popped : 20
Element pushed : 14
Element popped : 14
Element popped : 7
Stack top = 0

https://github.com/hbpatel1976/Data-Structure/blob/master/stack.c

Stack: Other Terminology

peep() – get the top data element of the stack, without removing it.

```
int peep ()
{
return S[top];
}
```

isFull() – check if stack is full.

```
int isFull()
{
if (top == size-1) return 1;
else return 0;
}
```

isEmpty() – check if stack is empty.

```
int isEmpty()
{
if (top == -1) return 1;
else return 0;
}
```

Stack: Assignment

Write a complete menu driven program that incorporates all the functionalities of the stack viz. push, pop, peep, isFull, isEmpty.

https://github.com/hbpatel1976/Data-Structure/blob/master/stackfull.c

Thank You

Next: Infix, Prefix & Postfix Notation

Infix : a + b

Prefix : + a b

Postfix : a b +

Infix Expressions

Expression: <operand> <operator> <operand>

Example: a + 5

Example: (b * 8) + 5

Infix notation or infix operation. Operator is there between operands

We need rules to evaluate infix expression. Why?

```
5 + 1 x 6  →  5 + 1 = 6, 6 x 6 = 36
           →  1 x 6 = 6, 5 + 6 = 11
```

Infix Expressions

Rules: Precedence and associativity rules

Priority	Operators	Associativity
HIGH-1	() {} []	
2	^	Right to Left
3	* /	Left to Right
LOW-4	+ -	Left to Right

5 + 1 x 6

1 x 6 = 6, 5 + 6 = 11

(5 + 1) x 6

5 + 1 = 6, 6 x 6 = 36

Infix Expressions

Rules: Precedence and associativity rules

Priority	Operators	Associativity
HIGH-1	() {} []	
2	^	Right to Left
3	* /	Left to Right
LOW-4	+ -	Left to Right

Complex Expressions

3+5*7-30/6

3+35-30/6

3+35-5

3+35-5

38-5

33

2 ^ 3 ^ 2

2 ^ 9

512

Prefix Expressions

Also known as Polish Notation

Expression: <operator> <operand> <operand>

Infix to Prefix

8 + 5 → + 8 5

A * B - C → * A B-C → -* A B C

Postfix Expressions

Also known as Reverse Polish Notation

Expression: <operand> <operand> <operator>

Infix to Prefix

8 + 5 → 8 5 +

A * B - C → A B * - C → A B * C -

Thank You

Next: Reverse Polish Notation

Reverse Polish Notation

Infix (a + b) => Postfix (a b +)

Rules: Converting Infix to Postfix

1. Scan the infix expression from left to right.
2. If the scanned character is an operand, output it.
3. Else,
…..**3.1** If the precedence of the scanned operator is greater than the precedence of the operator in the stack(or the stack is empty or the stack contains a ‘(‘), push it.
…..**3.2** Else, Pop all the operators from the stack which are greater than or equal to in precedence than that of the scanned operator. After doing that Push the scanned operator to the stack. (If you encounter parenthesis while popping then stop there and push the scanned operator in the stack.)
4. If the scanned character is an ‘(‘, push it to the stack.
5. If the scanned character is an ‘)’, pop the stack and and output it until a ‘(‘ is encountered, and discard both the parenthesis.
6. Repeat steps 2-6 until infix expression is scanned.
7. Print the output
8. Pop and output from the stack until it is not empty.

(a+b^c^d)*(e+f/d) [Scan from left to right]

Input Expression	Stack	Output Expression
(	(	
a	(	a
+	(+	a
b	(+	a b
^	(+ ^	a b
c	(+ ^	a b c
^	(+ ^	a b c
d	(+ ^^	a b c d
)		a b c d^^+
*	*	a b c d^^+
(	*(	a b c d^^+
e	*(	a b c d^^+e
+	*(+	a b c d^^+e
f	*(+	a b c d^^+ef
/	*(+/	a b c d^^+ef
d	*(+/	a b c d^^+efd
)		a b c d^^+efd/+*

Infix to Postfix Conversion using Stack

Convert given infix string to postfix notation using stack

(a+b^c^d)*(e+f/d)

Priority	Operators	Associativity
HIGH-1	() {} []	
2	^	Right to Left
3	* /	Left to Right
LOW-4	+ -	Left to Right

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Infix to Postfix Conversion using Stack

K + L - M * N + (O ^ P) * W / U / V * T + Q

Input Expression	Stack	Output Expression
K		K
+	+	K
L	+	KL
-	-	KL+
M	-	KL+M
*	- *	KL+M
N	- *	KL+MN
+	+	KL+MN*-
(	+(	KL+MN*-
O	+(	KL+MN*-O
^	+(^	KL+MN*-O
P	+(^	KL+MN*-OP
)	+	KL+MN*-OP^
*	+*	KL+MN*-OP^
W	+*	KL+MN*-OP^W
/	+/	KL+MN*-OP^W*
U	+/	KL+MN*-OP^W*U
/	+/	KL+MN*-OP^W*U/
V	+/	KL+MN*-OP^W*U/V
*	+*	KL+MN*-OP^W*U/V/
T	+*	KL+MN*-OP^W*U/V/T
+	+	KL+MN*-OP^W*U/V/T*+
Q	+	KL+MN*-OP^W*U/V/T*+Q
		KL+MN*-OP^W*U/V/T*+Q+

Priority	Operators	Associativity
HIGH-1	() {} []	
2	^	Right to Left
3	* /	Left to Right
LOW-4	+ -	Left to Right

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Online Infix to Postfix Conversion

https://www.mathblog.dk/tools/infix-postfix-converter/

Infix to postfix:

(a+b^c^d)*(e+f/d)

CONVERT

a b c d ^ ^ + e f d / + *

Infix to postfix:

K + L - M * N + (O ^ P) * W / U / V * T + Q

CONVERT

K L + M N * - O P ^ W * U / V / T * + Q +

Implementation: Infix to Postfix Conversion

```
#include<stdio.h>
char stack[20];
int top = -1;
void push(char x)
{
    stack[++top] = x;
}

char pop()
{
    if(top == -1)return -1;
    else return stack[top--];
}

int priority(char x)
{
    if(x == '(') return 0;
    if(x == '+' || x == '-')return 1;
    if(x == '*' || x == '/')return 2;
}
```

```
main()
{   char exp[20],x;
    int i=0;
    printf("Enter the expression :: ");
    scanf("%s",exp);
    while(exp[i] != '\0')
    {
        if(isalnum(exp[i])) printf("%c",exp[i]);
        else if(exp[i] == '(') push(exp[i]);
        else if(exp[i] == ')')
        {while((x = pop()) != '(') printf("%c", x);}
        else
        {while(priority(stack[top])>=priority(exp[i]))
          printf("%c",pop());
          push(exp[i]);
        }
        i++;
    }
    while(top != -1){printf("%c",pop());}
}
```

https://github.com/hbpatel1976/Data-Structure/blob/master/in2post.c

Thank You

Next: Polish Notation

Postfix to Infix Conversion

Postfix (a b +) => Infix (a + b)

Postfix to Infix Conversion

A B - C D E + * + F G + -

[Scan from left to right]

Input Expression	Stack	Output Expression
A	A	
B	A B	
-		A-B
C	C	A-B
D	C D	A-B
E	C D E	A-B
+	C	A-B D+E
*		A-B C*(D+E)
+		A-B + C*(D+E)
F	F	A-B + C*(D+E)
G	F G	A-B + C*(D+E)
+		A-B + (D+E)*C F+G
-		A-B + (D+E)*C – (F+G)

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Postfix to Infix Conversion

12, 7, 3, -, /, 2, 1, 5, +, * +

[Scan from left to right]

Input Expression	Stack	Output Expression
12	12	
7	12 7	
3	12 7 3	
-	12	7-3
/		12 / (7-3)
2	2	
1	2 1	
5	2 1 5	
+	2	12 / (7-3) (1+5)
*		(7-3) / 12 2*(5+1)
+		(7-3) / 12 + 2*(5+1)

Thank You

Next: Recursion

Recursion

```
int fact(int n)
     {
     if (n<=1)
          return 1;
     else
          return (n * fact(n-1));
     }
```

Terminating Condition

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Recursion

Normal Function Call

```
void main()
{
--
--
--
function1();
--
--
--
function2();
--
}
```

```
function1 ()
{
-
}
```

```
function2 ()
{
-
}
```

Recursive Function Call

```
void main()
{
--
--
--
main();
--
--
--
}
```

```
void function1()
{
--
--
--
function1();
--
--
--
}
```

Recursion

- Function calls itself
- Terminating condition?
- Not applicable to all problems
- Shorter code
- Complex to understand

Recursion Implementation

- Example 1: Factorial [n! = n * (n-1)!]
- Example 2: Power $x^y = x * x^{y-1}$
- Example 3: Fibonacci Series

  Next Term = Addition of Previous Two Terms

Recursion : Example 1 (factorial)

$n\,! = n \times (n-1)\,!$

$5\,! = 5 \times 4!$

$5\,! = 5 \times 4 \times 3!$

$5\,! = 5 \times 4 \times 3 \times 2!$

$5\,! = 5 \times 4 \times 3 \times 2 \times 1!$

$5\,! = 5 \times 4 \times 3 \times 2 \times 1$

Terminating Condition

$5\,! = 120$

Recursion : Example 1 (factorial)

www.hbpatel.in

```
#include <stdio.h>
void main()
          {
          int fact(int);
          int x=5,ans;
          ans=fact(x);
          printf("Factorial = %d",ans);
          }
int fact(int n)
          {
          if (n<=1) return 1;
          else return (n * fact(n-1));
          }
```

OUTPUT

```
Factorial = 120
```

```
main()
{
-
ans=fact(5);
printf ans
}
```

120

```
fact(n=5)
{
-
return 5 x fact(4);
}
```

5x24

```
fact(n=4)
{
-
return 4 x fact(3);
}
```

4x6

```
fact(n=3)
{
-
return 3 x fact(2);
}
```

3x2

```
fact(n=2)
{
-
return 2 x fact(1);
}
```

2x1

```
fact(n=1)
{
-
return 1;
}
```

https://github.com/hbpatel1976/C-Programming/blob/master/Ch0608.c

Recursion : Example 2 ($base^{exponent}$)

$b^e = b \times b^{e-1}$

$2^5 = 2 \times 2^4$

$2^5 = 2 \times 2 \times 2^3$

$2^5 = 2 \times 2 \times 2 \times 2^2$

$2^5 = 2 \times 2 \times 2 \times 2 \times 2^1$

$2^5 = 2 \times 2 \times 2 \times 2 \times 2 \times 2^0$

$2^5 = 2 \times 2 \times 2 \times 2 \times 2 \times 1$

$2^5 = 32$

Terminating Condition

Recursion : Example 2 (base^{exponent})

www.hbpatel.in

```
#include <stdio.h>
void main()
        {
        int pow(int,int);
        int b=2,e=5,ans;
        ans=pow(b,e);
        printf("%d power %d = %d",b,e,ans);
        }
int pow(int b, int e)
        {
        if(e<=0)return 1;
        else return (b * power(b,e-1));
        }
```

OUTPUT

```
2 power 5= 32
```

main()	pow(b=2, e=5)	pow(b=2,e=4)	pow(b=2,e=3)	pow(b=2,e=2)	pow(b=2,e=1)	pow(b=
{	{	{	{	{	{	{
-	-	-	-	-	-	-
ans=pow(b,e);	return 2xpow(2,4);	return 2xpow(2,3);	return 2xpow(2,2);	return 2xpow(2,1);	return 2xpow(2,0);	return 1
printf ans	}	}	}	}	}	}
}						

32

2x16

2x8

2x4

2x2

2x1

https://github.com/hbpatel1976/C-Programming/blob/master/Ch0609.c

Recursion : Example 3 (Fibonacci)

Last term (T1) = 1 , Second Last Term (T2) = 0

Next term (T3) = T1 + T2 = 1 + 0 = 1

T1 ← T2 (T1=0), T2 ← T3 (T2=1)

Next term (T3) = T1 + T2 = 0 + 1 = 1

T1 ← T2 (T1=1), T2 ← T3 (T2=1)

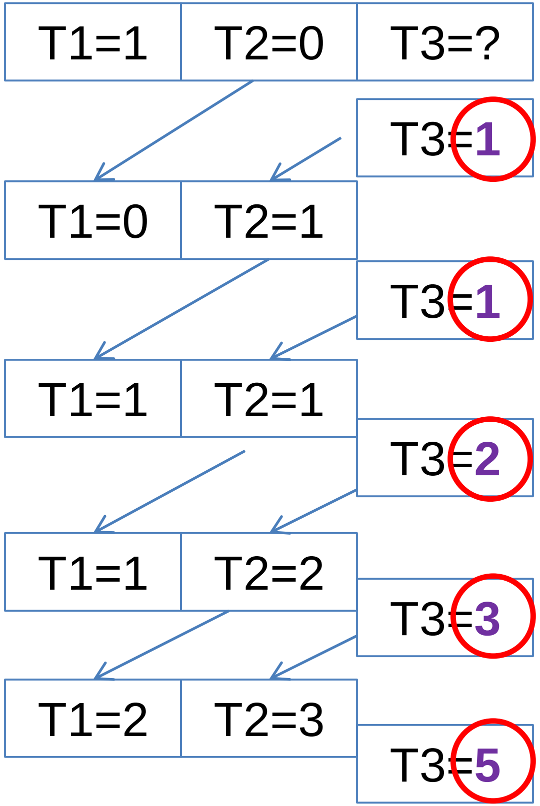
Next term (T3) = T1 + T2 = 1 + 1 = 2

T1 ← T2 (T1=1), T2 ← T3 (T2=2)

Next term (T3) = T1 + T2 = 1 + 2 = 3

T1 ← T2 (T1=2), T2 ← T3 (T2=3)

Next term (T3) = T1 + T2 = 2 + 3 = 5



Recursion : Example 3 (Fibonacci)

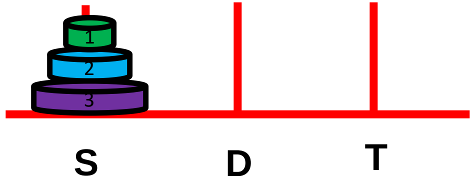
```
#include <stdio.h>
void main()
{void fibo(int,int,int);
fibo(1,0,5); /* First term, second term, total terms */
}

void fibo(int t1, int t2, int totalterms)
{
printf("%d\t",t1+t2);
if(totalterms<=1) {return;}
else        {fibo(t2,t1+t2,totalterms-1);}
}
```

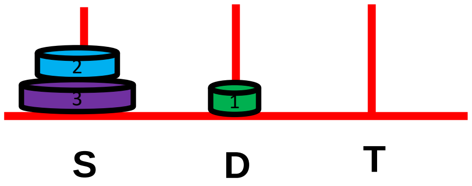
OUTPUT				
1	1	2	3	5

main()	fibo(t1=1,t2=0, tt=5)	fibo(t1=0,t2=1, tt=4)	fibo(t1=1,t2=1, tt=3)	fibo(t1=1,t2=2, tt=2)	fibo(t1=2,t2=3, tt=1)
{	{	{	{	{	{
-	print **1**	print **1**	print **2**	print **3**	print **5**
fibo(1,0,5)	fibo(0,1,4)	fibo(1,1,3)	fibo(1,2,2)	fibo(2,3,1)	return
}	}	}	}	}	}

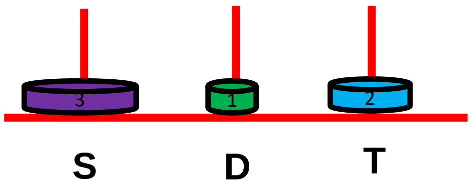
https://github.com/hbpatel1976/C-Programming/blob/master/Ch0610.c

Recursion : Example 4 (Tower of Hanoi)

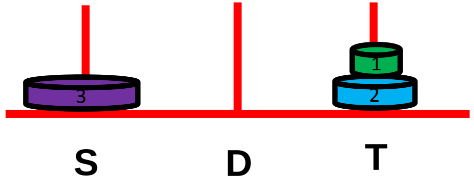




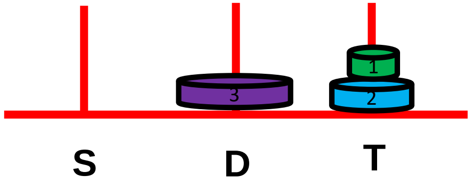
Move disk # 1 from S to D



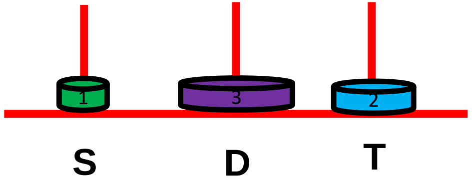
Move disk # 2 from S to T



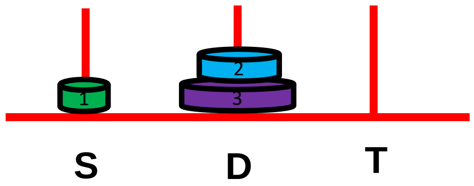
Move disk # 1 from D to T



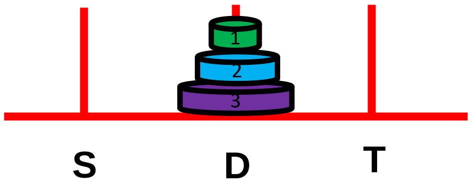
Move disk # 3 from S to D



Move disk # 1 from T to S



Move disk # 2 from T to D



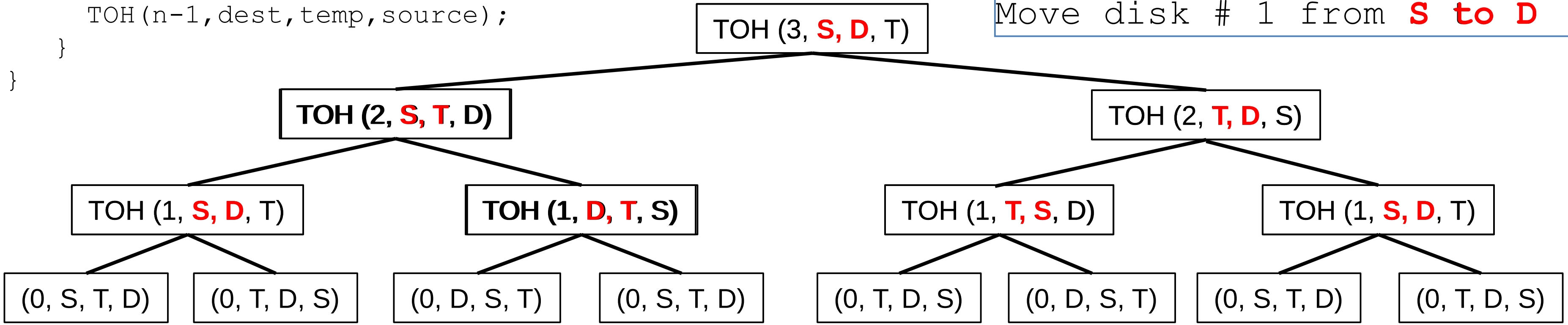
Move disk # 1 from S to D

Recursion : Example 4 (Tower of Hanoi)

```
#include<stdio.h>
int main()
{   int n=3;
    TOH(n,‘S',‘D',‘T');
}
void TOH(int n, char source, char temp, char dest)
{   if(n>0)
    {
      TOH(n-1,source,dest,temp);
      printf("move disk # %d from %c to %c\n",n,source,temp);
      TOH(n-1,dest,temp,source);
    }
}
```

OUTPUT

```
Move disk # 1 from S to D
Move disk # 2 from S to T
Move disk # 1 from D to T
Move disk # 3 from S to D
Move disk # 1 from T to S
Move disk # 2 from T to D
Move disk # 1 from S to D
```



https://github.com/hbpatel1976/Data-Structure/blob/master/TOH.c

Thank You

Next: Queue

Queue

99	7	-6	34	12

Insertion

Rear / Tail

Image source: alerttech.net

Deletion

Head / Front

Queue

Linear data structure

Abstract data type

It is an ordered list

First In First Out (FIFO) – First Come First Serve (FCFS) - LILO

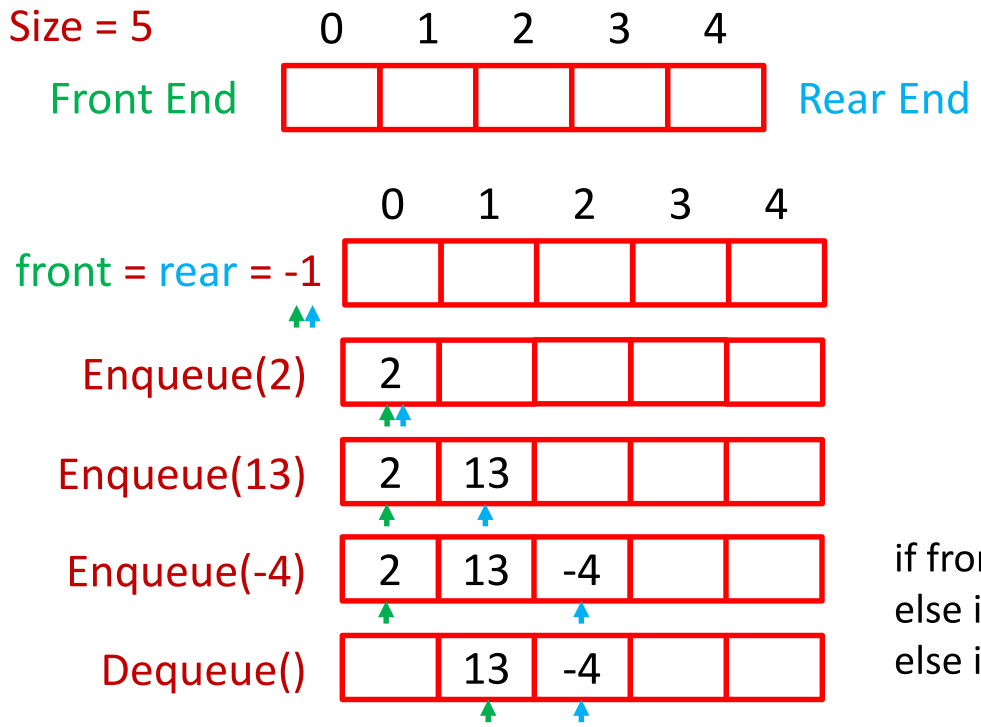
Insertion is known as Enqueue and Deletion is knows as Dequeue

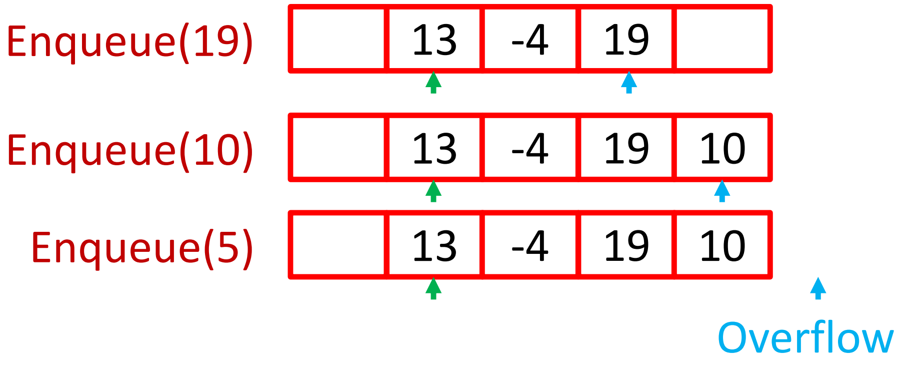
Stack Vs. Queue

	Stack	Queue
Data Structure	Linear	Linear
List	Ordered	Ordered
Type	LIFO	FIFO
End	One	Two
Insertion	Push	Enqueue
Deletion	Pop	Dequeue

Operations on Queue

Enqueue (x) **Dequeue** **front() / peep ()** **isFull()** **isEmpty()**





if front = rear = -1 then queue is empty
else if rear = size-1 then queue is full
else if front = rear then Only one element in the queue

Applications Queue

To buffer the requests received for a common shared resource (E.g. a printer shared in a network)

Instructions waiting for their turn to get executed by the processor

Queue Implementation (Using Arrays)

```
void enqueue(int element)
{
if(rear==size-1)
  {
  printf("Overflow\n");
  }
else if(front==-1 && rear==-1)
  {
  front=rear=0;
  queue[rear]=element;
  }
else
  {
  rear++;
  queue[rear]=element;
  }
}
```

Queue Implementation (Using Arrays)

```
void dequeue(void)
{
if(front==-1 && rear==-1)
  {
  printf("Underflow\n");
  }
else if(front==rear)
  {
  printf("Element deleted=%d\n",queue[front]);
  front=rear=-1;
  }
else
  {
  printf("Element deleted=%d\n",queue[front]);
  front++;
  }
}
```

Queue Implementation (Using Arrays)

```
void peep (void)
{
if(front==-1 && rear==-1)
			printf("Queue Empty\n");
else
			printf("Data at front=%d\n",queue[front]);
}
```

Queue Implementation (Using Arrays)

```
void display(void)
{
int i;
if(front==-1 && rear==-1)
  printf("Queue Empty\n");
else
  {
  for(i=front; i<=rear; ++i){printf("%d\t",queue[i]);}
  printf("\n");
  }
}
```

Queue Implementation (Using Arrays)

```
#include <stdio.h>
#define size 5
int queue[size];
int front=-1, rear=-1;

int main()
{
enqueue(10);
enqueue(20);
enqueue(-5);
display();
peep();
dequeue();
peep();
display();
return 0;
}
```

```
void enqueue(int element)
{if(rear==size-1){printf("Overflow\n");}
else if(front==-1 && rear==-1){front=rear=0;queue[rear]=element;}
else {rear++;queue[rear]=element;}
}

void dequeue(void)
{if(front==-1 && rear==-1){printf("Underflow\n");}
else if(front==rear){printf("Element deleted=%d\n",queue[front]); front=rear=-1;}
else {printf("Element deleted=%d\n",queue[front]); front++;}
}

void display(void)
{int i;
if(front==-1 && rear==-1)printf("Queue Empty\n");
else {for(i=front; i<=rear; ++i)printf("%d\t",queue[i]);printf("\n");}
}

void peep (void)
{if(front==-1 && rear==-1)printf("Queue Empty\n");
else printf("Data at front=%d\n",queue[front]);
}
```

OUTPUT

```
10        20        -5
Data at front=10
Element deleted=10
Data at front=20
20        -5
```

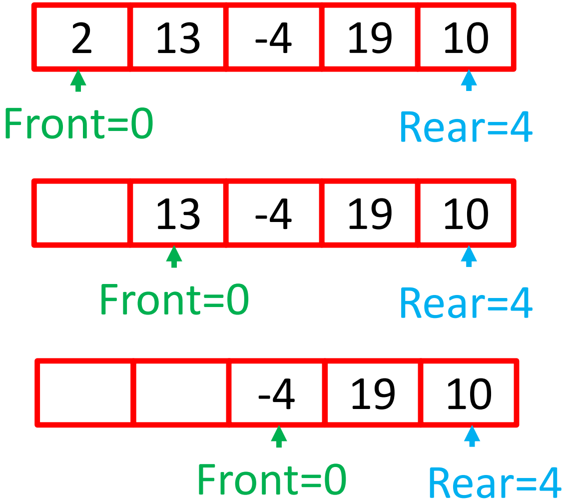
https://github.com/hbpatel1976/Data-Structure/blob/master/queue1.c

Thank You

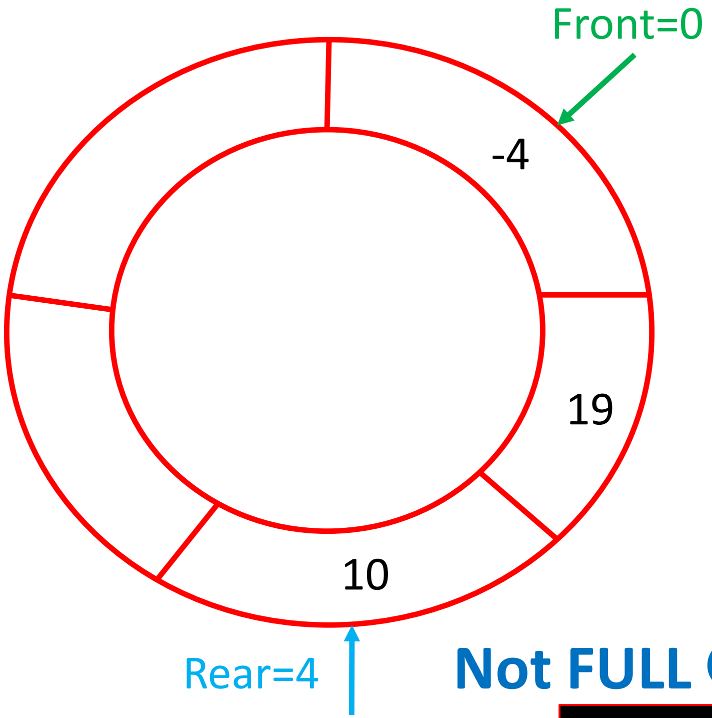
Next: Circular Queue

Circular Queue

Normal Queue



Queue FULL ☹



Not FULL ☺

Circular Queue

Drawback of regular linear queue is…

2	13	-4	19	10

size = 5

Front=0 Rear=4

```
void enqueue(int element)
{
if(rear==size-1)
  {
  printf("Overflow\n");
  }
---
}
```

So, this queue is full !

Dequeue()

	13	-4	19	10

Front=1 Rear=4

Dequeue()

		-4	19	10

Front=2 Rear=4

Still the queue is full !

Queue is full ☹

Circular Queue

If we can modify the condition little bit such that…..

Rear=0

Enqueue(67)

67		-4	19	10

Front=2

size = 5

Rear=1

Enqueue(56)

67	56	-4	19	10

Front=2

```
if ((rear+1)%size == front)
      {
      --
      }
```

What could be the condition?

Circular Queue

Previous

```
void enqueue(int element)
{
if(rear==size-1)
  {
  printf("Overflow\n");
  }
else if(front==-1 && rear==-1)
  {
  front=rear=0;
  queue[rear]=element;
  }
else
  {
  rear++;
  queue[rear]=element;
  }
}
```

New

```
void enqueue(int element)
{
if((rear+1)%size==front)
  {
  printf("Overflow\n");
  }
else if(front==-1 && rear==-1)
  {
  front=rear=0;
  queue[rear]=element;
  }
else
  {
  rear=(rear+1)%size;
  queue[rear]=element;
  }
}
```

Circular Queue

Previous

```
void dequeue(void)
{
if(front==-1 && rear==-1)
   {
   printf("Underflow\n");
   }
else if(front==rear)
   {
   printf("Element deleted=%d\n",queue[front]);
   front=rear=-1;
   }
else
   {
   printf("Element deleted=%d\n",queue[front]);
   front++;
   }
}
```

New

```
void dequeue(void)
{
if(front==-1 && rear==-1)
   {
   printf("Underflow\n");
   }
else if(front==rear)
   {
   printf("Element deleted=%d\n",queue[front]);
   front=rear=-1;
   }
else
   {
   printf("Element deleted=%d\n",queue[front]);
   front=(front+1)%size;
   }
}
```

Circular Queue

Previous

```
void display(void)
{
int i;
if(front==-1 && rear==-1)
  printf("Queue Empty\n");
else
  {
  for(i=front; i<=rear; ++i)
        {
        printf("%d\t",queue[i]);
        }
  printf("\n");
  }
}
```

New

```
void display(void)
{
int i=front;
if(front==-1 && rear==-1)
  printf("Queue Empty\n");
else
  {
  while(i != rear)
        {
        printf("%d\t",queue[i]);
        i=(i+1)%size;
        }
  printf("\n");
  }
}
```

Circular Queue Implementation (Using Arrays)

```
#include <stdio.h>
#define size 5
int queue[size];
int front=-1, rear=-1;

int main()
{
enqueue(10);
enqueue(20);
enqueue(-5);
display();
peep();
dequeue();
peep();
display();
return 0;
}
```

```
void enqueue(int element)
{
----
}

void dequeue(void)
{
----
}

void display(void)
{
----
}

void peep (void)
{
----
}
```

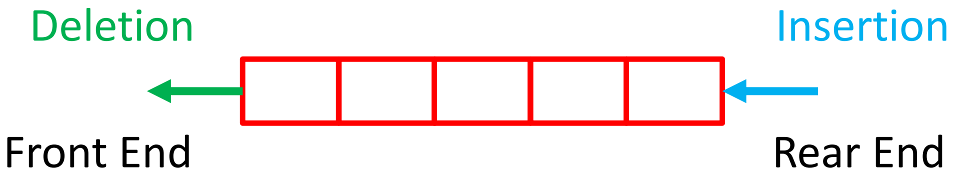
https://github.com/hbpatel1976/Data-Structure/blob/master/cqueue.c

Thank You

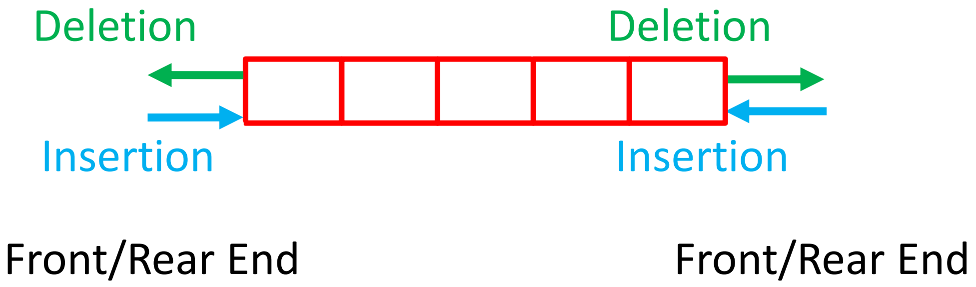
Next: Double Ended Queue (DQ)

Double Ended Queue

Normal Queue



Double Ended Queue



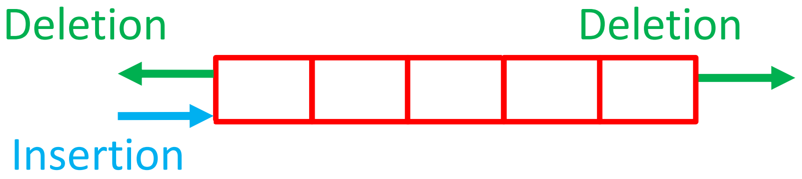
Double Ended Queue (Dequeue)

Properties of Dequeue

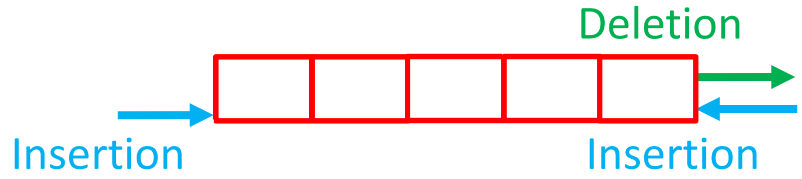
It is having properties of both, stack (LIFO) and queue (FIFO)

Two types of Dequeue: (a) Input restricted and (b) Output restricted

(a) Input restricted: Insertion is allowed from only one end, but deletion from both the ends

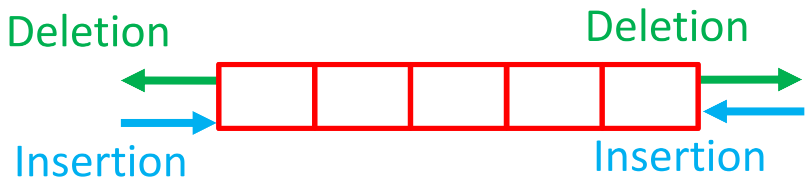


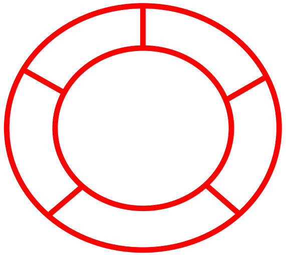
(b) Output restricted: Insertion is allowed from both end, but deletion from one end only



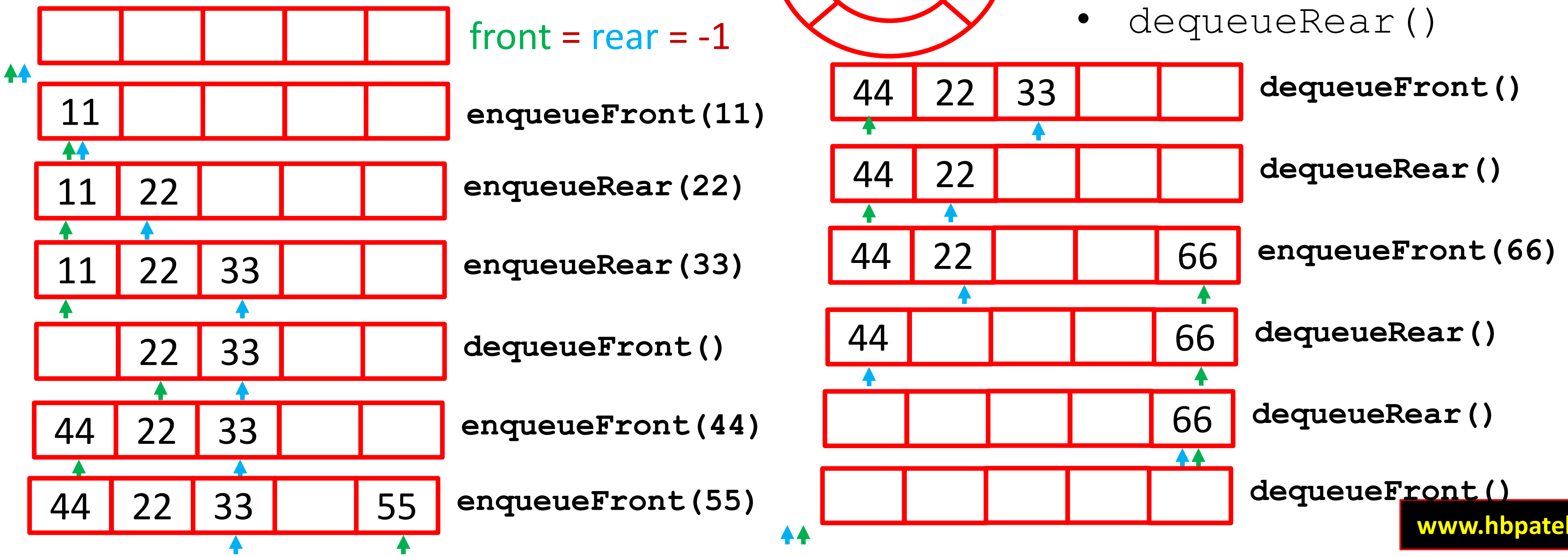
Operations on Dequeue: (i) Insert at front (ii) Delete from front (iii) Insert at rear and (iv) Delete from rear (v) getFront (vi) getRear

Dequeue Implementation





- enqueueFront()
- enqueueRear()
- dequeueFront()
- dequeueRear()



Dequeue Implementation

```
void enqueueFront(int element)
{
if((front==0 && rear==size-1) || (front==rear+1)) {printf("Queue is full\n");}
else if(front==-1 && rear==-1) {front=rear=0; dequeue[front]=element;}
else if(front==0) {front=size-1; dequeue[front]=element;}
else {front--; dequeue[front]=element;}
}
```

Dequeue Implementation

```
void enqueueRear(int element)
{
          if((front==0 && rear==size-1) || (front==rear+1)) {printf("Queue is full\n");}
          else if(front==-1 && rear==-1) {front=rear=0; dequeue[rear]=element;}
          else if(rear==size-1) {rear=0; dequeue[rear]=element;}
          else {rear++; dequeue[rear]=element;}
}
```

Dequeue Implementation

```
void dequeueFront(void)
{
          if(front==-1 && rear==-1){printf("Queue is empty\n");}
          else if(front==rear) {printf("Element deleted = %d\n",dequeue[front]); front=rear=-1;}
          else if (front==size-1) {printf("Element deleted = %d\n",dequeue[front]); front=0;}
          else {printf("Element deleted = %d\n",dequeue[front]); front++;}
}
```

Dequeue Implementation

```
void dequeueRear(void)
{
        if(front==-1 && rear==-1){printf("Queue is empty\n");}
        else if(front==rear) {printf("Element deleted = %d\n",dequeue[rear]); front=rear=-1;}
        else if (rear==0) {printf("Element deleted = %d\n",dequeue[front]); rear=size-1;}
        else {printf("Element deleted = %d\n",dequeue[rear]); rear--;}
}
```

Dequeue Implementation

```
void display(void)
{
int i=front;
printf("Dequeue -> \t");
while (i != rear)
          {
          printf("%d\t",dequeue[i]);
          i=(i+1)%size;
          }
printf("%d\n",dequeue[rear]);
}
```

```
void getFront (void)
{
printf("Front Element = %d\n",dequeue[front]);
}
```

```
void getRear (void)
{
printf("Rear Element = %d\n",dequeue[rear]);
}
```

Dequeue Implementation

```
#include <stdio.h>
#define size 5
int dequeue[size];
int front=-1, rear=-1;
int main()
{
enqueueFront(11);
enqueueRear(22);
enqueueRear(33);
display();
dequeueFront();
enqueueFront(44);
enqueueFront(55);
getFront();
display();
dequeueFront();
dequeueRear();
dequeueRear();
enqueueFront(66);
display();
getRear();
dequeueRear();
dequeueFront();
display();
return 0;
}
```

OUTPUT

```
Dequeue ->          11          22          33
Element deleted = 11
Front Element = 55
Dequeue ->          55          44          22          33
Element deleted = 55
Element deleted = 33
Element deleted = 22
Dequeue ->          66          44
Rear Element = 44
Element deleted = 44
Element deleted = 66
Dequeue ->          0
```

https://github.com/hbpatel1976/Data-Structure/blob/master/dequeue.c

Thank You

Next: Priority Queue

Priority Queue

Elements	Priority	
A	2	
B	4	
C	1	Highest
D	5	Lowest
E	3	

Without Priority

A	B	C	D	E

With Priority

C	A	E	B	D

Implementation
1. Arrays
2. Linked List
3. Heap

Array Implementation of PQ

Elements	A	B	C	D	E
Priority	2	4	1	5	3

Insertion

A				
2				

A	B			
2	4			

C	A	B		
1	2	4		

C	A	B	D	
1	2	4	5	

C	A	E	B	D
1	2	3	4	5

Deletion (E, 3)

C	A	E	B	D
1	2	3	4	5

C	A	B	D
1	2	4	5

Array Implementation of PQ

```
void PQInsert(char newElement, int newPriority)
{
        int count=0, k;
        while (count < totalElement)
                {
                        if(newPriority>=PQPriority[count])count++;
                        else break;
                }
        if(count!=totalElement)
                for(k=totalElement; k>count; --k)
                        {
                                PQElement[k]=PQElement[k-1];
                                PQPriority[k]=PQPriority[k-1];
                        }
        PQElement[count]=newElement;
        PQPriority[count]=newPriority;
        totalElement++;
}
```

https://github.com/hbpatel1976/Data-Structure/blob/master/pqueue.c

Array Implementation of PQ

```
void PQDelete(char deleteElement, int deletePriority)
{
	int count=0,i;
	while (count < totalElement)
		{
		if(PQElement[count]==deleteElement&&PQPriority[count]==deletePriority)break;
		else count++;
		}
	if(count==totalElement)printf("The element to delete did not find in the list\n");
	else
		{
		for(i=count; i<totalElement; ++i)
			{
			PQElement[i]=PQElement[i+1];
			PQPriority[i]=PQPriority[i+1];
			}
		totalElement--;
		printf("Element %c deleted\n",deleteElement);
		}
}
```

https://github.com/hbpatel1976/Data-Structure/blob/master/pqueue.c

Array Implementation of PQ

```c
#include <stdio.h>
#define size 5
char PQElement[size*2];
int PQPriority[size*2];
int totalElement = 0;
int main()
{
          void PQInsert(char, int);
          void PQDelete(char, int);
          void display (void);
          PQInsert('A',2);
          PQInsert('B',4);
          PQInsert('C',1);
          PQInsert('D',5);
          PQInsert('E',3);
          PQInsert('F',3);
          display();
          PQDelete('C',1);
          display();
          return 0;
}
```

```c
void display(void)
{
int i;
for(i=0; i<totalElement; ++i)
  {
  printf("Element: %c Priority : %d\n", PQElement[i],PQPriority[i]);
  }
}
```

OUTPUT

```
Element: C Priority: 1
Element: A Priority: 2
Element: E Priority: 3
Element: F Priority: 3
Element: B Priority: 4
Element: D Priority: 5
Element C deleted
Element: A Priority: 2
Element: E Priority: 3
Element: F Priority: 3
Element: B Priority: 4
Element: D Priority: 5
```

https://github.com/hbpatel1976/Data-Structure/blob/master/pqueue.c

Thank You

Next: Linked List

Linked List

Static Memory Allocation

int marks [5] = {35, 89, 67, 83, 71};

marks

35	89	67	83	71
0	1	2	3	4

marks[0]	35	1000
marks[1]	89	1002
marks[2]	67	1004
marks[3]	83	1006
marks[4]	71	1008

Insertion

11

35	89	67	83	71

35	89	11	67	83	71

Deletion

35	89	67	83	71

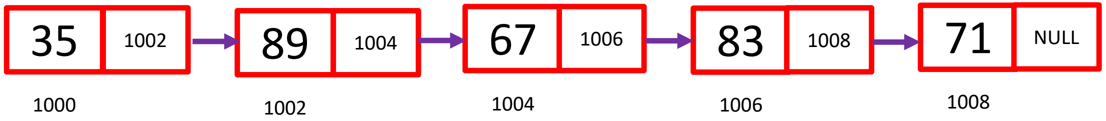
35	89	83	71

Linked List

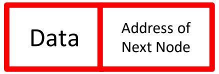
A linked list is a linear data structure consisting of a group of nodes where each node point to the next node by means of a pointer. Each node is composed of data and a reference (in other words, a link) to the next node in the sequence.

Linked List

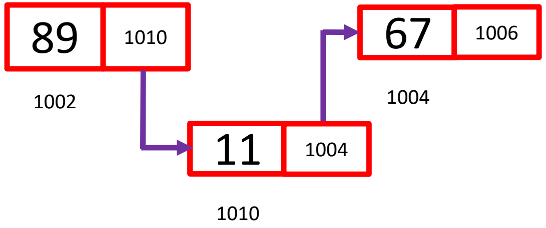
Dynamic Memory Allocation



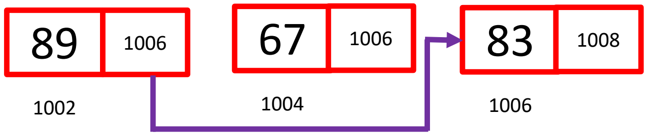
node



Insertion



Deletion



Linked List

Static Memory Allocation

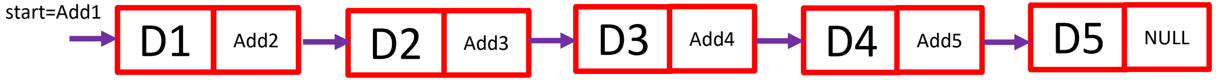
- Memory is allocated at compile time (before running/execution).
- Maximum size is fixed
- Example: Array
- Advantage: Fast (random) access. Disadvantage: Slower insertion/deletion, memory waste

Dynamic Memory Allocation

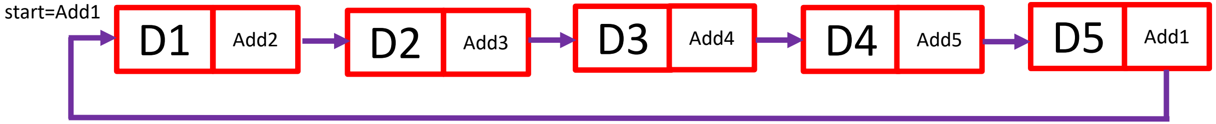
- Memory is allocated at run time
- Maximum size is flexible (can be increased/reduced)
- Example: Linked list
- Advantage: Faster insertion/deletion, Memory save Disadvantage: Slow (linear) access, Computation overhead

Linked List

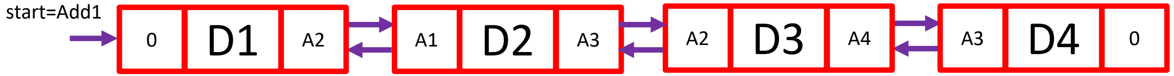
Singly Linked List



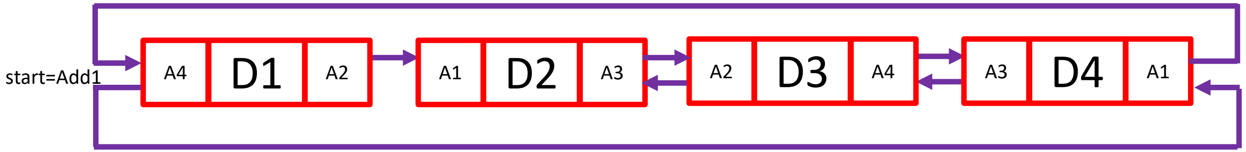
Circular Linked List



Doubly Linked List



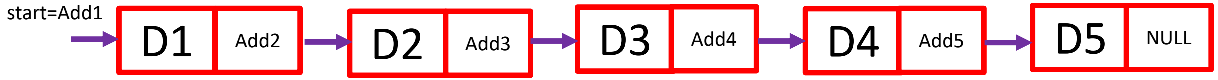
Doubly Circular Linked List



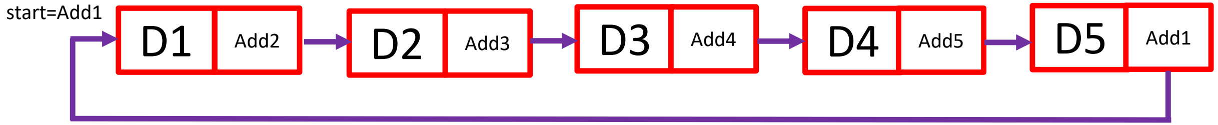
www.hbpatel.in

Linked List

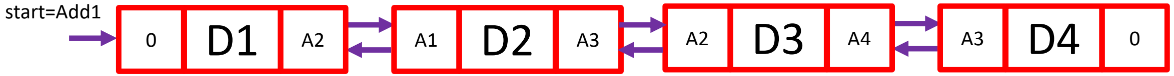
Singly Linked List



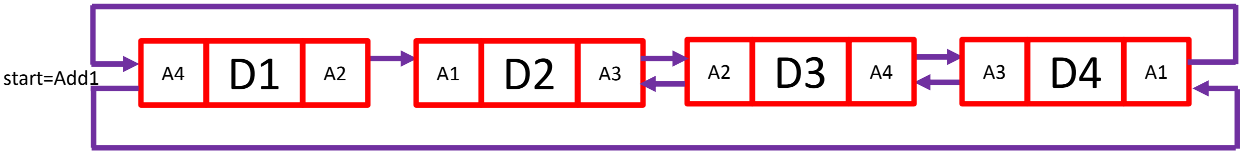
Circular Linked List



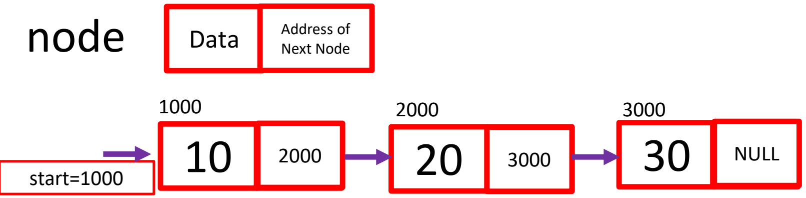
Doubly Linked List



Doubly Circular Linked List



How to create/access structure members?




```
struct node
        {
        int data;
        struct node *next;
        };
```

```
struct node *start=NULL, *newnode, *temp;
newnode = (struct node*)malloc (sizeof(struct node));
printf("Enter data : ");
scanf("%d",&newnode->data);
newnode->next=NULL;
```

Singly Linked List (Initialization)

```
#include <stdio.h>
struct node
        {
        int data;
        struct node *next;
        };
int main ()
{
struct node *start=NULL, *newnode, *temp;
int choice;
```

Singly Linked List (Creation)

```
do
{
newnode = (struct node*)malloc (sizeof(struct node));
printf("Enter data : ");
scanf("%d",&newnode->data);
newnode->next=NULL;
if(start==NULL) {start = temp = newnode;}
else
		{
		temp->next = newnode;
		temp=newnode;
		}
printf("Do you wish to continue? (1 For Yes / 0 For No) : ");
scanf("%d",&choice);
}
while(choice != 0);
```

Singly Linked List (Display)

```
temp = start;
while (temp != NULL)
			{
			printf("%d\t",temp->data);
			temp=temp->next;
			}
}
```

Singly Linked List (Whole Program)

```
#include <stdio.h>
struct node
		{
		int data;
		struct node *next;
		};
int main ()
{
struct node *start=NULL, *newnode, *temp;
int choice;
do
		{
		newnode = (struct node*)malloc (sizeof(struct node));
		printf("Enter data : ");
		scanf("%d",&newnode->data);
		newnode->next=NULL;
		if(start==NULL) {start = temp = newnode;}
		else
				{
				temp->next = newnode;
				temp=newnode;
				}
		printf("Do you wish to continue? (1 For Yes / 0 For No) : ");
		scanf("%d",&choice);
		}while(choice != 0);
temp = start;
while (temp != NULL)
		{
		printf("%d\t",temp->data);
		temp=temp->next;
		}
}
```

```
Enter data : 10
Do you wish to continue? (1 For Yes / 0 For No) : 1
Enter data : 20
Do you wish to continue? (1 For Yes / 0 For No) : 1
Enter data : 30
Do you wish to continue? (1 For Yes / 0 For No) : 0
10      20      30
```

https://github.com/hbpatel1976/Data-Structure/blob/master/llist1.c

Thank You

Next: Linked List (Insertion)

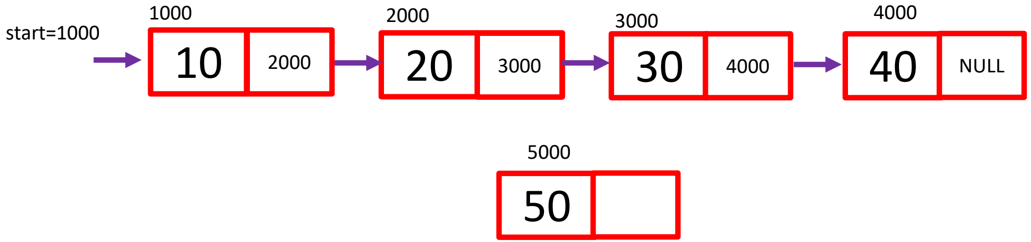
Insertion in Singly Linked List

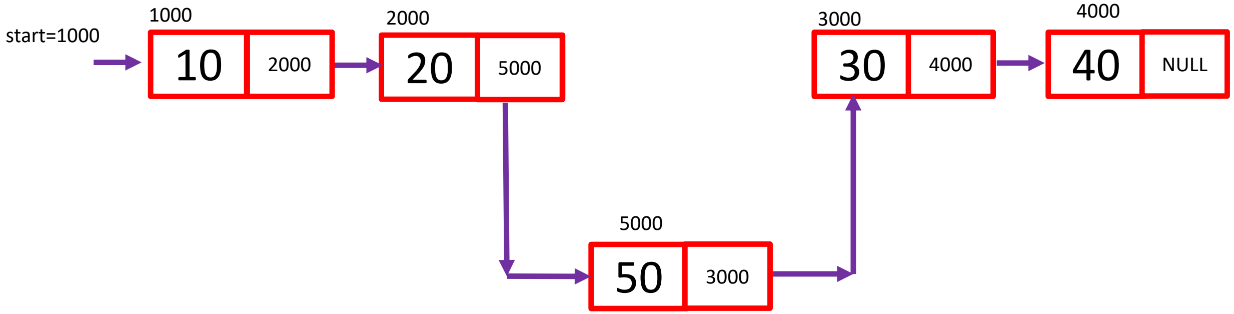
Insertion in the Beginning

Insertion at the End

Insertion in between (after *pos*)

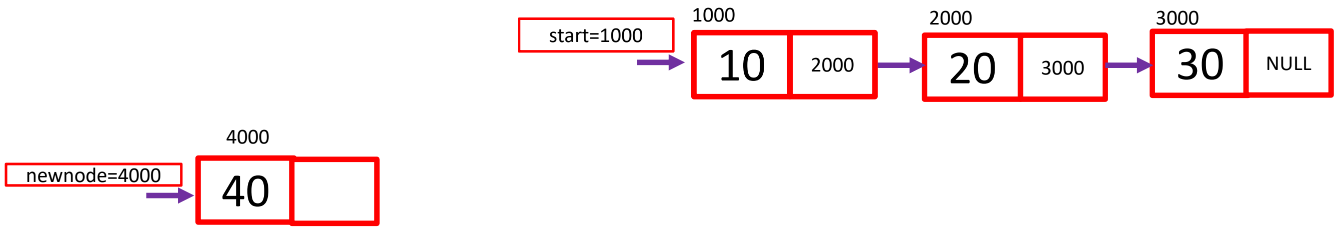
Insertion in Singly Linked List





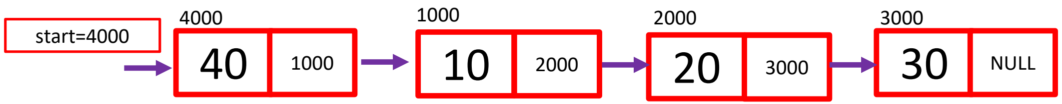
Insertion in Singly Linked List

Insertion in the Beginning



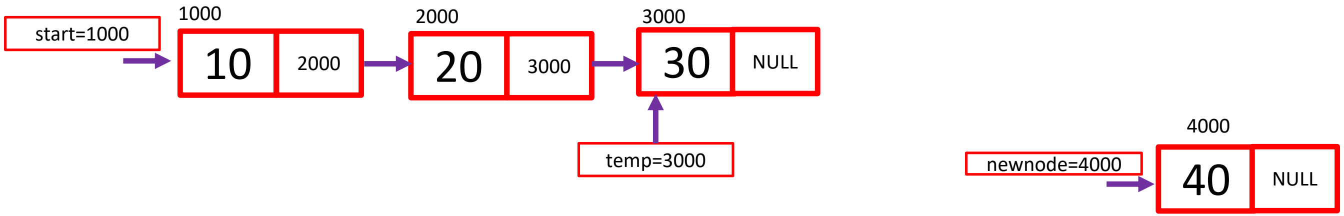

```
newnode = (struct node*) malloc (sizeof (struct node));
```

```
void insertBegin(void)
{
newnode->next=start;
start=newnode;
}
```



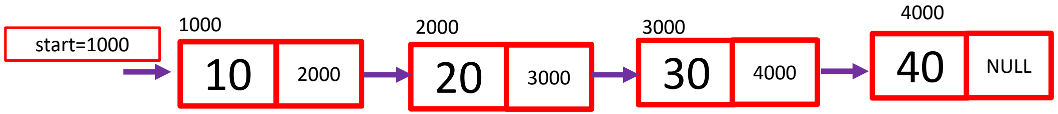
Insertion in Singly Linked List

Insertion at the End



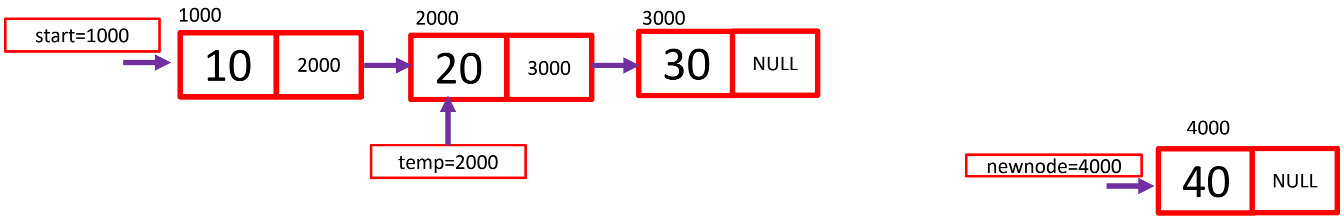

```
newnode = (struct node*) malloc (sizeof (struct node));
```

```
void insertEnd(void)
{
temp = start;
while (temp->next != NULL)
          {
          temp=temp->next;
          }
temp->next = newnode;
}
```



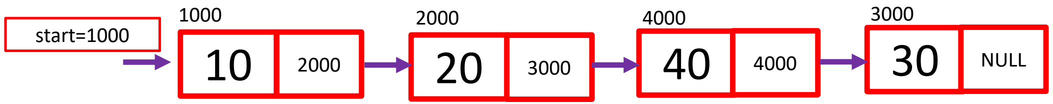
Insertion in Singly Linked List

Insertion in between (after *pos*)




```
void insertPos(int p)
{
int count=1;
temp=start;
while (count < p)
          {
          temp=temp->next;
          count++;
          }
newnode->next = temp->next;
temp->next = newnode;
}
```

```
newnode = (struct node*) malloc (sizeof (struct node));
pos=2;
```



Insertion in Singly Linked List

```
#include <stdio.h>
struct node
        {
        int data;
        struct node *next;
        };
int totalNode=0;
struct node *start=NULL, *newnode, *temp;
int main ()
{
int choice, pos;
do      {
        printf("\n1: Insert in beginning\n");
        printf("2: Insert at end\n");
        printf("3: Insert after a position\n");
        printf("4: Display\n");
        printf("5: Exit\n");
        printf("Enter your choice : ");
        scanf("%d", &choice);
        if(choice==1 || choice==2 || choice==3)
        {       newnode = (struct node*) malloc (sizeof (struct node));
                printf("Enter data : ");
                scanf("%d",&newnode->data);
                newnode->next=NULL;
        }
        switch(choice)  {case 1:        insertBegin();break;
                        case 2:         insertEnd();break;
                        case 3:         printf("Enter position: ");
                                        scanf("%d",&pos);
                                        insertPos(pos);break;
                        case 4:         display();break;
                        case 5:         break;
                        default:        printf("Invalid Choice...Please try again...\n");
                        }
        }while(choice != 5);
}
```

Insertion in Singly Linked List

```
void insertBegin(void)
{
newnode->next=start;
start=newnode;
}
```

```
void insertPos(int p)
{
int count=1;
temp=start;
while (count < p)
        {
        temp=temp->next;
        count++;
        }
newnode->next = temp->next;
temp->next = newnode;
}
```

```
void insertEnd(void)
{
temp = start;
while (temp->next != NULL)
        {
        temp=temp->next;
        }
temp->next = newnode;
}
```

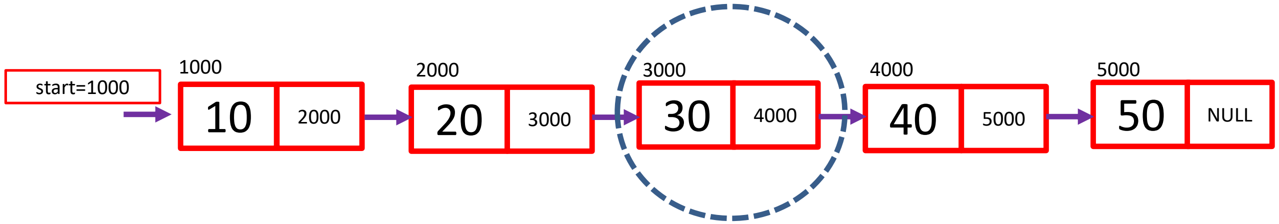
```
void display(void)
{
temp=start;
while(temp!=NULL)
{
        printf("%d\t",temp->data);
        temp=temp->next;
}
}
```

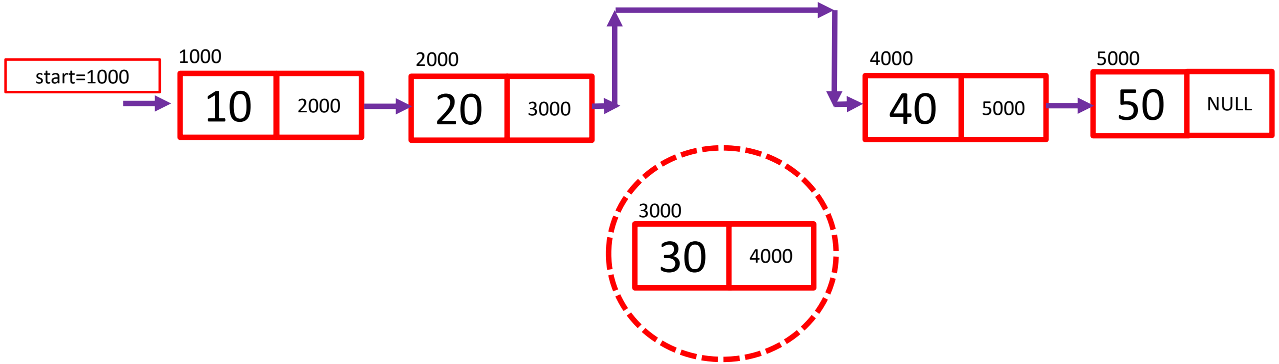
https://github.com/hbpatel1976/Data-Structure/blob/master/llinsert.c

Thank You

Next: Linked List (Deletion)

Deletion from Singly Linked List





Deletion from Singly Linked List

Deletion from the Beginning

Deletion from the End

Deletion from specific *pos*

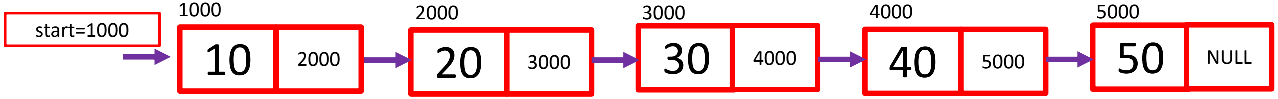
Deletion from Singly Linked List

Insert at the End

```
void insertEnd(int element)
{
newnode = (struct node *) malloc (sizeof(struct node));
newnode -> data = element;
newnode -> next = NULL;
if(start==NULL)
          {
          start=newnode;
          }
else
          {
          temp = start;
          while (temp->next != NULL)
                    {
                    temp=temp->next;
                    }
          temp->next = newnode;
          }
}
```

Deletion from Singly Linked List

Deletion from the Beginning

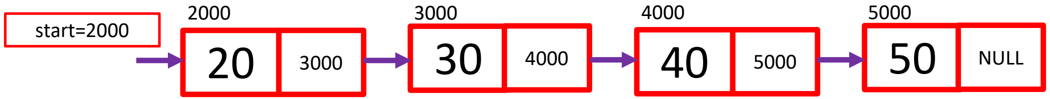


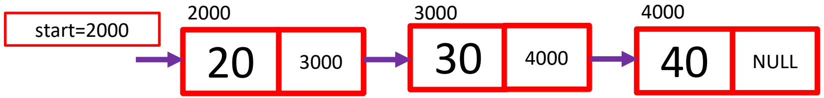

```
void deleteBeginning ()
{
if(start == NULL)
{
          printf("No Element in the List\n");
}
else
{
          temp = start;
          start = start -> next;
          free (temp);
}
}
```

Deletion from Singly Linked List

Deletion from the End

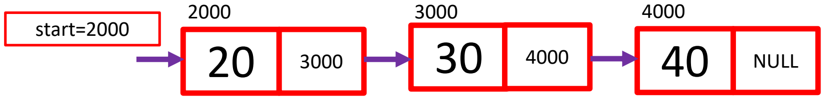
```
void deleteEnd ()
{
temp = start;
if (temp->next == NULL)
{           start = NULL;
            free (temp);
}
else
{           while (temp -> next -> next != NULL)
            {
                        temp = temp -> next;
            }
            free (temp->next);
            temp->next=NULL;
}
}
```



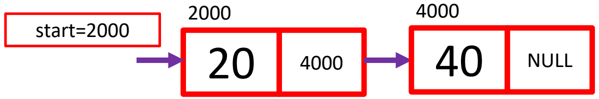


Deletion from Singly Linked List

Deletion from specific *pos*



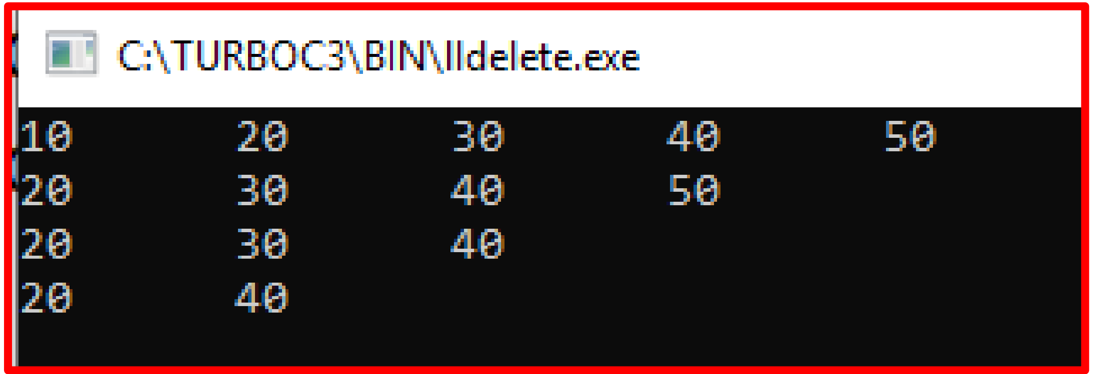

```
void deletePosition (int p)
{
            temp = start;
            int i;
            for(i=1; i<p-1; ++i)
            {
                        temp = temp -> next;
            }
            nextnode = temp -> next;
            temp -> next = nextnode -> next;
            free (nextnode);
}
```



Deletion from Singly Linked List

```
#include <stdio.h>
struct node
          {
          int data;
          struct node *next;
          };
struct node *start=NULL, *newnode,
int main ()
{
          insertEnd(10);
          insertEnd(20);
          insertEnd(30);
          insertEnd(40);
          insertEnd(50);
          display();
          deleteBeginning();
          display();
          deleteEnd();
          display();
          deletePosition(2);
          display();
}
```

```
void insertEnd(int element)
{
---
```



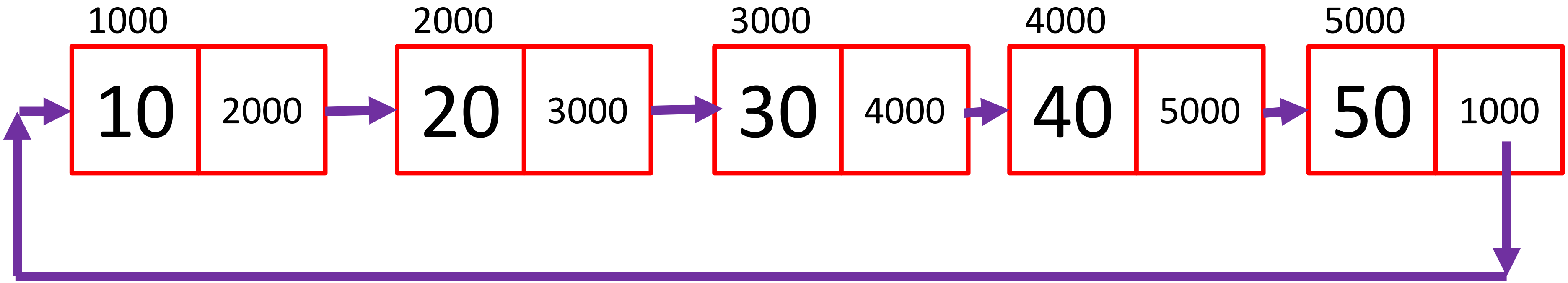

```
{
---
}
void display(void)
{
---
}
```

https://github.com/hbpatel1976/Data-Structure/blob/master/lldelete.c

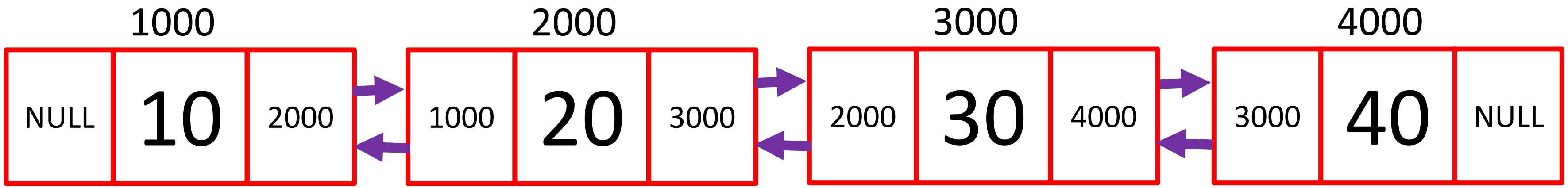
Thank You

Next: Circular Linked List

Circular Linked List

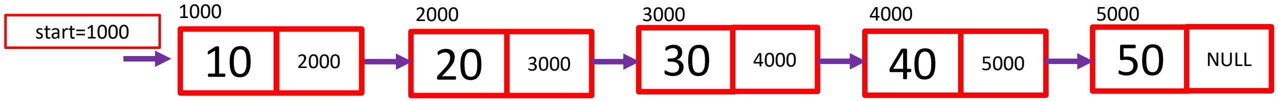


Doubly Linked List

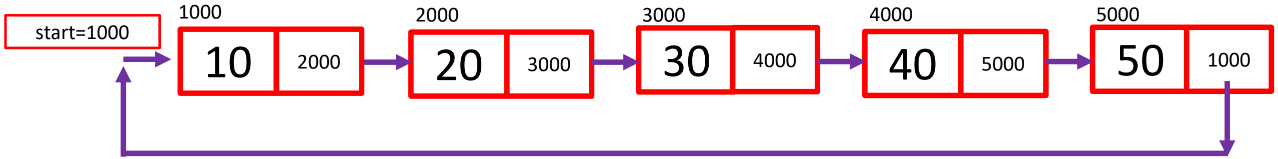


Circular Linked List

Singly Linked List



Circular Linked List



Circular Linked List

```
void createCircularLinkedList(void)
{
struct node * newnode;
int choice=1;
while (choice != 0)
    {
            newnode = (struct node *)malloc(sizeof(struct node));
            printf("Enter data to insert : ");
            scanf("%d",&newnode->data);
            newnode->next=NULL;
            if (start==NULL)start=temp=newnode;
            else
            {
                    temp->next=newnode;
                    temp=newnode;
            }
            temp->next=start;
            printf("Continue? 1: Yes, 0: No => ");
            scanf("%d",&choice);
    }
}
```

Circular Linked List

```
#include <stdio.h>
struct node     {
                int data;
                struct node *next;
                };
struct node *start=NULL, *temp;
void main ()
{               void createCircularLinkedList(void);
                void display(void);
                createCircularLinkedList();
                display();
}
void display(void)
{               temp=start;
                do
                {               printf("%d\t",temp->data);
                                temp=temp->next;
                }while(temp != start);
                printf("\n");
}
void createCircularLinkedList(void)
{--
}
```

D:\Personal\MyLectures\DSA\Programs\llcircular.exe

```
Enter data to insert : 10
Continue? 1: Yes, 0: No => 1
Enter data to insert : 20
Continue? 1: Yes, 0: No => 1
Enter data to insert : 30
Continue? 1: Yes, 0: No => 1
Enter data to insert : 40
Continue? 1: Yes, 0: No => 0
10      20      30      40
```

https://github.com/hbpatel1976/Data-Structure/blob/master/llcircular.c

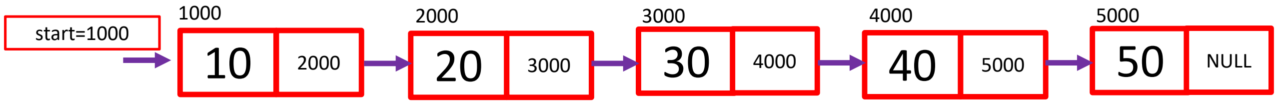
Thank You

Next: Doubly Linked List

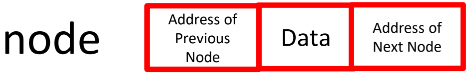
Doubly Linked List

Singly Linked List

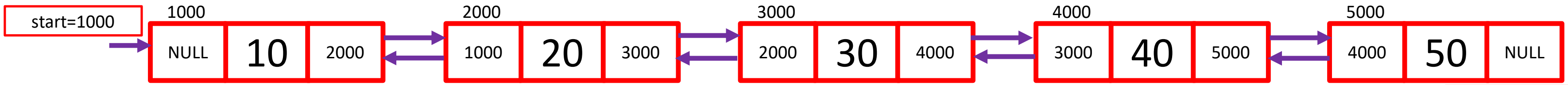

```
struct node
        {
        int data;
        struct node *next;
        };
```



Doubly Linked List




```
struct node
        {
        int data;
        struct node *next, *prev;
        };
```



Doubly Linked List

```
void createDoublyLinkedList(void)
{
struct node * newnode;
int choice=1;
while (choice != 0)
  {
            newnode = (struct node *)malloc(sizeof(struct node));
            printf("Enter data to insert : ");
            scanf("%d",&newnode->data);
            newnode->next=newnode->prev=NULL;
            if (start==NULL)start=temp=newnode;
            else
            {
                        temp->next=newnode;
                        newnode->prev=temp;
                        temp=newnode;
            }
            printf("Continue? 1: Yes, 0: No => ");
            scanf("%d",&choice);
  }
}
```

Doubly Linked List

```
#include <stdio.h>
struct node        {
                   int data;
                   struct node *next, *prev;
                   };
struct node *start=NULL, *temp;
void main ()
{                  createDoublyLinkedList();
                   display();
}

void createDoublyLinkedList(void)
{--}
void display(void)
{                  temp=start;
                   do
                   {
                            printf("%d\t",temp->data);
                            temp=temp->next;
                   }while(temp != NULL);
                   printf("\n");
}
```

D:\Personal\MyLectures\DSA\Programs\lldoubly.exe

```
Enter data to insert : 10
Continue? 1: Yes, 0: No => 1
Enter data to insert : 20
Continue? 1: Yes, 0: No => 1
Enter data to insert : 30
Continue? 1: Yes, 0: No => 1
Enter data to insert : 40
Continue? 1: Yes, 0: No => 0
10      20      30      40
```

https://github.com/hbpatel1976/Data-Structure/blob/master/lldoubly.c

Thank You

Next: Doubly Circular Linked List

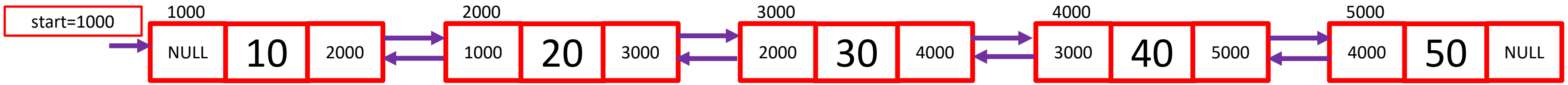
Doubly Circular Linked List

Doubly Linked List

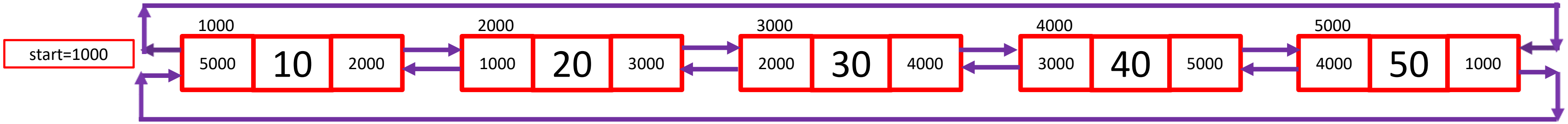
```
struct node
{
int data;
struct node *next, *prev;
};
```

node

Address of Previous Node	Data	Address of Next Node



Doubly Circular Linked List



Doubly Circular Linked List

```
#include <stdio.h>
struct node
        {
        int data;
        struct node *next, *prev;
        };
struct node *start=NULL, *end=NULL, *temp;
void main ()
{
        createDoublyCircularLinkedList();
        displayForward();
        displayBackward();
}
```

Doubly Circular Linked List

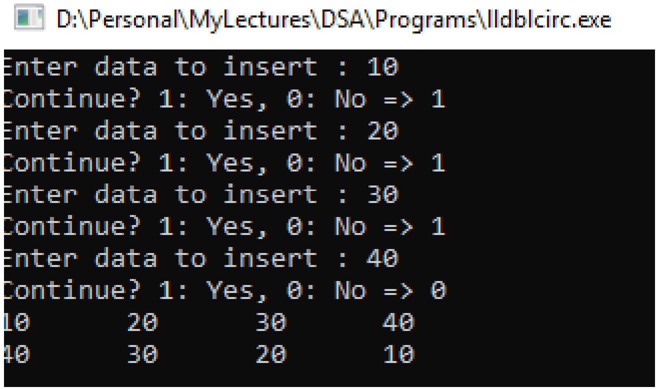
```
void createDoublyCircularLinkedList(void)
{struct node * newnode;
int choice=1;
while (choice != 0)
{                   newnode = (struct node *)malloc(sizeof(struct node));
                    printf("Enter data to insert : ");
                    scanf("%d",&newnode->data);
                    newnode->next=newnode->prev=NULL;
                    if (start==NULL){start=end=newnode;
                                        start->next=start;
                                        start->prev=start;
                                        }
                    else                {end->next=newnode;
                                        newnode->prev=end;
                                        newnode->next=start;
                                        start->prev=newnode;
                                        end=newnode;
                                        }
                    printf("Continue? 1: Yes, 0: No => ");
                    scanf("%d",&choice);
}
}
```

D:\Personal\MyLectures\DSA\Programs\lldblcirc.exe

```
Enter data to insert : 10
Continue? 1: Yes, 0: No => 1
Enter data to insert : 20
Continue? 1: Yes, 0: No => 1
Enter data to insert : 30
Continue? 1: Yes, 0: No => 1
Enter data to insert : 40
Continue? 1: Yes, 0: No => 0
10      20      30      40
40      30      20      10
```

Doubly Circular Linked List

```
void displayForward(void)
{
        temp=start;
        do
        {
                printf("%d\t",temp->data);
                temp=temp->next;
        }while(temp != start);
        printf("\n");
}

void displayBackward(void)
{
        temp=end;
        do
        {
                printf("%d\t",temp->data);
                temp=temp->prev;
        }while(temp != end);
        printf("\n");
}
```

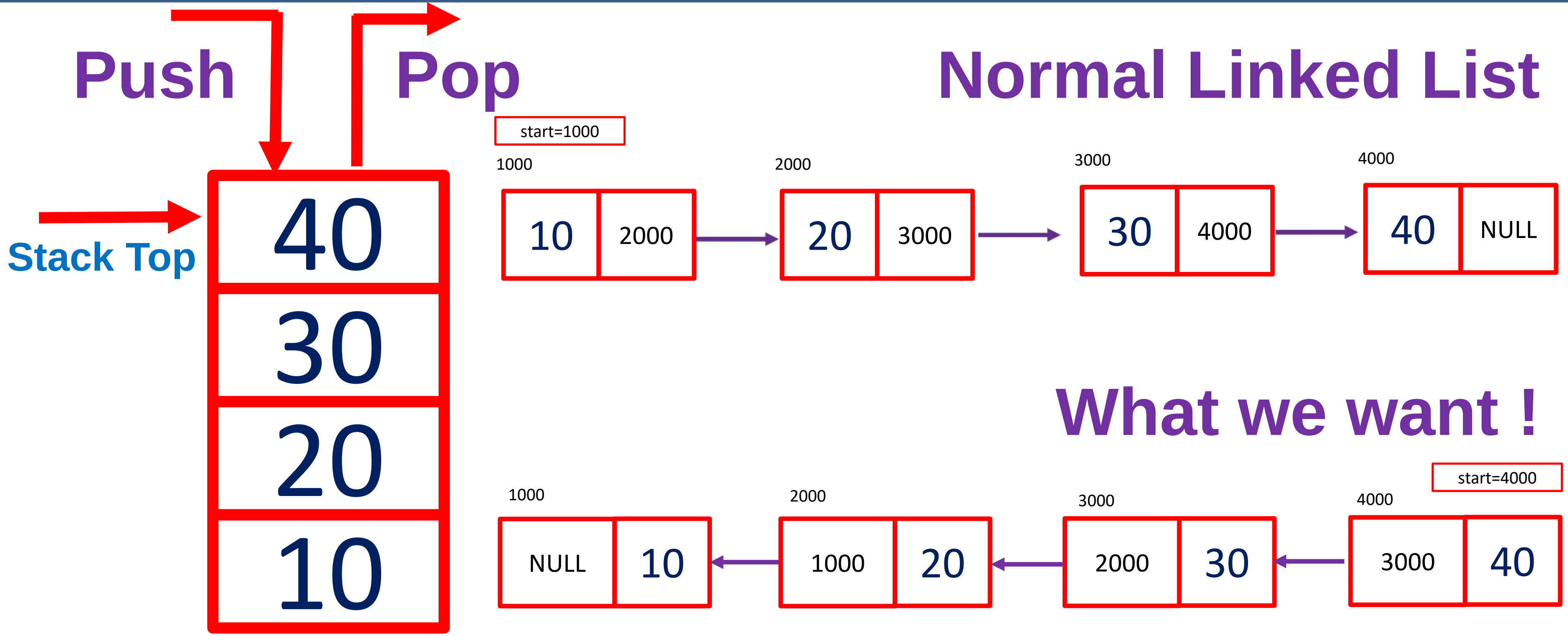


https://github.com/hbpatel1976/Data-Structure/blob/master/lldblcirc.c

Thank You

Next: Stack Implementation using Linked List

Stack Implementation using Linked List



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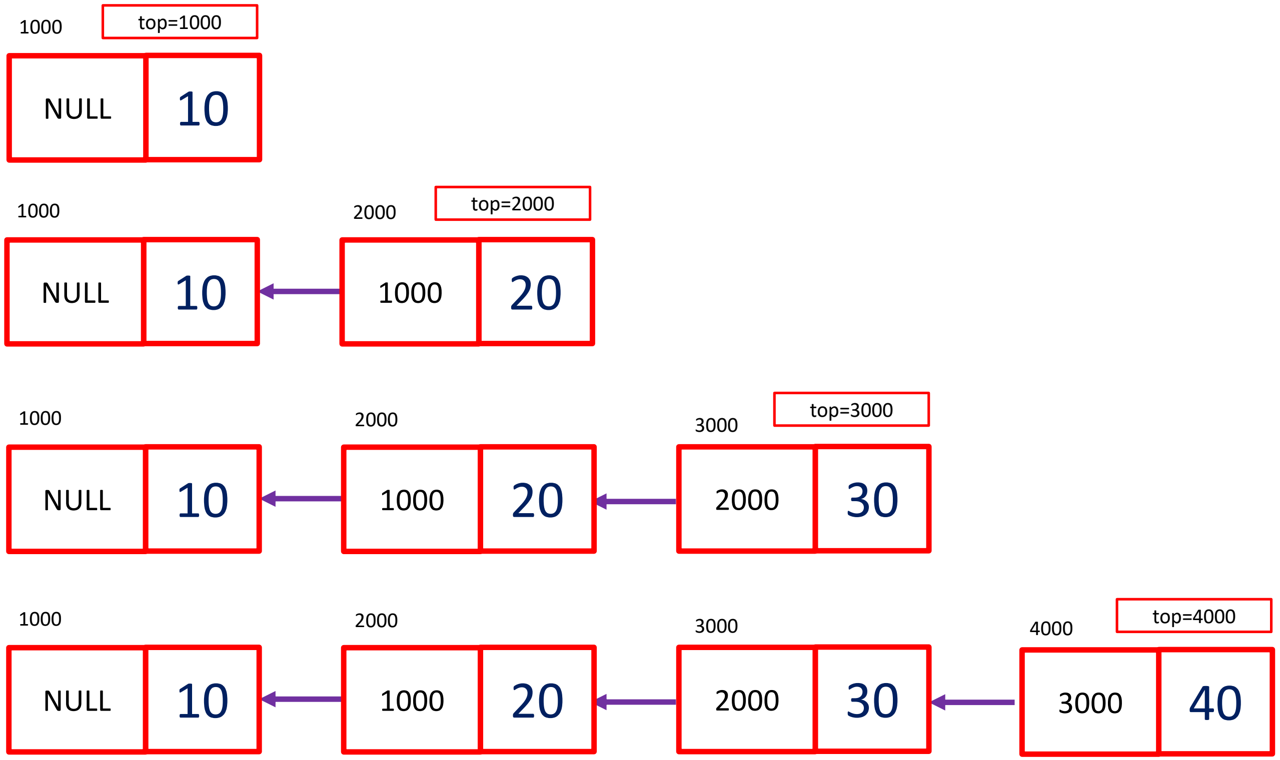
Stack Implementation using Linked List



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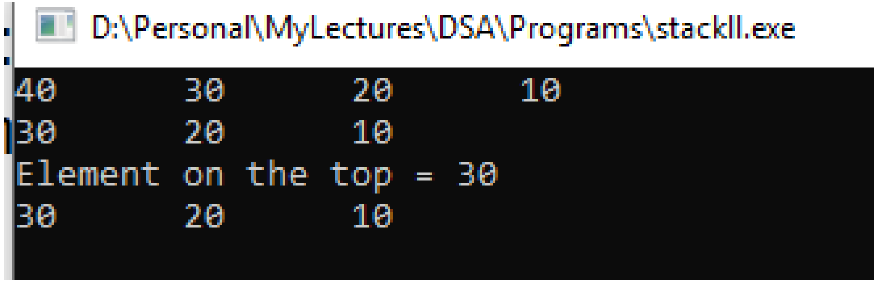
Stack Implementation using Linked List

```
#include <stdio.h>
struct node
            {
            int data;
            struct node *prev;
            };
struct node *top=NULL;
void main ()
{
            push(10);
            push(20);
            push(30);
            push(40);
            display();
            pop();
            display();
            peep();
}
```



Stack Implementation using Linked List

```
void push(int item)
{
		struct node *newnode = (struct node *)malloc(sizeof(struct node));
		newnode->data=item;
		newnode->prev=top;
		top=newnode;
}
```

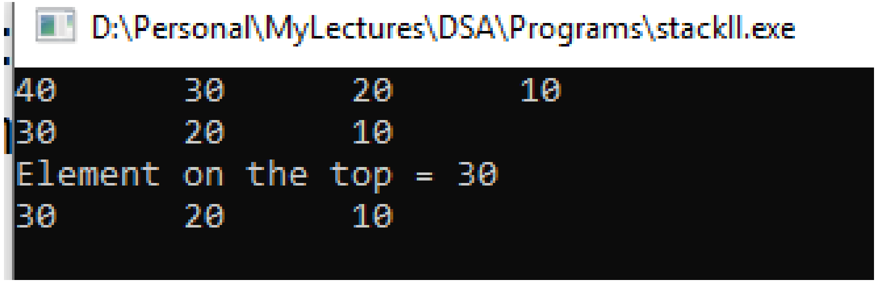
Stack Implementation using Linked List

```
void pop(void)
{
		struct node *temp=top;
		if(top==NULL){printf("Stack Empty"); return;}
		else {top=top->prev;free(temp);}
}

void peep(void)
{
		if(top==NULL){printf("Stack Empty"); return;}
		else {printf("Element on the top = %d\n",top->data);}
}
```

Stack Implementation using Linked List

```
void display(void)
{
        struct node *temp=top;
        while(temp!=NULL)
        {
                printf("%d\t",temp->data);
                temp=temp->prev;
        }
        printf("\n");
}
```



https://github.com/hbpatel1976/Data-Structure/blob/master/stackll.c

Thank You

Next: Queue Implementation using Linked List

Queue Implementation using Linked List

10	20	30	40	50

Insertion

Rear / Tail

Image source: alerttech.net

Deletion

Head / Front

front=1000

1000		2000		3000		4000		5000	
10	2000	20	3000	30	4000	40	5000	40	NULL

rear=5000

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Queue Implementation using Linked List

```
struct node
{int data;
struct node *next;
};
struct node *front=NULL, *rear=NULL;

void enqueue(int item)
{
struct node *newnode = (struct node *)malloc(sizeof(struct node));
newnode->data=item;
newnode->next=NULL;
if(front==NULL && rear==NULL)front=rear=newnode;
else {rear->next=newnode; rear=newnode;}
}
```

Queue Implementation using Linked List

```
void dequeue(void)
{
		struct node *temp=front;
		if(front==NULL){printf("Queue Empty"); return;}
		else {front=front->next;free(temp);}
}
```

Queue Implementation using Linked List

```
void peep(void)
{
		if(front==NULL){printf("Queue Empty"); return;}
		else
		{
				printf("Element at the front = %d\n",front->data);
				printf("Element at the end = %d\n",rear->data);
		}
}
```

Queue Implementation using Linked List

```
void display(void)
{
        struct node *temp=front;
        while(temp!=NULL)
        {
                printf("%d\t",temp->data);
                temp=temp->next;
        }
        printf("\n");
}
```

Queue Implementation using Linked List

```
void main ()
{
        enqueue(10);
        enqueue(20);
        enqueue(30);
        enqueue(40);
        display();
        dequeue();
        display();
        peep();
        display();
}
```

D:\Personal\MyLectures\DSA\Programs\queuell.exe

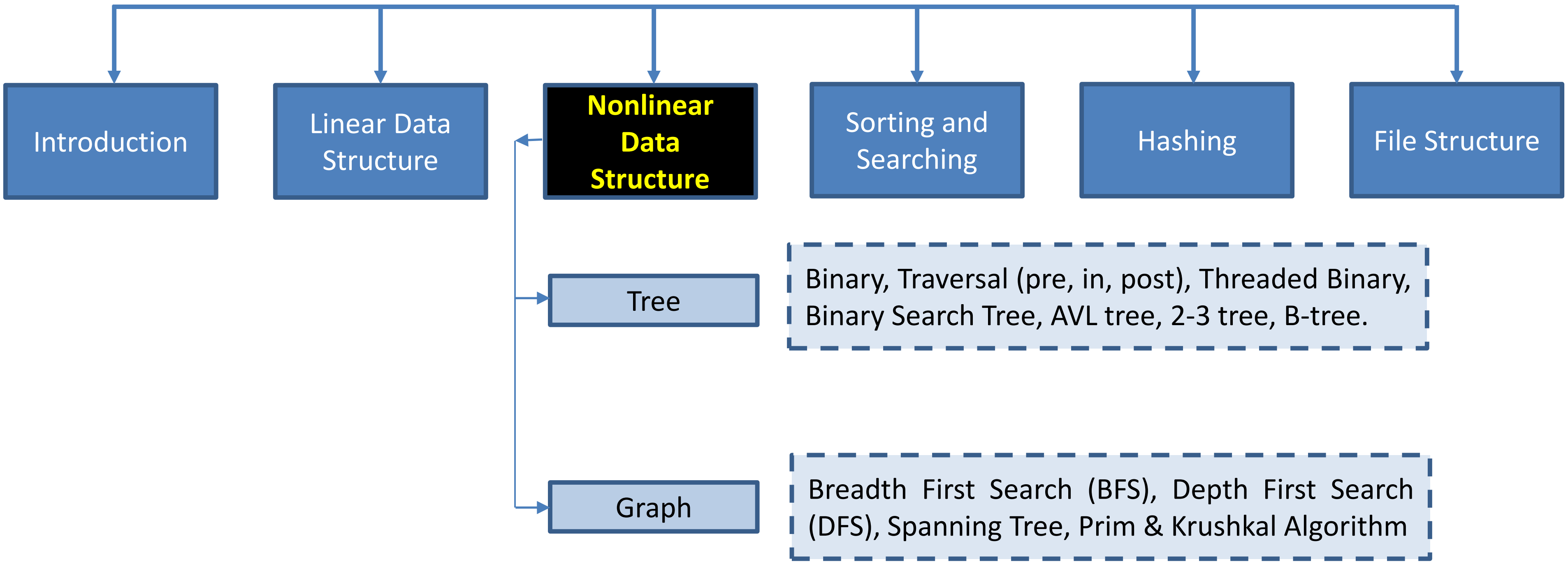
```
10      20      30      40
20      30      40
Element at the front = 20
Element at the end = 40
20      30      40
```

https://github.com/hbpatel1976/Data-Structure/blob/master/queuell.c

Thank You

Next: Introduction to Tree Data Structures

DSA: Nonlinear Data Structure



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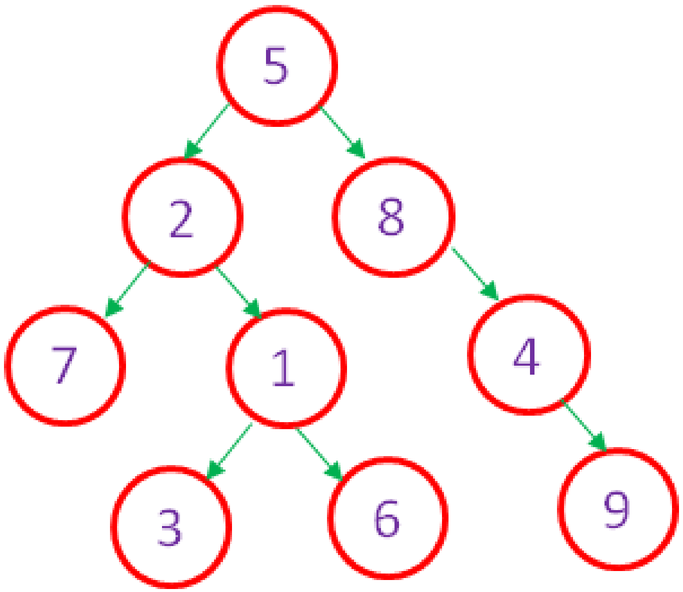
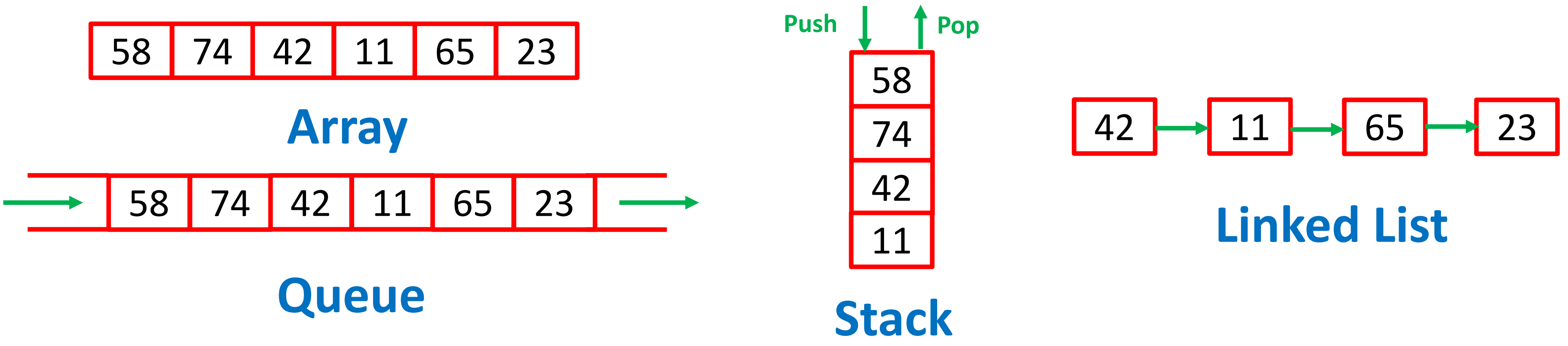
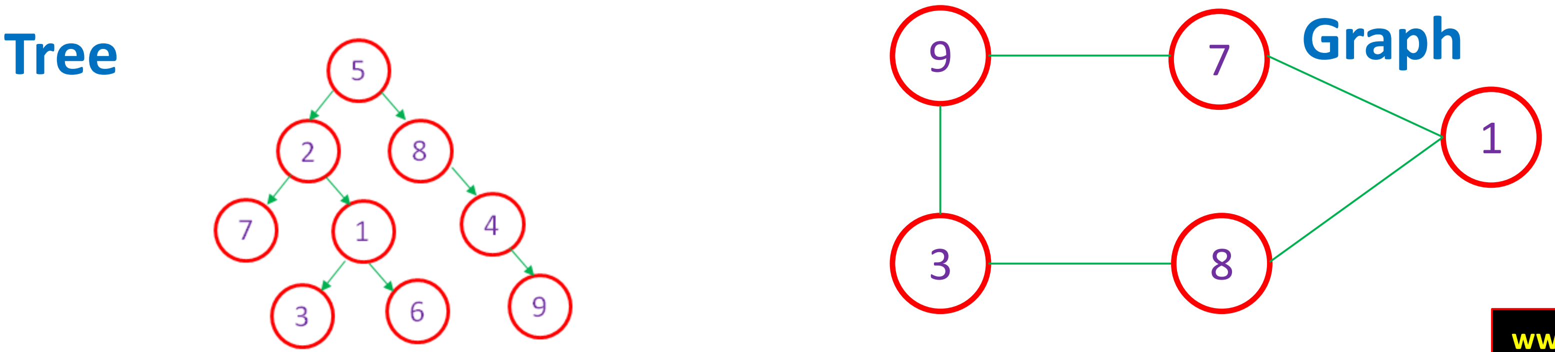
TREE Data Structures



Linear Data Structures



Nonlinear Data Structures



Linear Vs. Non-Linear DS

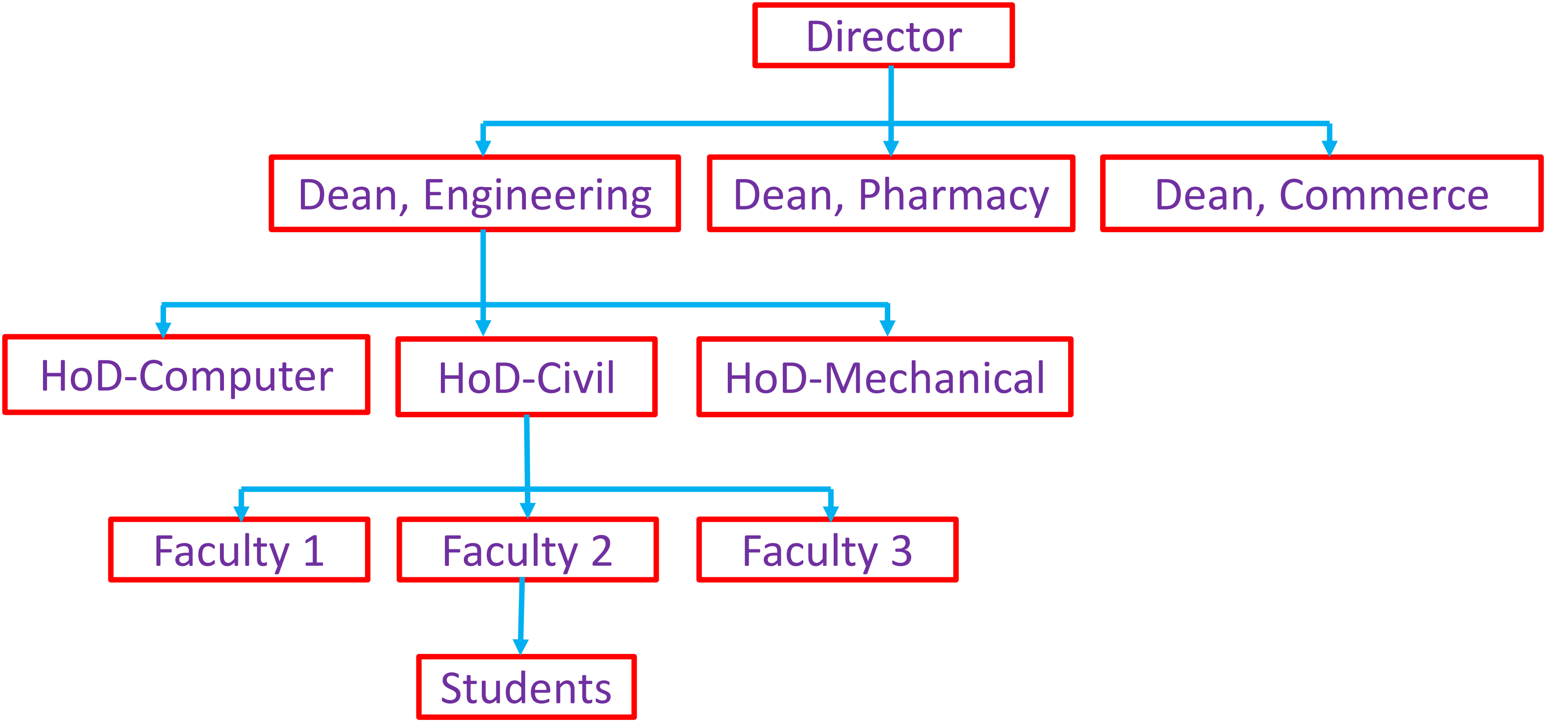
Linear Data Structure

- It arranges the data in orderly manner where the elements are attached adjacently
- Level: Single
- Implementation: Easier
- Example: Array, Stack, Linked List, Queue

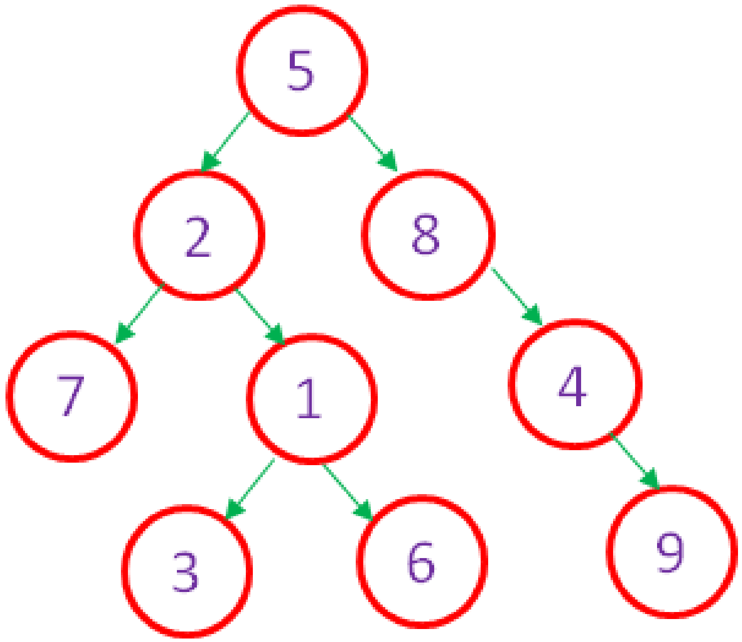
Non-linear Data Structure

- It arranges the data in sorted order, creating a relationship among the data element
- Level: Multiple
- Implementation: Difficult
- Example: Tree, Graph

Tree: Example

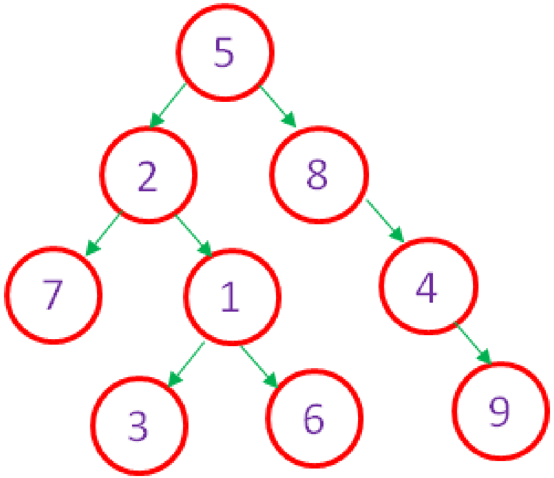


Tree



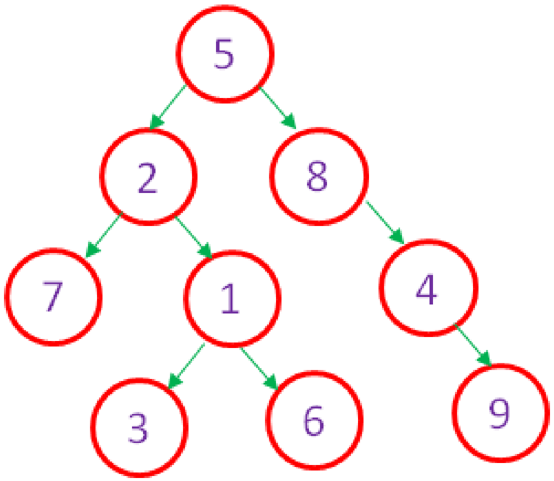
A tree is a widely used abstract data type that simulates a hierarchical tree structure, with a root value and subtrees of children with a parent node, represented as a set of linked nodes.

Tree Terminology



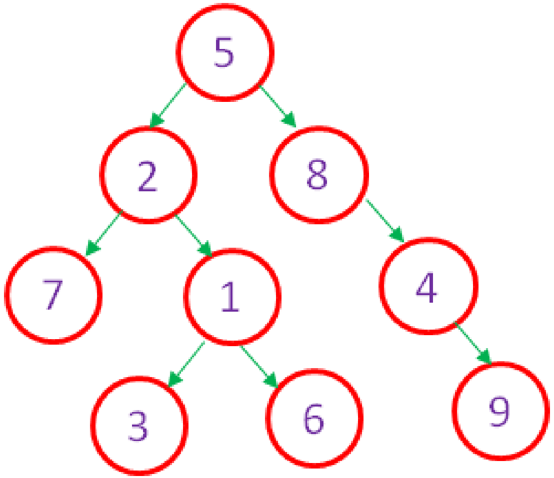
A **node** is a structure which may contain a value or condition. The topmost node in a tree is called the **root** node. Each node in a tree has zero or more **child** nodes, which are below it in the tree. A node that has a child is called the child's **parent** node (or superior). Child nodes with the same parent are **sibling** nodes.

Tree Terminology



Path refers to the sequence of nodes along the edges of a tree. The node which does not have any child node is called the **leaf** node. The **depth of a node** is the number of edges from the root to the node. The **height of a node** is the number of edges from the node to the deepest leaf. **Degree of a node** is the total number of children of that node. **Degree of a tree** is the highest degree of a node among all the nodes in the tree.

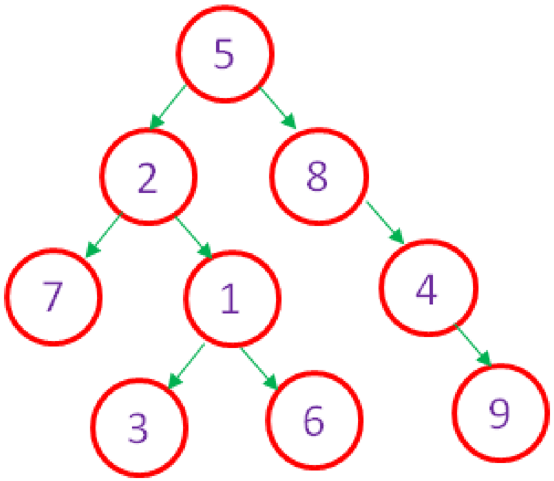
Tree Terminology



A **subtree** of a tree T is a tree S consisting of a node in T and all of its descendants in T.

The subtree corresponding to the root node is the **entire tree**; the subtree corresponding to any other node is called a **proper subtree**.

Tree Terminology



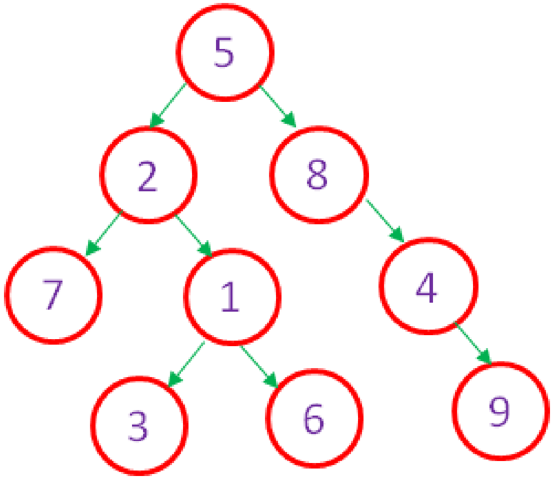
Height of a tree is height of a root node. **Level of a node** is the number of edges/distance from root to that node.

Level of a tree is **height of a tree** but **level of a node** may or may not be same as **height of a node**.

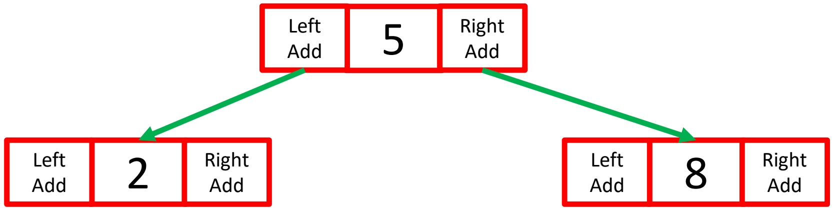
Thank You

Next: Binary Tree

Binary Tree

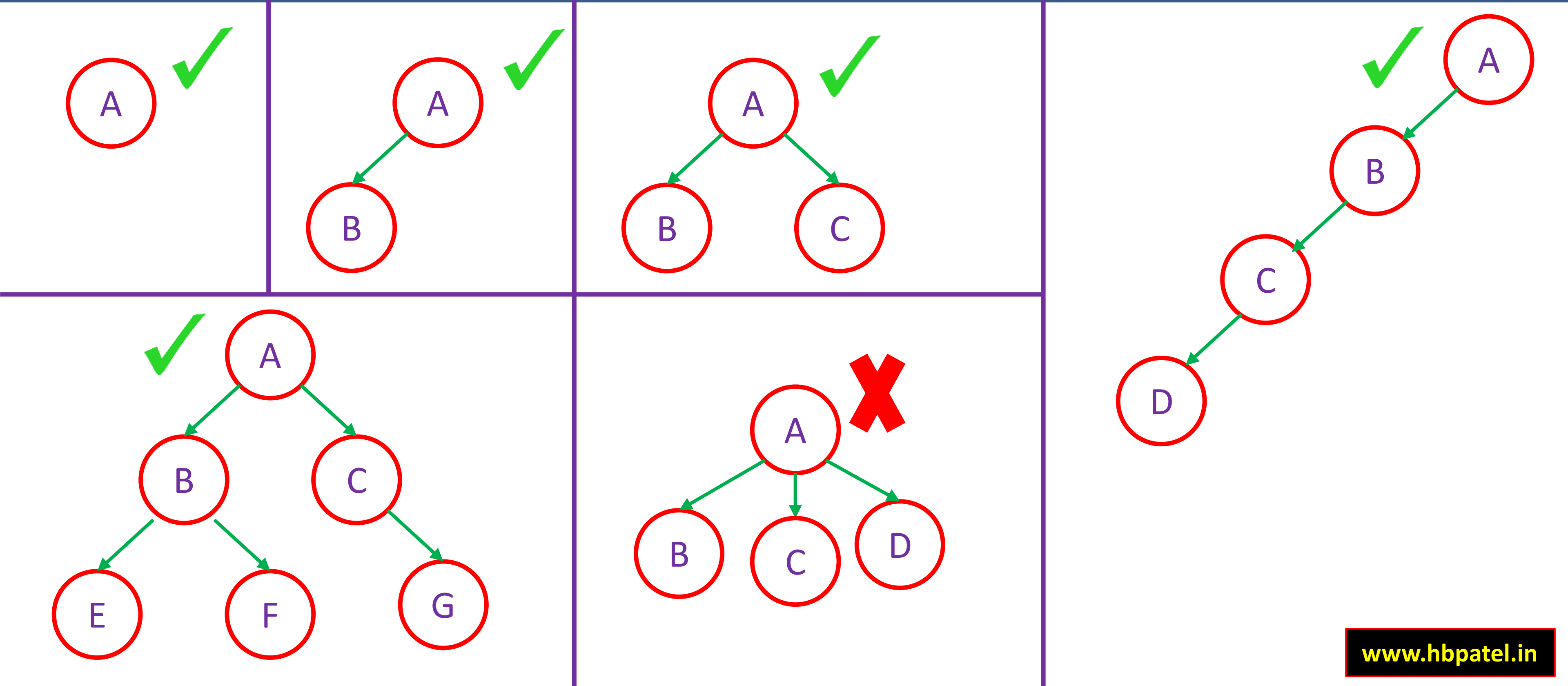


A **binary tree** is a hierarchical data structure in which each node has **at most two children** generally referred as left child and right child. Each node contains three components: Pointer to left subtree. Pointer to right subtree. Data element.




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

Binary Tree



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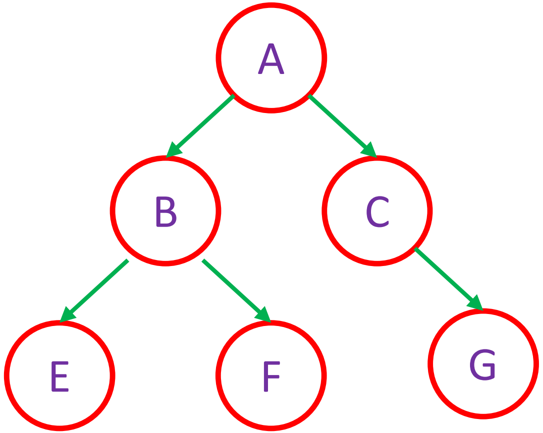
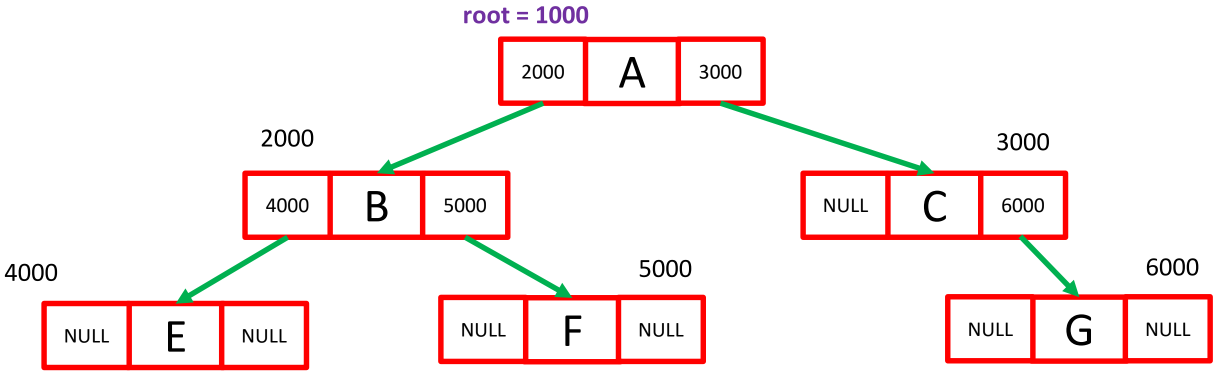
Binary Tree


A
B
C
E
F
G


root = 1000
2000
A
3000
2000
4000
B
5000
3000
NULL
C
6000
4000
NULL
E
NULL
5000
NULL
F
NULL
6000
NULL
G
NULL

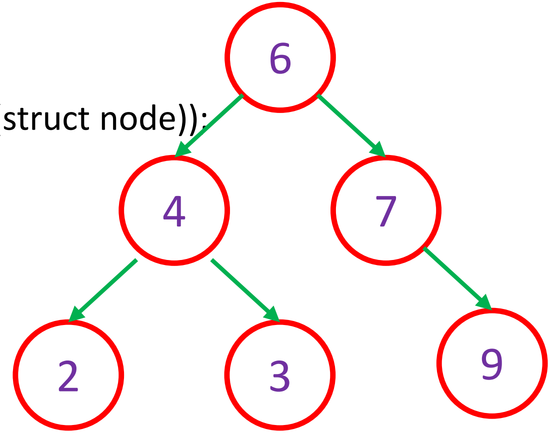
Implementation of Binary Tree

```
#include <stdio.h>
struct node
{
int data;
struct node *right, *left;
};

void main()
{
struct node *createBinTree(void);
struct node *root=NULL;
root=createBinTree();
}
```

Implementation of Binary Tree

```
struct node *createBinTree(void)
{
int d;
struct node *newnode;
printf("Enter data : (-1 to exit) : ");
scanf("%d",&d);
if(d==-1)return NULL;
newnode = (struct node*)malloc(sizeof(struct node));
newnode->data=d;
printf("Enter left node of %d :\n",d);
newnode->left = createBinTree();
printf("Enter right node of %d :\n",d);
newnode->right = createBinTree();
return newnode;
}
```



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```
Enter data : (-1 to exit) : 6
Enter left node of 6 :
Enter data : (-1 to exit) : 4
Enter left node of 4 :
Enter data : (-1 to exit) : 2
Enter left node of 2 :
Enter data : (-1 to exit) : -1
Enter right node of 2 :
Enter data : (-1 to exit) : -1
Enter right node of 4 :
Enter data : (-1 to exit) : 3
Enter left node of 3 :
Enter data : (-1 to exit) : -1
Enter right node of 3 :
Enter data : (-1 to exit) : -1
Enter right node of 6 :
Enter data : (-1 to exit) : 7
Enter left node of 7 :
Enter data : (-1 to exit) : -1
Enter right node of 7 :
Enter data : (-1 to exit) : 9
Enter left node of 9 :
Enter data : (-1 to exit) : -1
Enter right node of 9 :
Enter data : (-1 to exit) : -1
```

Source Code: https://github.com/hbpatel1976/Data-Structure/blob/master/bintree.c

Binary Tree: Properties

- Each node can have maximum 2 children
- At any level, maximum number of nodes can be 2^n, where n is the level number
- Maximum number of nodes in a tree having height h = $n^{h+1}-1$
- Minimum number of nodes in a tree having height h = h+1

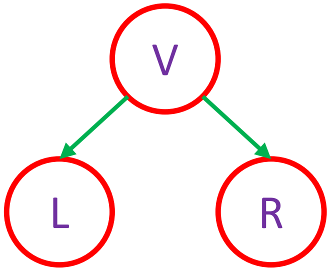
Thank You

Next: Tree Traversal

Tree Traversal

Inorder

L → V → R



Preorder

V → L → R

Postorder

L → R → V

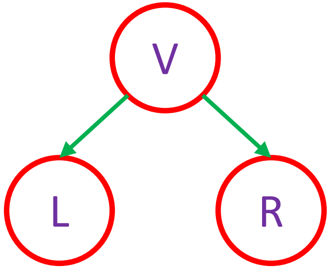
Tree Traversal

Inorder

L → V → R

Preorder

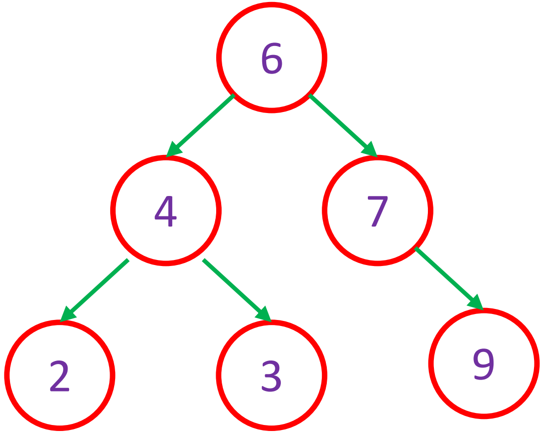
V → L → R



Postorder

L → R → V

Tree Traversal

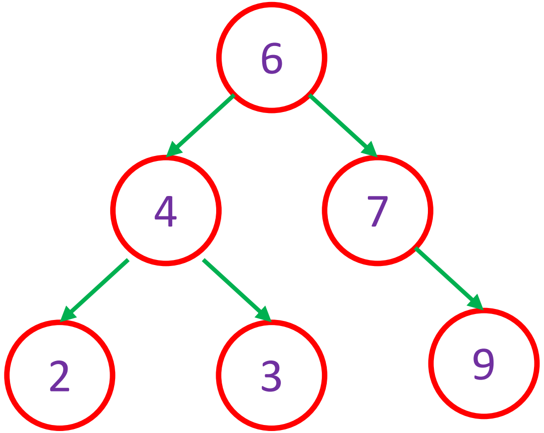


In-order Traversal: 2→4→3→6→7→9

Pre-order Traversal: 6→4→2→3→7→9

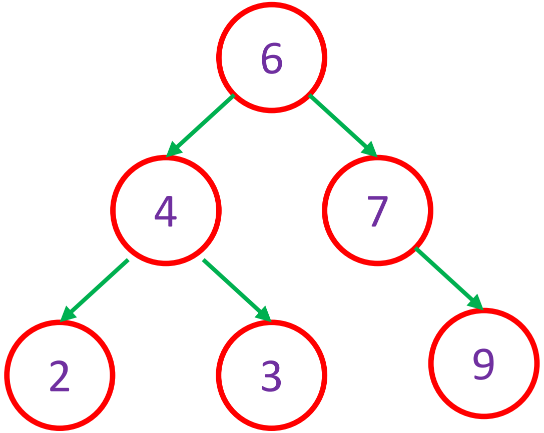
Post-order Traversal: 2→3→4→9→7→6

Pre-Order Tree Traversal



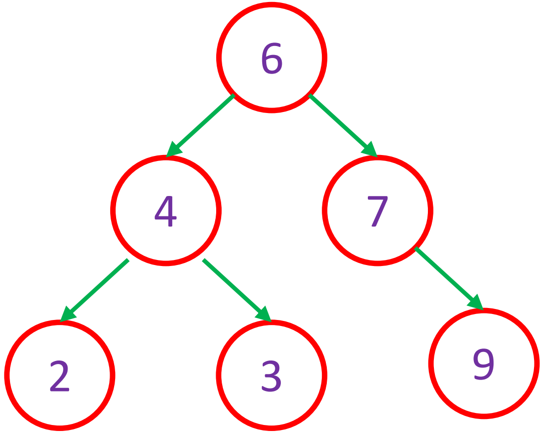

```
void preOrderTraversal (struct node *ptr)
{
        if(ptr==NULL)return;
        printf("%d ",ptr->data);
        preOrderTraversal(ptr->left);
        preOrderTraversal(ptr->right);
}
```

Post-Order Tree Traversal




```
void postOrderTraversal (struct node *ptr)
{
        if(ptr==NULL)return;
        preOrderTraversal(ptr->left);
        preOrderTraversal(ptr->right);
        printf("%d ",ptr->data);
}
```

In-Order Tree Traversal




```
void inOrderTraversal (struct node *ptr)
{
        if(ptr==NULL)return;
        preOrderTraversal(ptr->left);
        printf("%d ",ptr->data);
        preOrderTraversal(ptr->right);
}
```

Complete Tree Traversal

```
#include <stdio.h>
struct node
{
int data;
struct node *right, *left;
};
void main()
{
struct node *createBinTree(void);
void preOrderTraversal (struct node *ptr);
void postOrderTraversal (struct node *ptr);
void inOrderTraversal (struct node *ptr);

struct node *root=NULL;
root=createBinTree();

printf("\n Pre Order Tranversal : ");preOrderTraversal(root);
printf("\n Post Order Tranversal : ");postOrderTraversal(root);
printf("\n In Order Tranversal : ");inOrderTraversal(root);
}
```

```
struct node *createBinTree(void)
{
int d;
struct node *newnode = (struct node*)malloc(sizeof(struct node));
printf("Enter data : (-1 to exit) : ");
scanf("%d",&d);
if(d==-1)return NULL;
newnode->data=d;
newnode->right=NULL;
newnode->left=NULL;
printf("Enter left node of %d :\n",d);
newnode->left = createBinTree();
printf("Enter right node of %d :\n",d);
newnode->right = createBinTree();
return newnode;
}
```

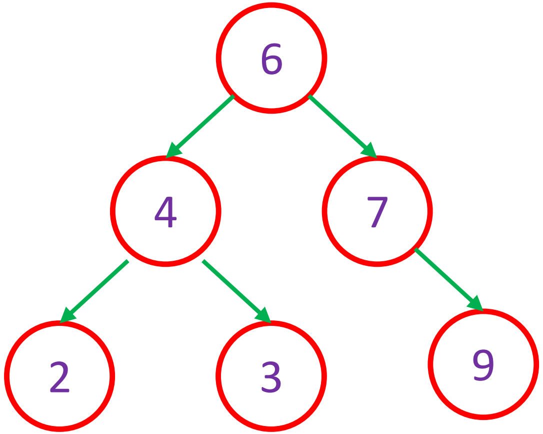
Complete Tree Traversal

```
void preOrderTraversal (struct node *ptr)
{
if(ptr==NULL)return;
printf("%d ",ptr->data);
preOrderTraversal(ptr->left);
preOrderTraversal(ptr->right);
}
void postOrderTraversal (struct node *ptr)
{
if(ptr==NULL)return;
postOrderTraversal(ptr->left);
postOrderTraversal(ptr->right);
printf("%d ",ptr->data);
}
void inOrderTraversal (struct node *ptr)
{
if(ptr==NULL)return;
inOrderTraversal(ptr->left);
printf("%d ",ptr->data);
inOrderTraversal(ptr->right);
}
```

D:\Personal\MyLectures\DSA\Programs\btreetraverse.e

```
Enter data : (-1 to exit) : 6
Enter left node of 6 :
Enter data : (-1 to exit) : 4
Enter left node of 4 :
Enter data : (-1 to exit) : 2
Enter left node of 2 :
Enter data : (-1 to exit) : -1
Enter right node of 2 :
Enter data : (-1 to exit) : -1
Enter right node of 4 :
Enter data : (-1 to exit) : 3
Enter left node of 3 :
Enter data : (-1 to exit) : -1
Enter right node of 3 :
Enter data : (-1 to exit) : -1
Enter right node of 6 :
Enter data : (-1 to exit) : 7
Enter left node of 7 :
Enter data : (-1 to exit) : -1
Enter right node of 7 :
Enter data : (-1 to exit) : 9
Enter left node of 9 :
Enter data : (-1 to exit) : -1
Enter right node of 9 :
Enter data : (-1 to exit) : -1

 Pre Order Tranversal : 6 4 2 3 7 9
 Post Order Tranversal : 2 3 4 9 7 6
 In Order Tranversal : 2 4 3 6 7 9
--------------------------------
```



Source code: https://github.com/hbpatel1976/Data-Structure/blob/master/btreetraverse.c

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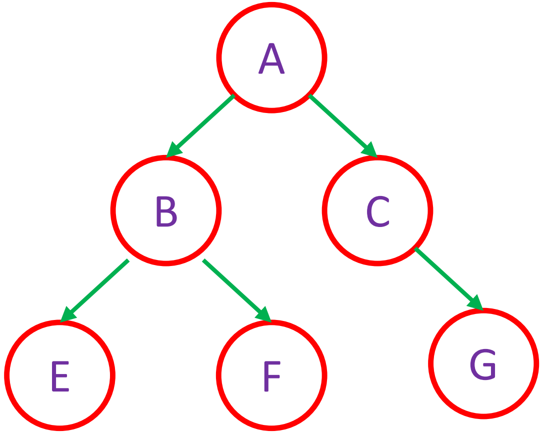
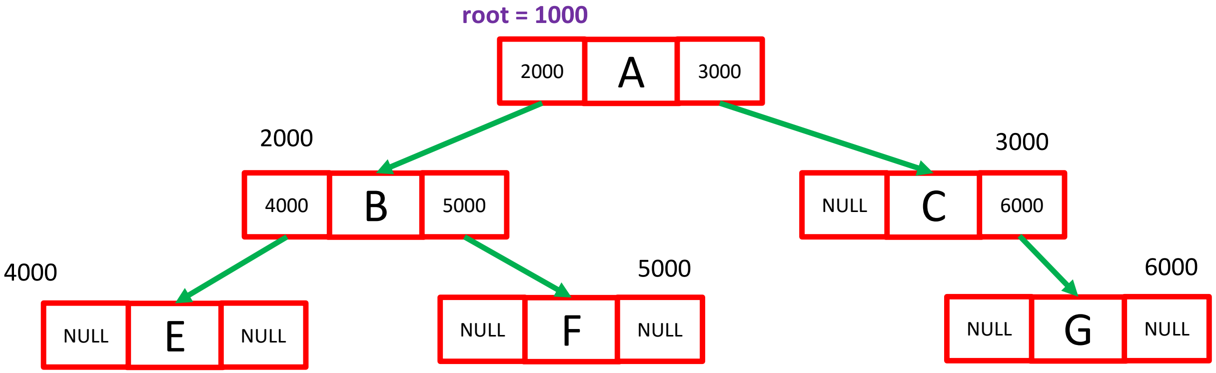
Thank You

Next: Threaded Binary Tree

Threaded Binary Tree (TBT)





Can I use the pointers, where NULL is stored, to store some other address?

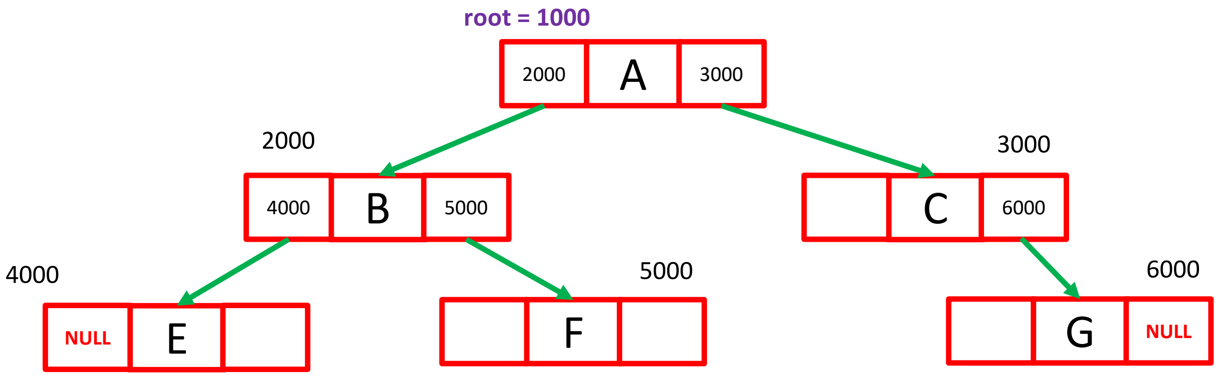
Threaded Binary Tree

Can I use the pointers, where NULL is stored, to store some other address?

Step:

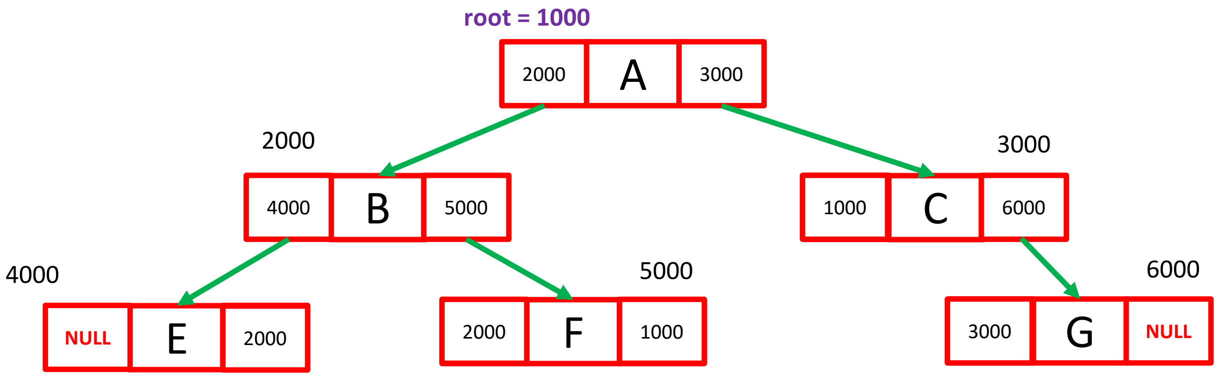
1. Keep the LEFT most and RIGHT most NULL pointers as NULL
2. Change all other NULL pointers as
   - 2.1 Left Pointer = Inorder Predecessor
   - 2.2 Right Pointer = Inorder Successor

Threaded Binary Tree



1. Keep the LEFT most and RIGHT most NULL pointers as NULL

Threaded Binary Tree



2.1 Left Pointer = Inorder Predecessor
2.2 Right Pointer = Inorder Successor

Inorder Traversal
E → B → F → A → C → G
NULL → E → B → F → A → C → G → NULL

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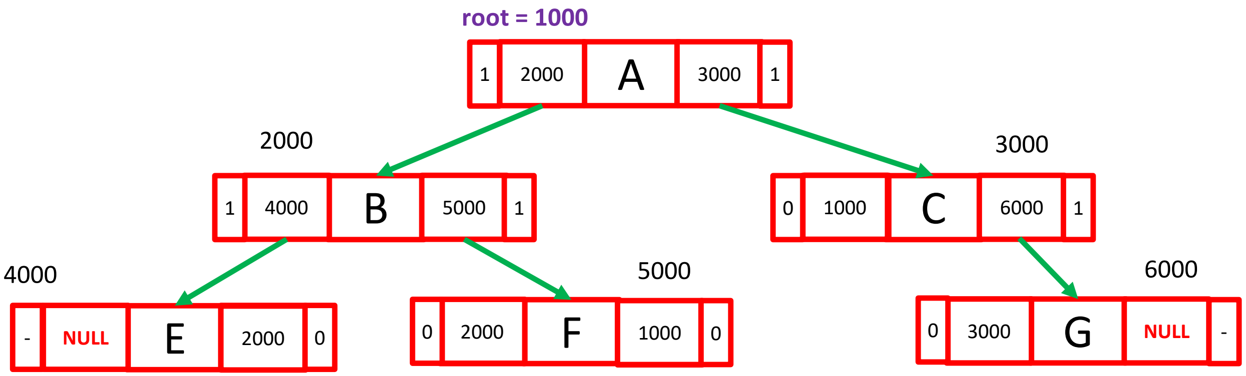
Threaded Binary Tree

How do I know that the pointer points to the parent node or some other node?

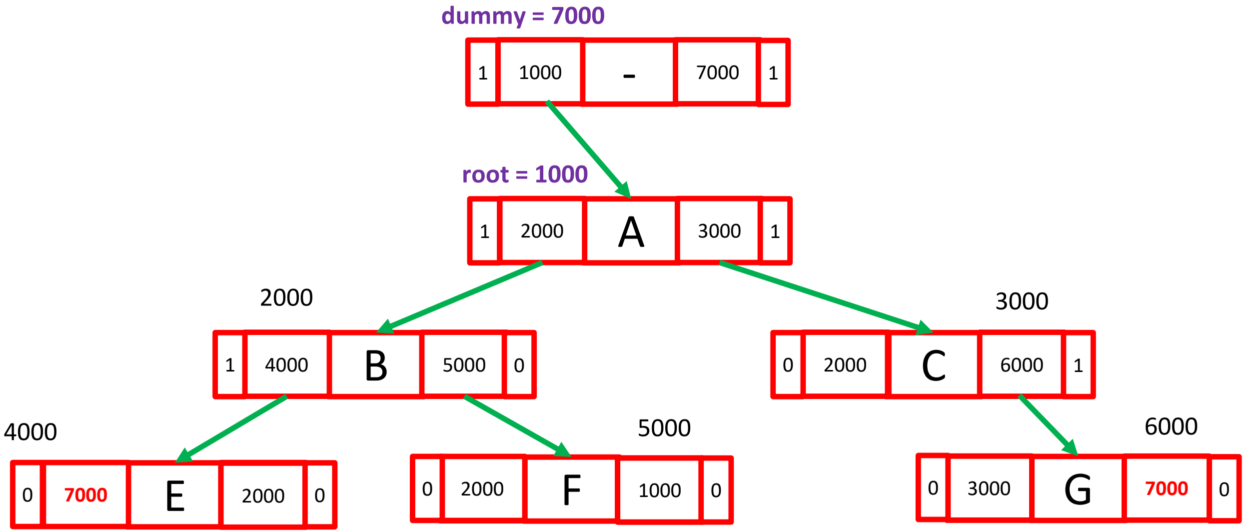
```
Struct node
        {
        char data;
        int left_flag,right_flag;
        struct node *left, *right;
        };
```

Threaded Binary Tree

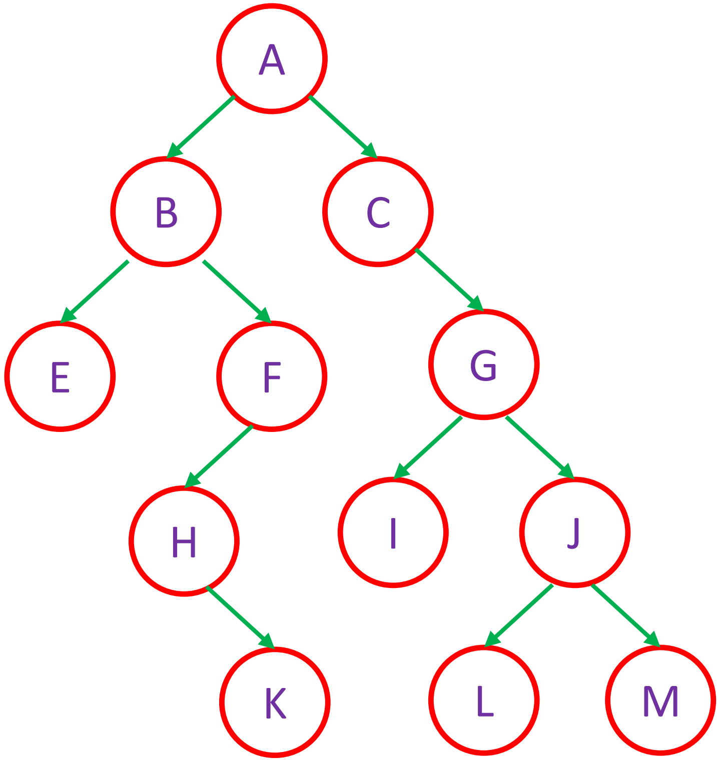


Flag = 1, the pointer points to the child node
Flag = 0, the pointer points to the parent/ancestor node

Threaded Binary Tree



Laboratory Exercise: TBT



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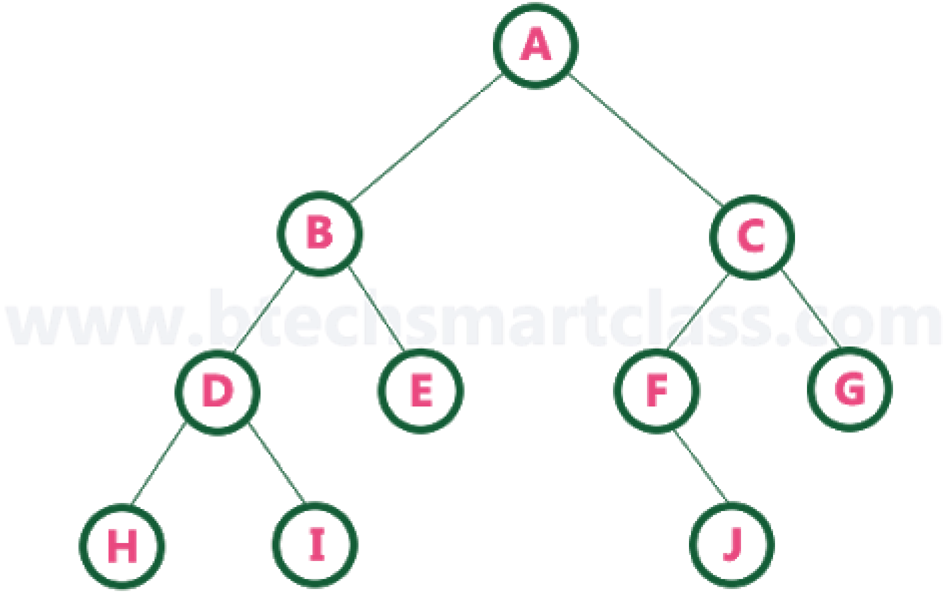
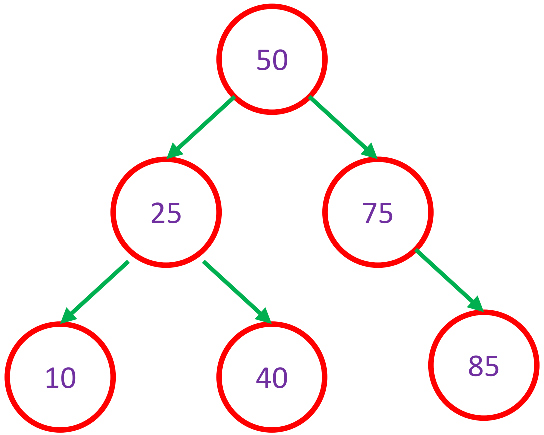
Laboratory Exercise: TBT



Thank You

Next: Binary Search Tree

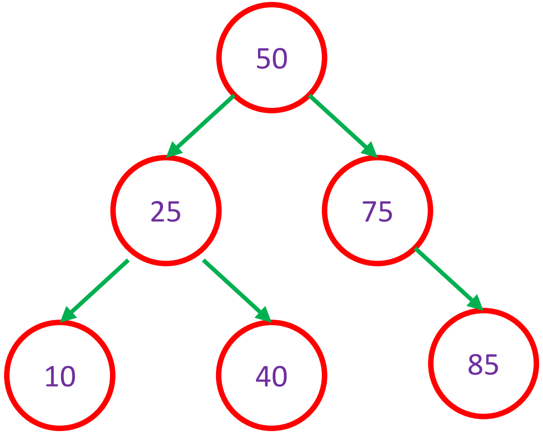


Binary Search Tree (BST)

Condition 1: Maximum Number of Children = 2

Condition 2: L < V < R

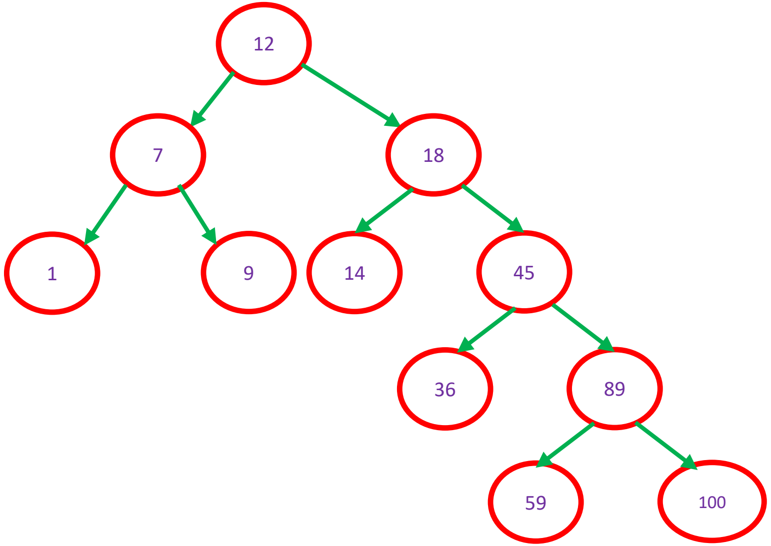
Binary Search Tree (BST)



Left subtree should contain values less than the vertex and right subtree should contain values greater than the vertex.

Binary Search Tree (BST)

Create binary search tree for following sequence of numbers:
12, 7, 9, 18, 14, 1, 45, 89, 100, 36 59



Binary Search Tree - Delete

Deleting a data/node from BST

The node to be deleted may have 0, 1 or 2 child node(s).

Case 1: Node to be deleted has 0 child

Simply delete the child and set the parent/successor link to NULL

Case 2: Node to be deleted has 1 child

Its successor (left/right) is to be connected with its parent node.

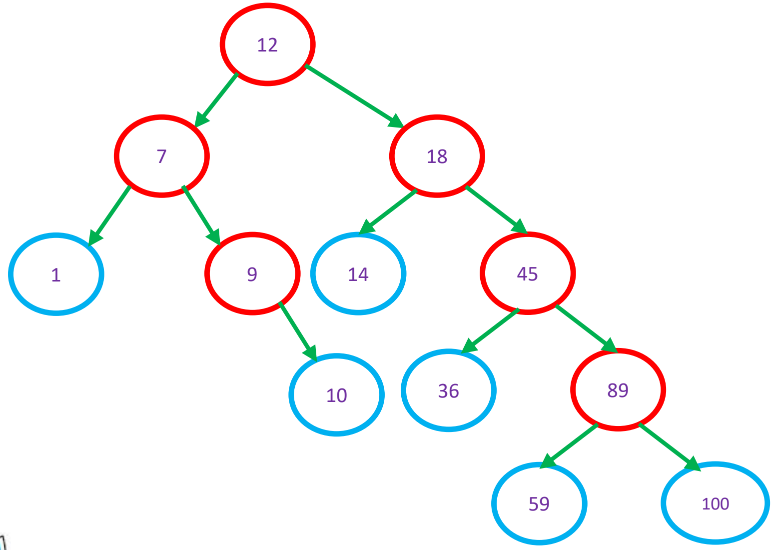
Case 3: Node to be deleted has 2 children

The node could be deleted (or replaced with) its (a) inorder predecessor OR (b) inorder successor

Binary Search Tree - Delete

Case 1: Node to be deleted has 0 child

Simply delete the child and set the parent/successor link to NULL



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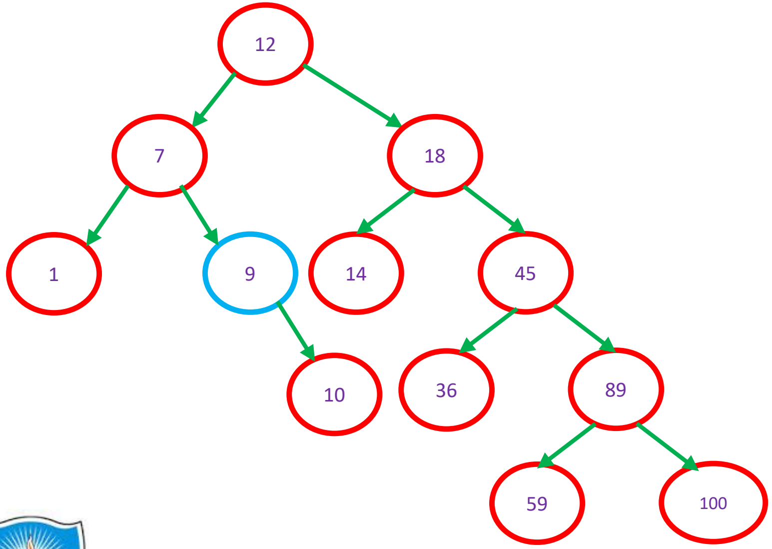
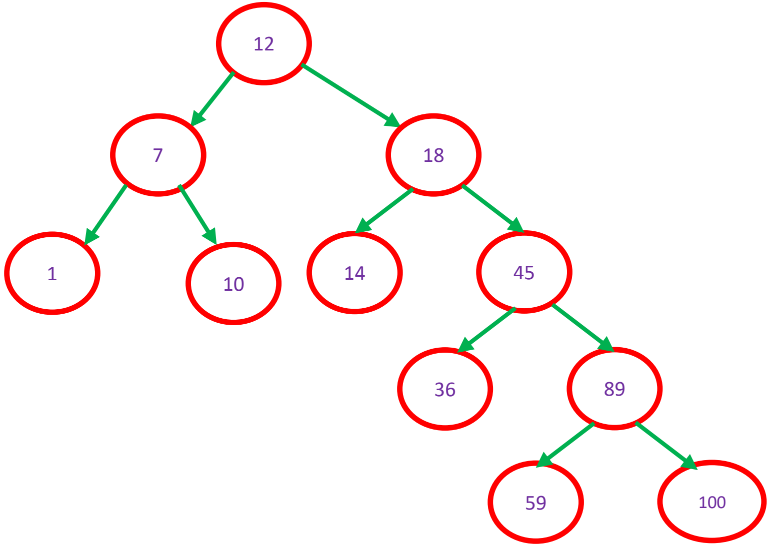
Binary Search Tree - Delete

Case 2: Node to be deleted has 1 child

Its successor (left/right) is to be connected with its parent node.

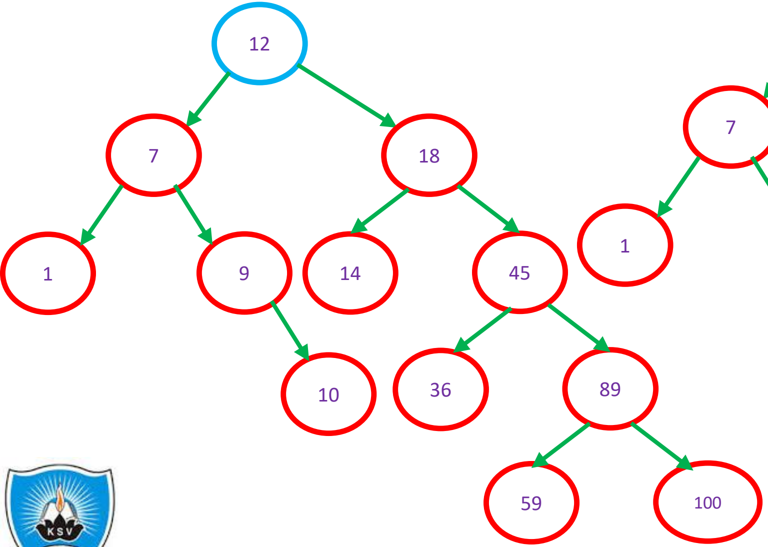


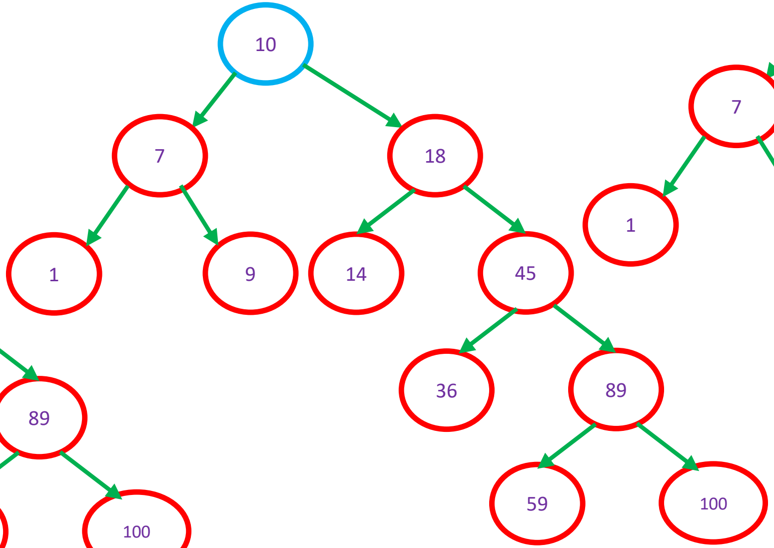


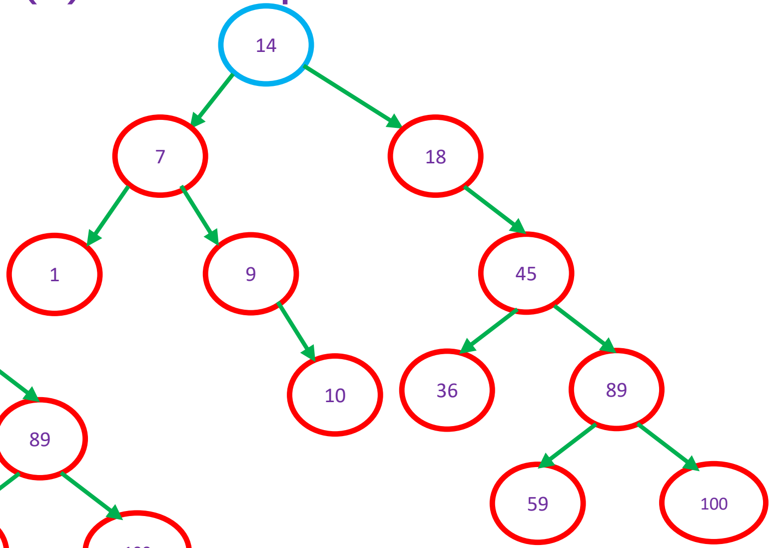
Binary Search Tree - Delete

Case 3: Node to be deleted has 2 children

The node could be deleted (or replaced with) its (a) inorder predecessor OR (b) inorder successor







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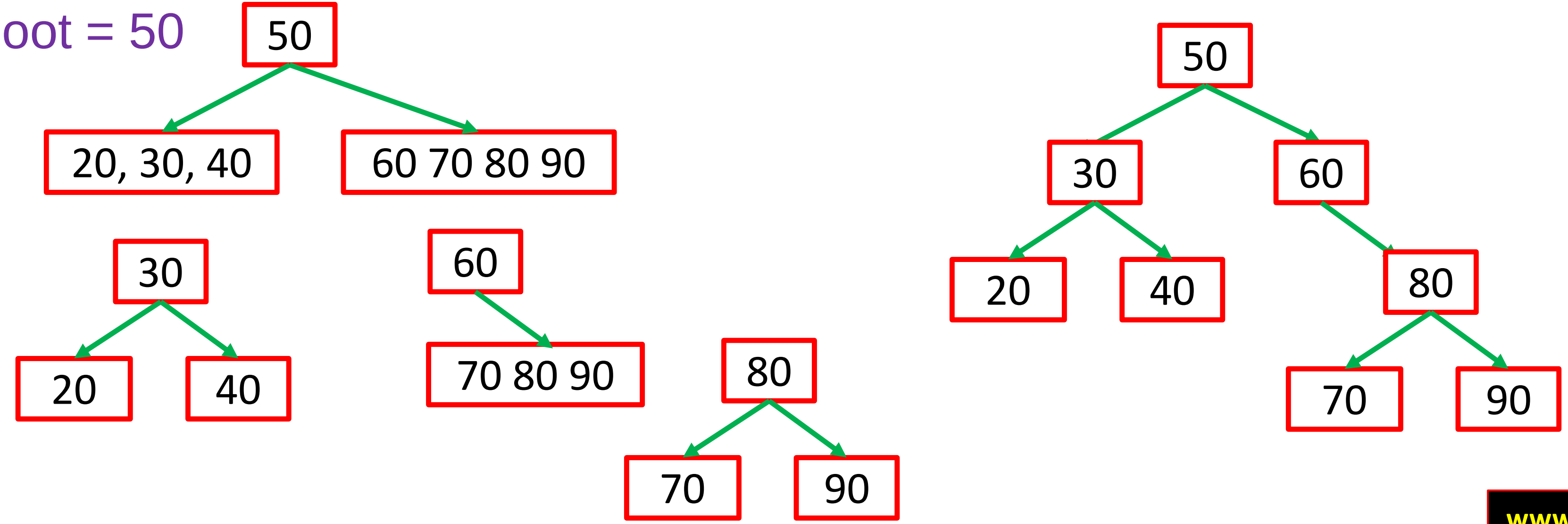
Constructing BST from Preorder Data

Given: Preorder (VLR): 50 30 20 40 60 80 70 90

Find: Inorder (LVR - Sorted): 20 30 40 50 60 70 80 90

Root = 50

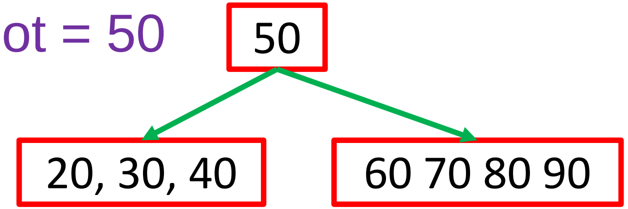


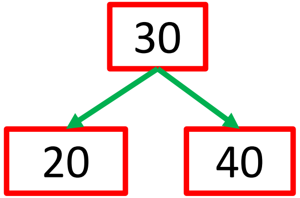
Constructing BST from Postorder Data

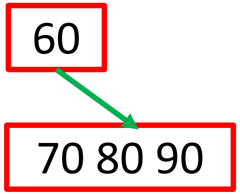
Given: Postorder (LRV): 20 40 30 70 90 80 60 50

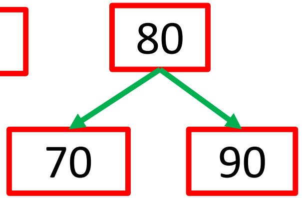
Find: Inorder (LVR - Sorted): 20 30 40 50 60 70 80 90

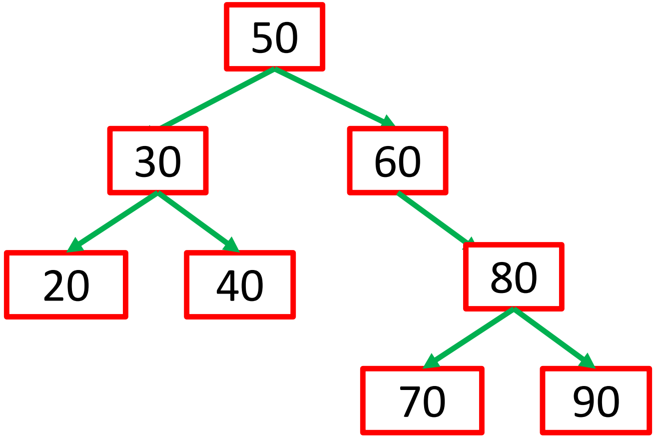
Root = 50



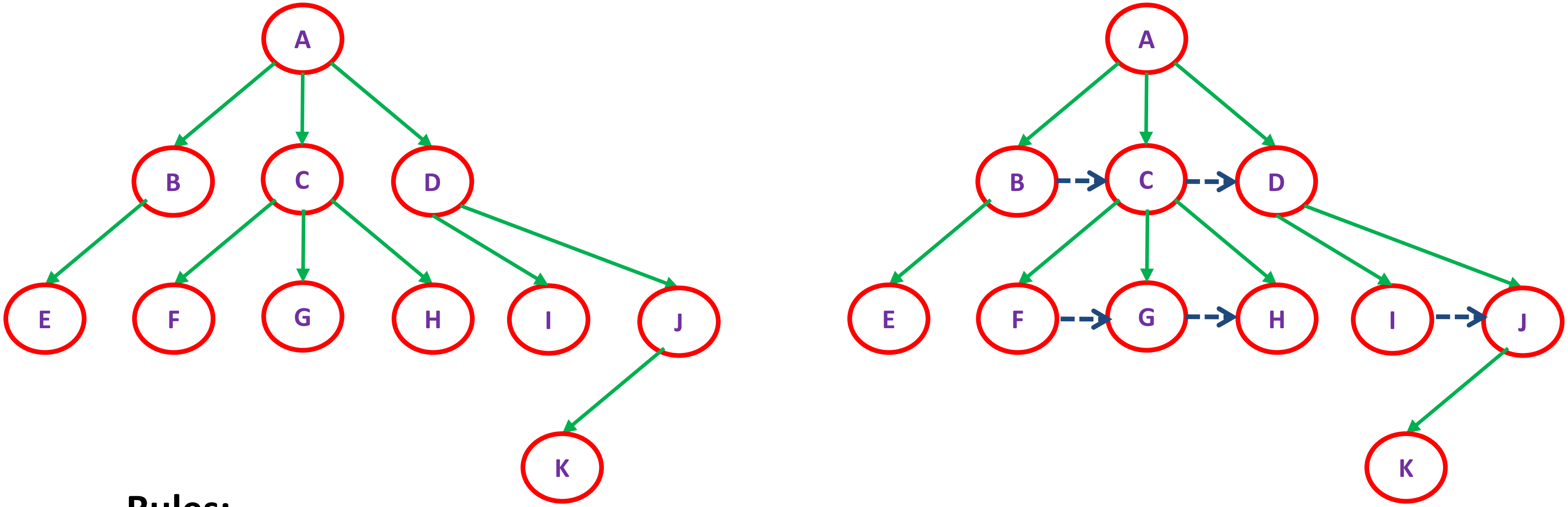








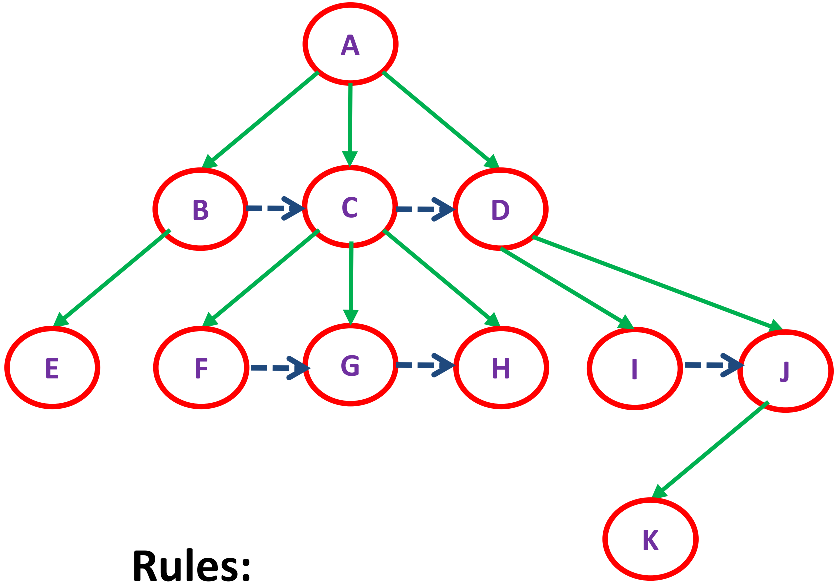
Constructing Binary Tree from General Tree

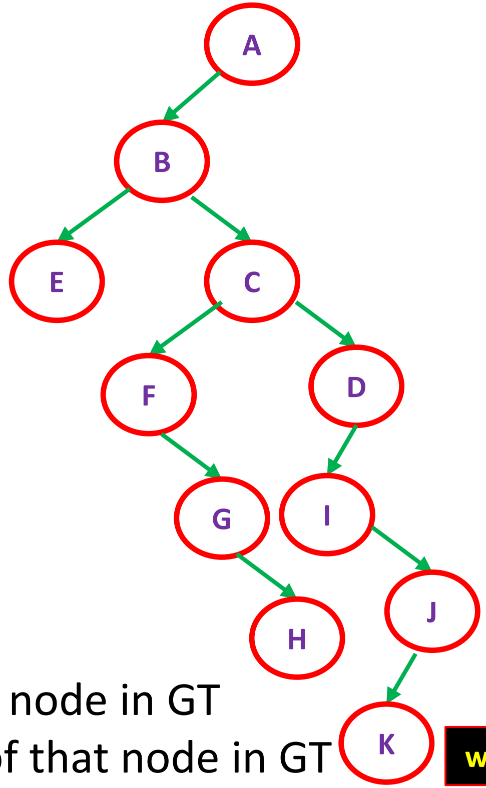


Rules:

1. Root node of BT = Root node of GT
2. Left child of the node in BT = Left most child of the node in GT
3. Right child of the node in BT = Next (right) sibling of that node in GT

Constructing Binary Tree from General Tree





Rules:

1. Root node of BT = Root node of GT
2. Left child of the node in BT = Left most child of the node in GT
3. Right child of the node in BT = Next (right) sibling of that node in GT

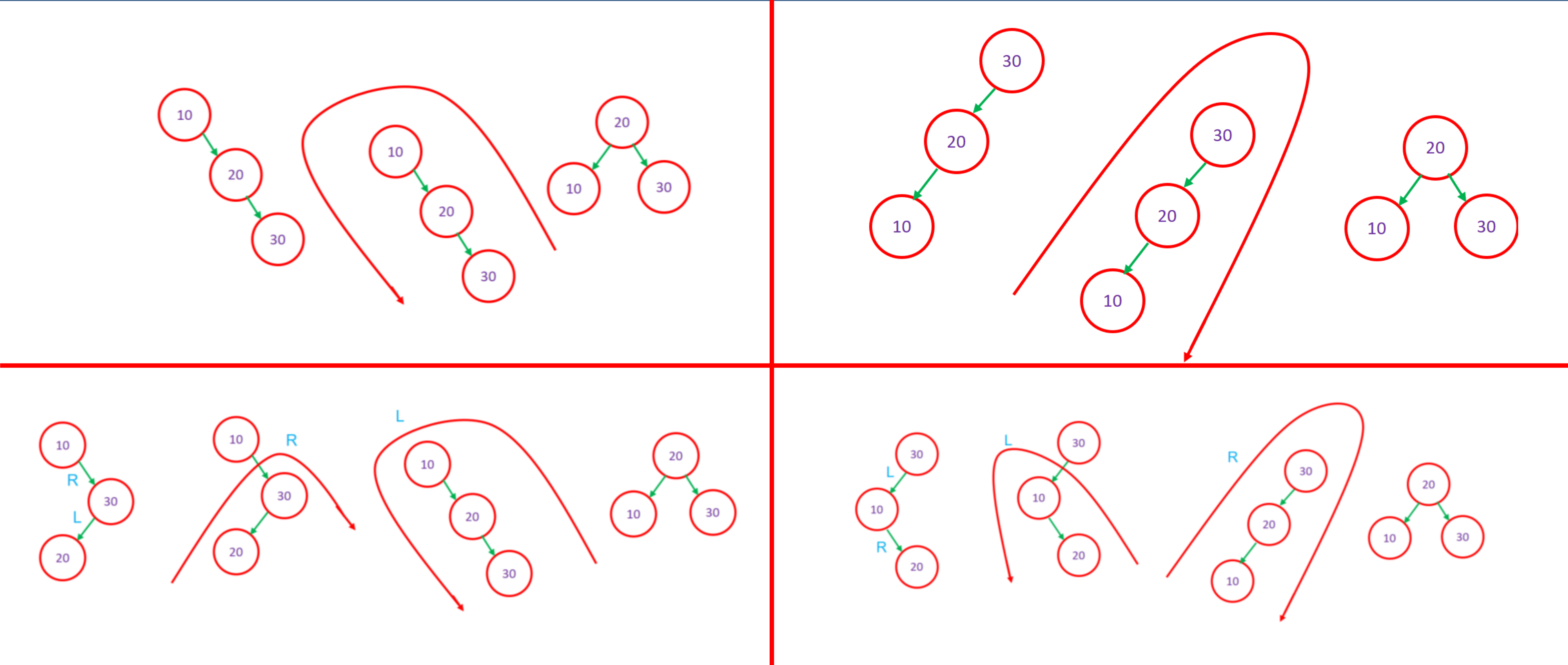
Laboratory Exercise: BST

Create BST For:
50, 25, 75, 12, 100, 30, 28, 90, 150, 112, 80, 83

Thank You

Next: AVL Tree

AVL Tree



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30

AVL Tree

An AVL tree (named after inventors **A**delson-**V**elsky and **L**andis) is a self-balancing binary search tree.

1. It is a BST
2. Height of Left Subtree – Height of Right Subtree = {-1,0, 1}

Balance Factor = Height of Left Subtree – Height of Right Subtree = {-1, 0, 1}

AVL Tree

After every insertion in AVL, we calculate balance factor, and if it happens to be outside {-1, 0, 1}, we have to balance out the tree in such a way that the balance factor lies in {-1, 0, 1}

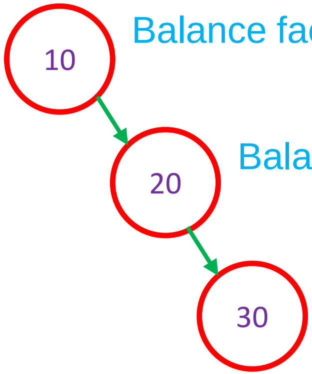
How to balance out a tree?

There are 4 different cases

Balancing AVL Tree

Case 1:

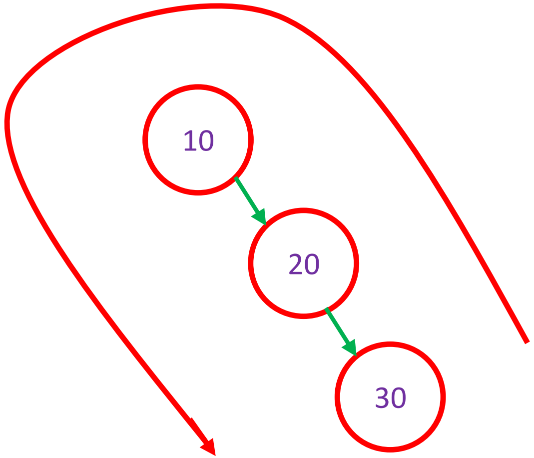
Left Rotation / Anti-clockwise turn



Balance factor of “10” = 0 – 2 = -2

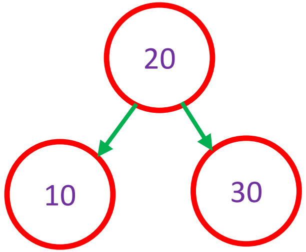
Balance factor of “20” = 0 – 1 = -1

Balance factor of “30” = 0 – 0 = 0



Balance factor of “20” = 0

Result



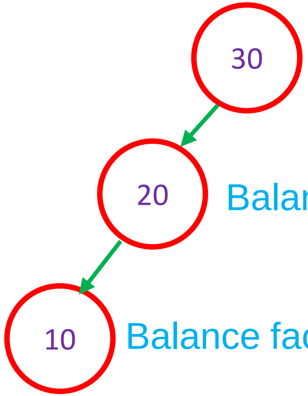
Balance factor of “10” = 0

Balance factor of “30” = 0

Balancing AVL Tree

Case 2:

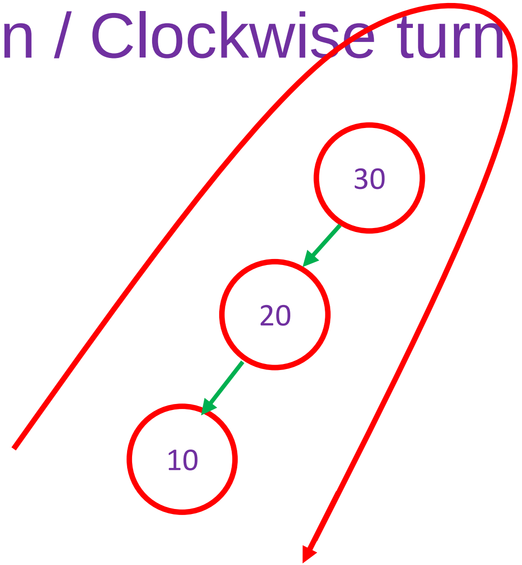
Right Rotation / Clockwise turn



Balance factor of “30” = 2 – 0 = 2

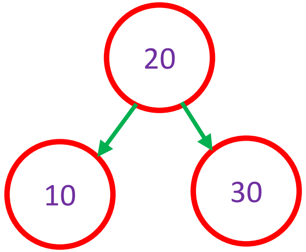
Balance factor of “20” = 1 – 0 = 1

Balance factor of “10” = 0 – 0 = 0



Balance factor of “20” = 0

Result

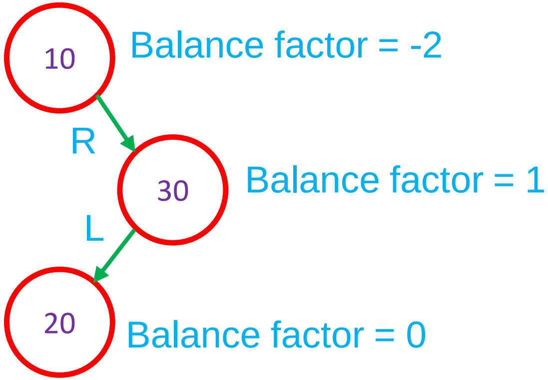


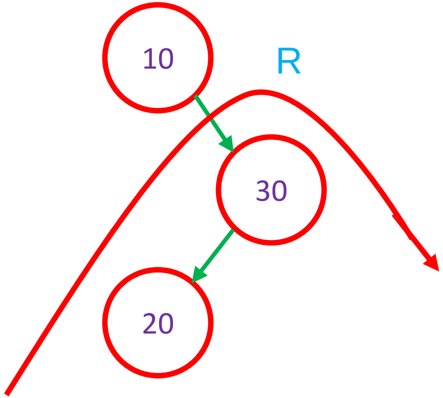
Balance factor of “10” = 0

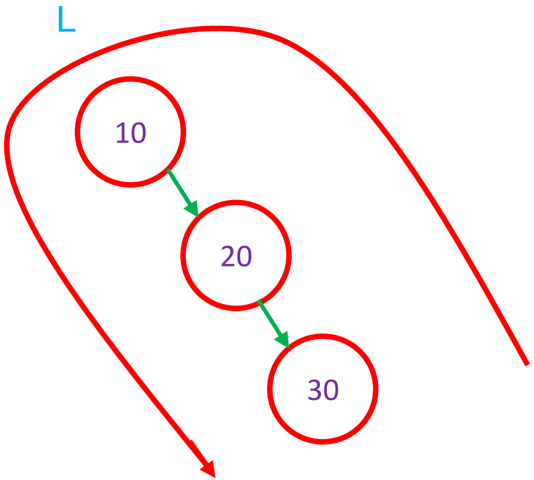
Balance factor of “30” = 0

Balancing AVL Tree

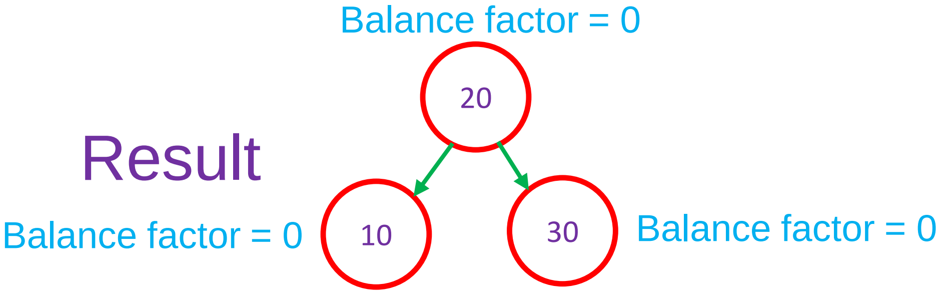
Case 3:





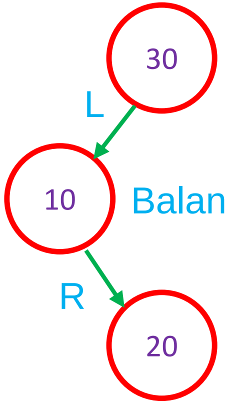


Result



Balancing AVL Tree

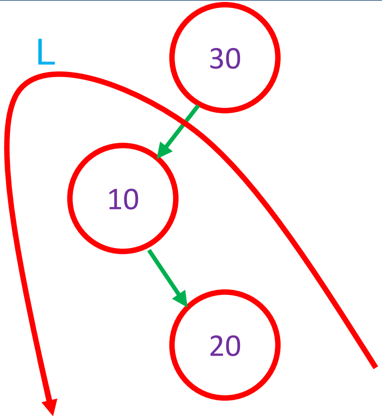
Case 4:

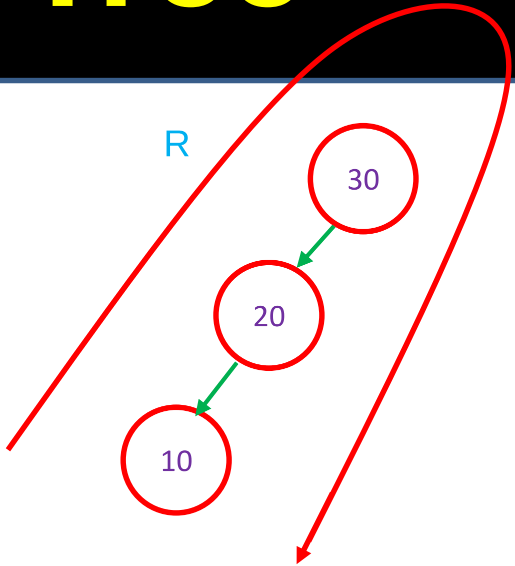


Balance factor = 2

Balance factor = -1

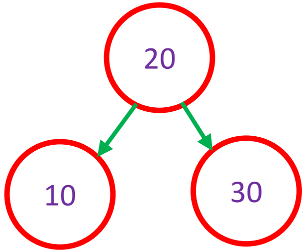
Balance factor = 0





Balance factor = 0

Result



Balance factor = 0

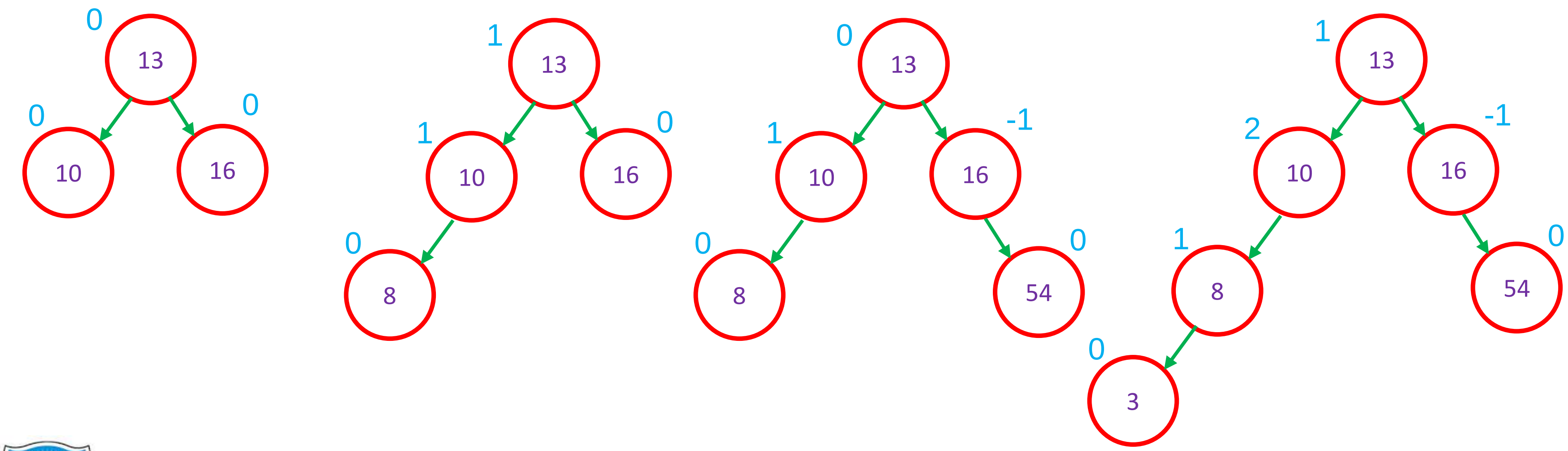
Balance factor = 0

Balancing AVL Tree

Source: https://upload.wikimedia.org/wikipedia/commons/f/fd/AVL_Tree_Example.gif

Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21



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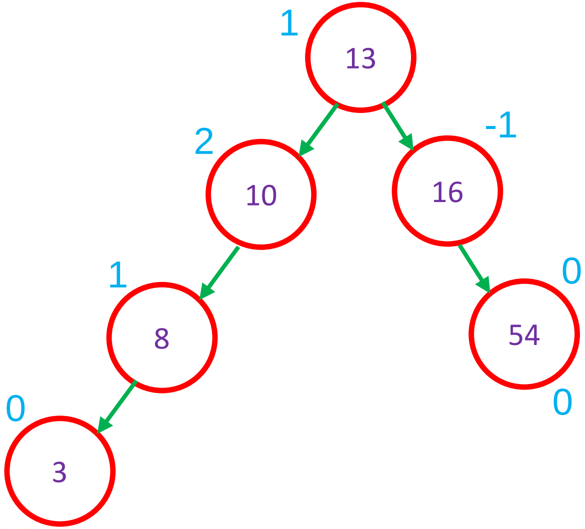
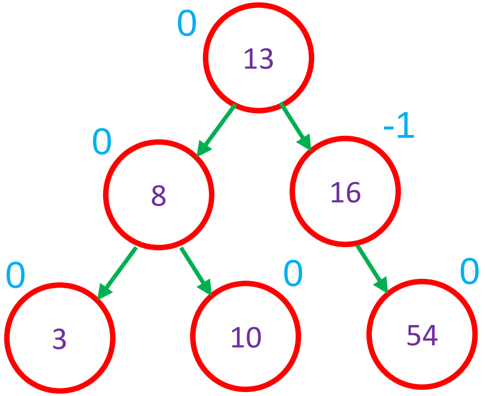
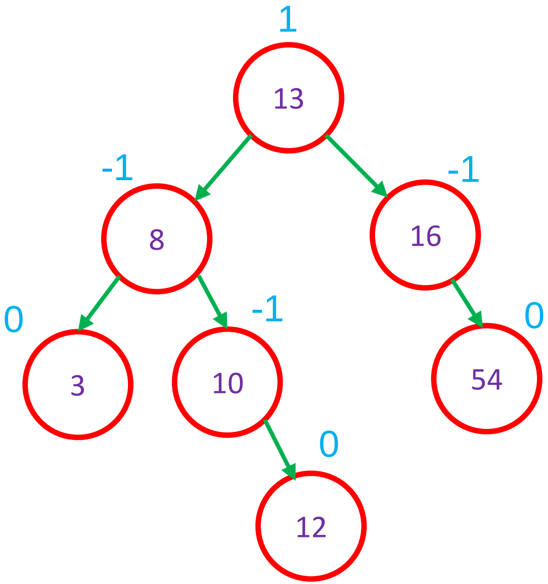
Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21







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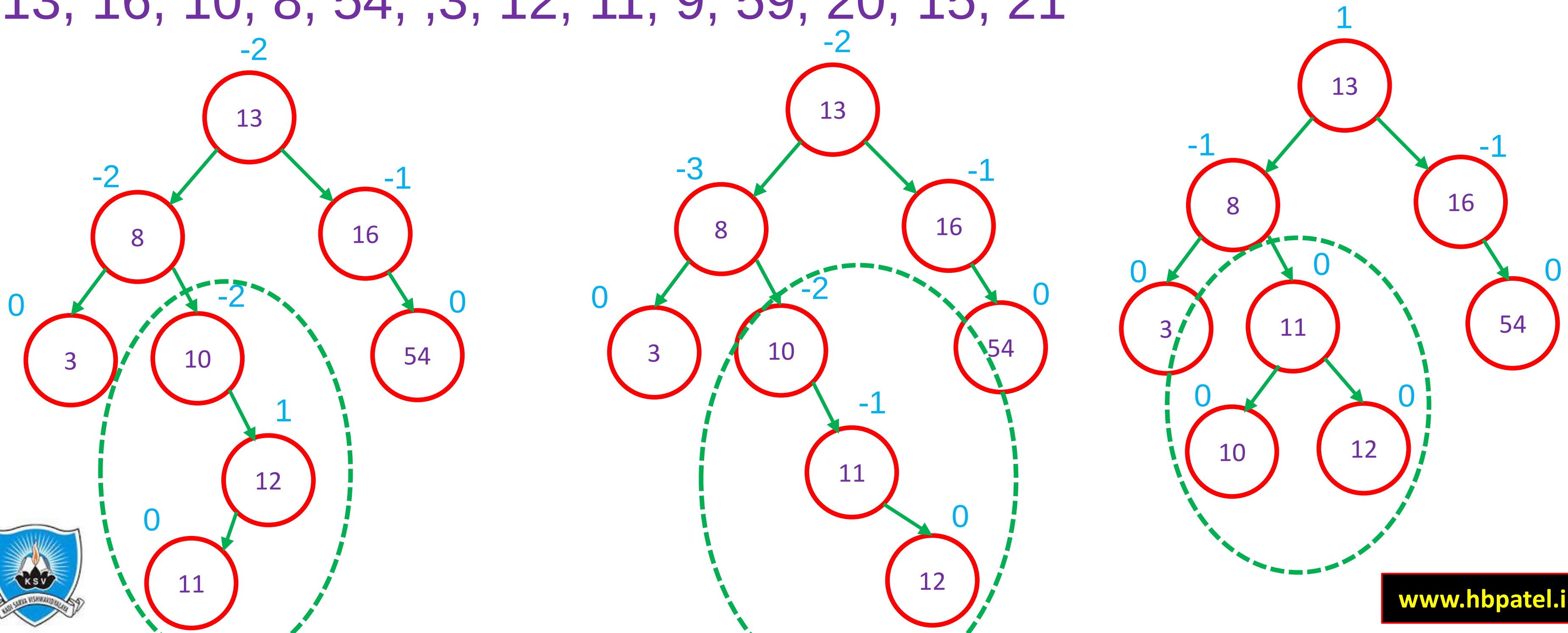
13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21



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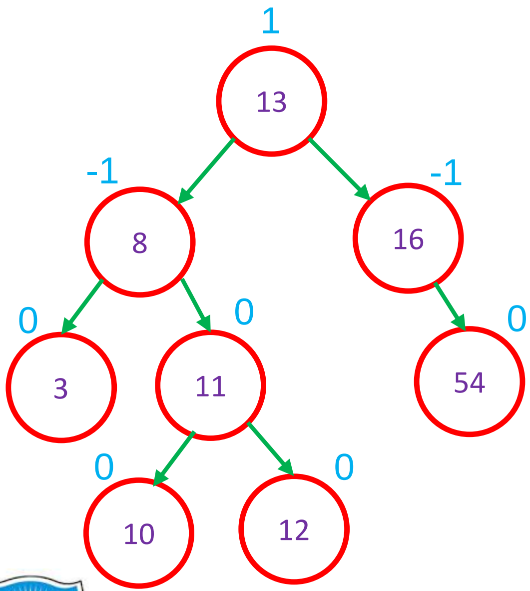
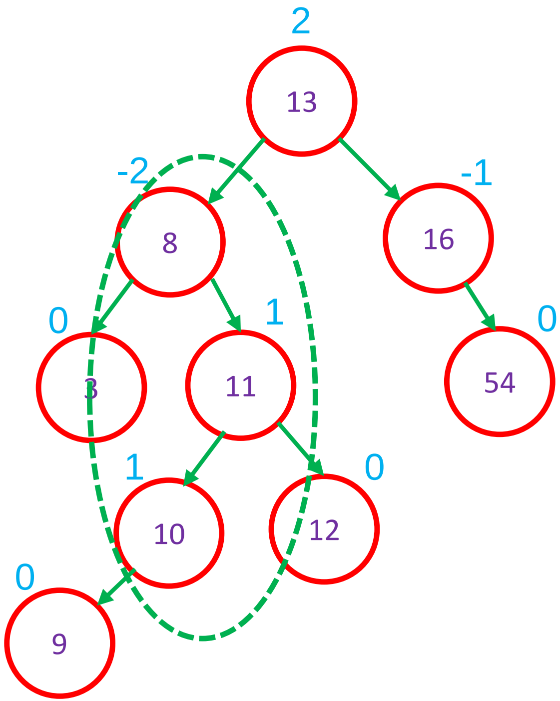
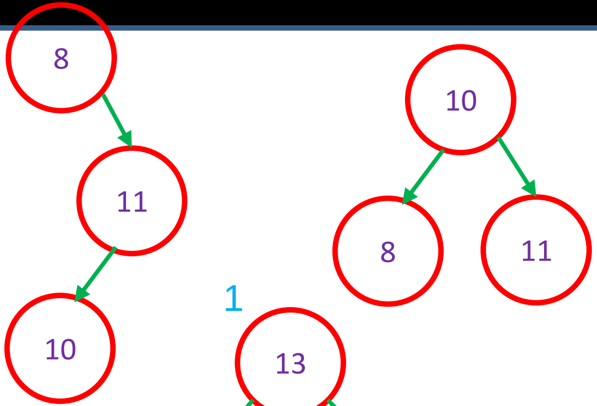
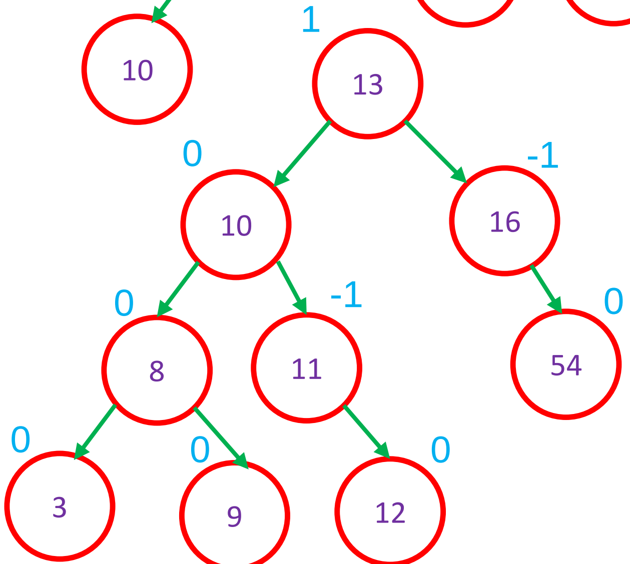
Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21









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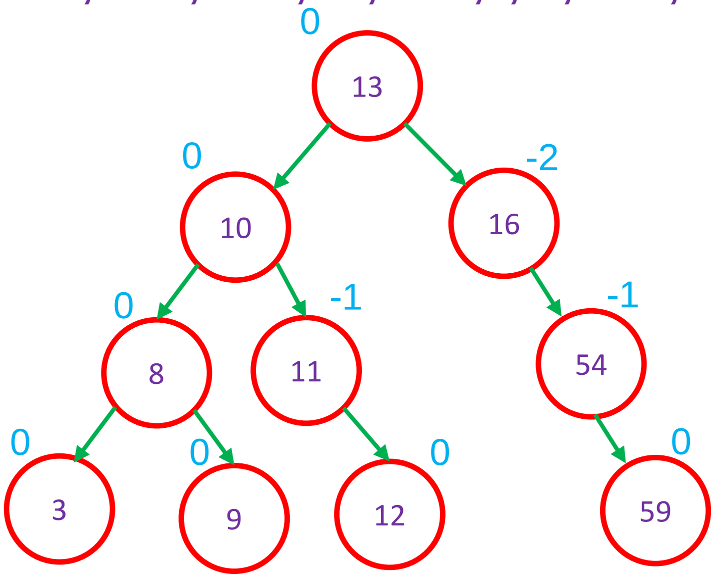
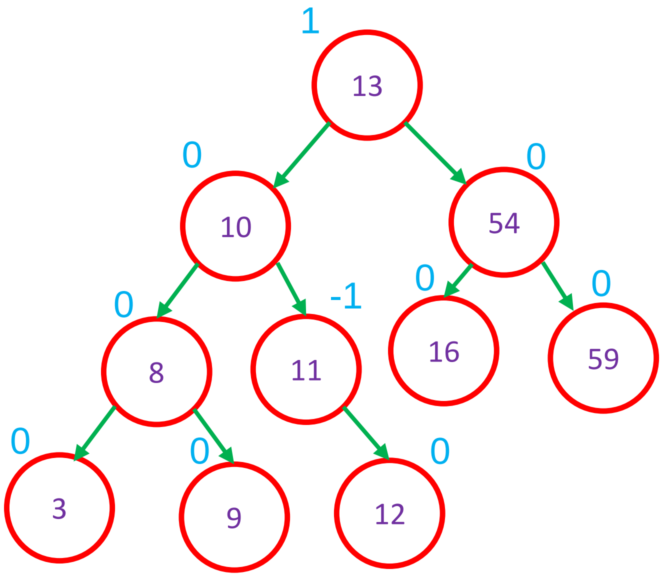
Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21





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Assignment: Construct AVL Tree

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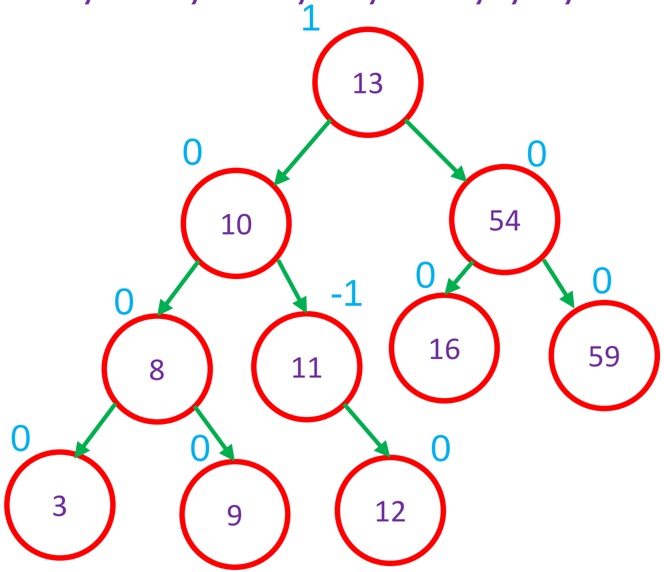
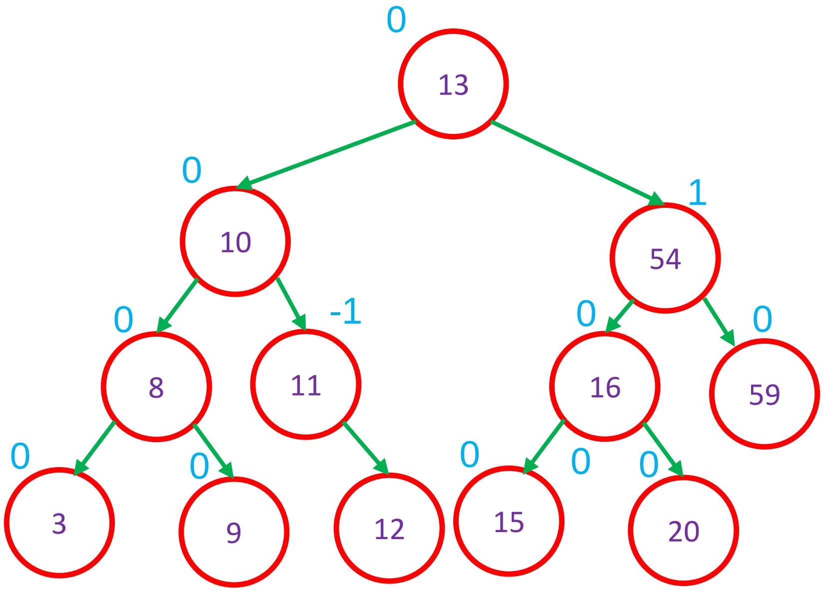
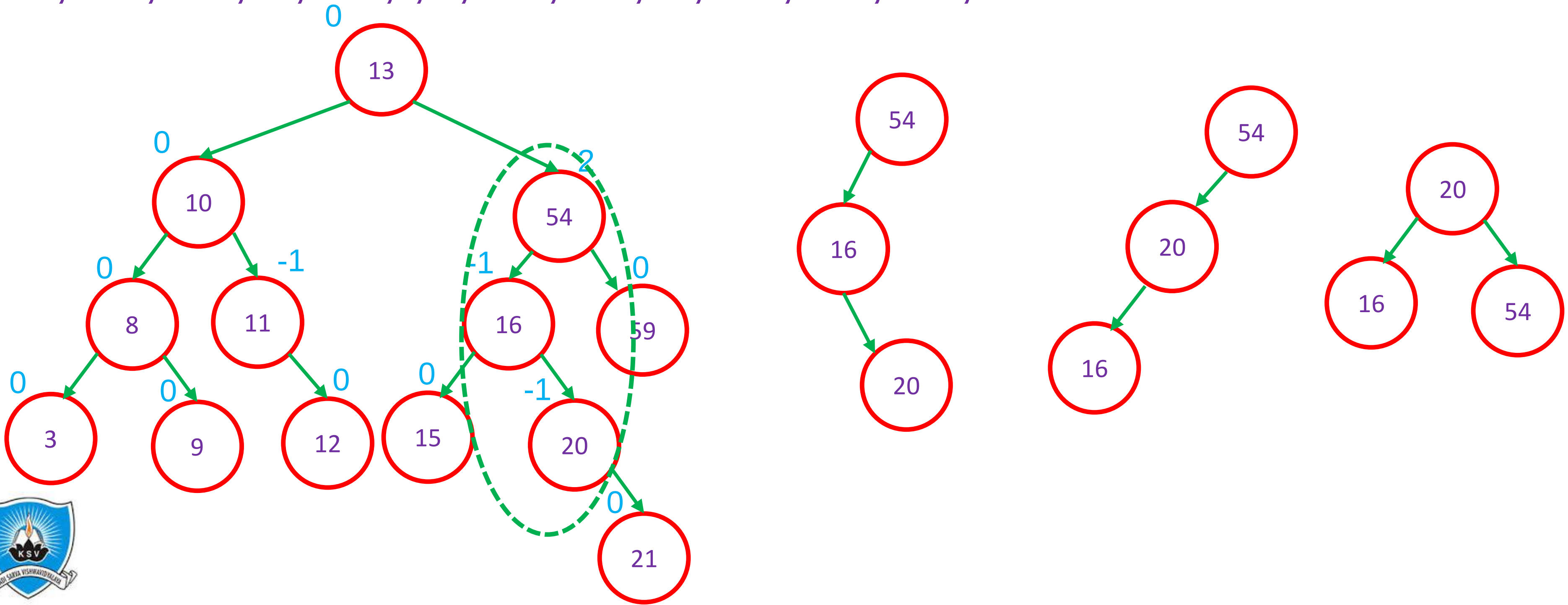




Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21



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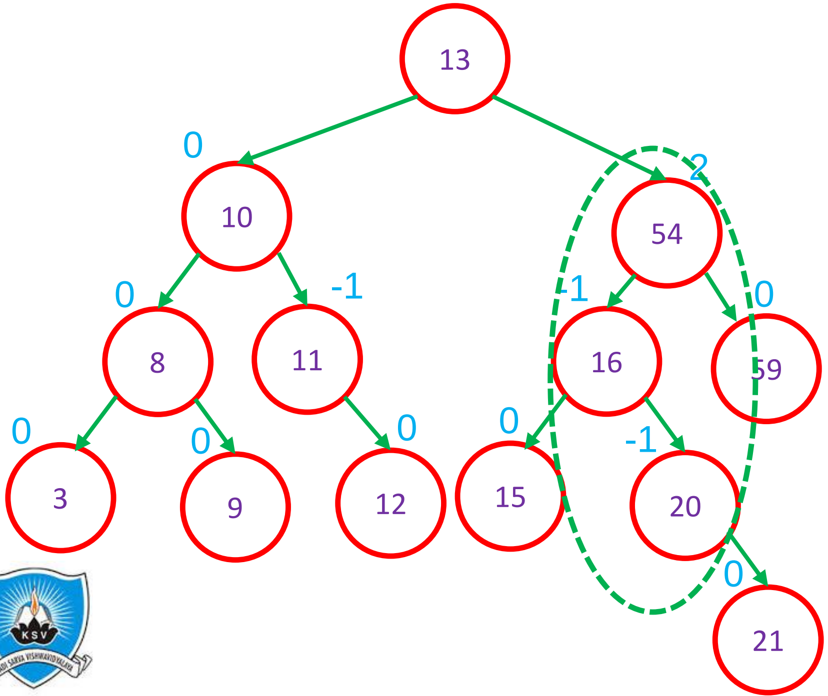
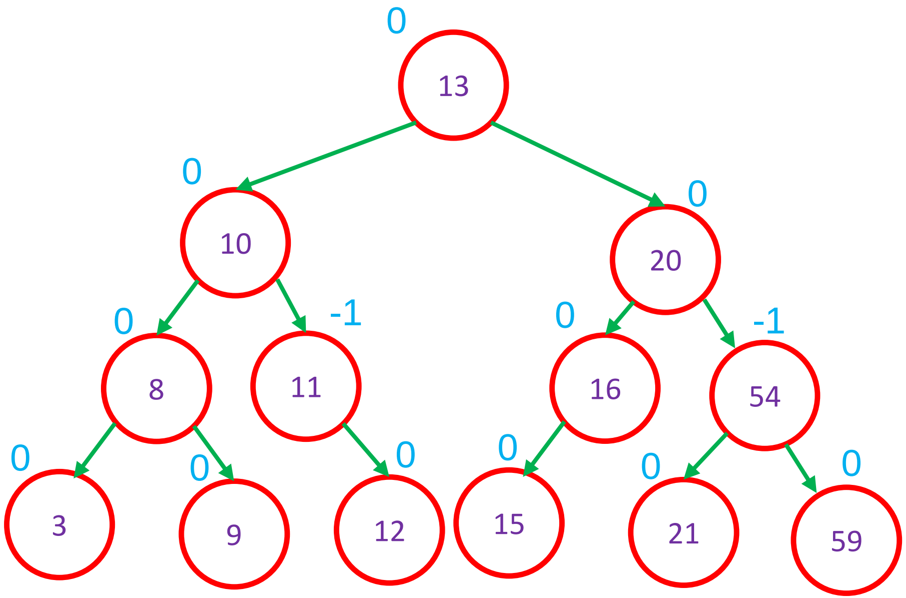
Assignment: Construct AVL Tree

13, 16, 10, 8, 54, ,3, 12, 11, 9, 59, 20, 15, 21





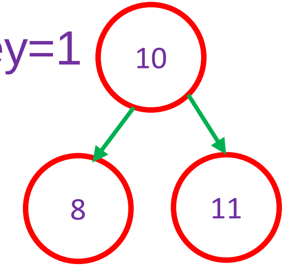
Thank You

Next: B-Tree

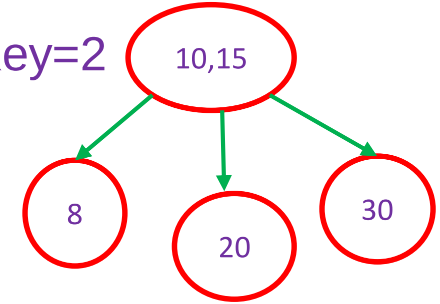
B-Tree

- Balanced m-way tree (where m is order of the tree)
- Generalization of BST in which a node can have more than two children and more than one key

Key=1



Key=2



B-Tree

- Maintains data in sorted order
- All the leaf nodes must be at the same level
- B-tree of order ‘m’ has following properties:

Children

- Every node has maximum ‘m’ children
- For leaf, maximum children = 0
- For root, maximum children = 2
- For internal node, minimum children = [m/2] (upper ceiling)

Keys

- Every node has maximum (m-1) keys
- For root node, minimum key = 1
- For all other nodes, minimum number of keys = [m/2]-1 (upper ceiling)

B-Tree

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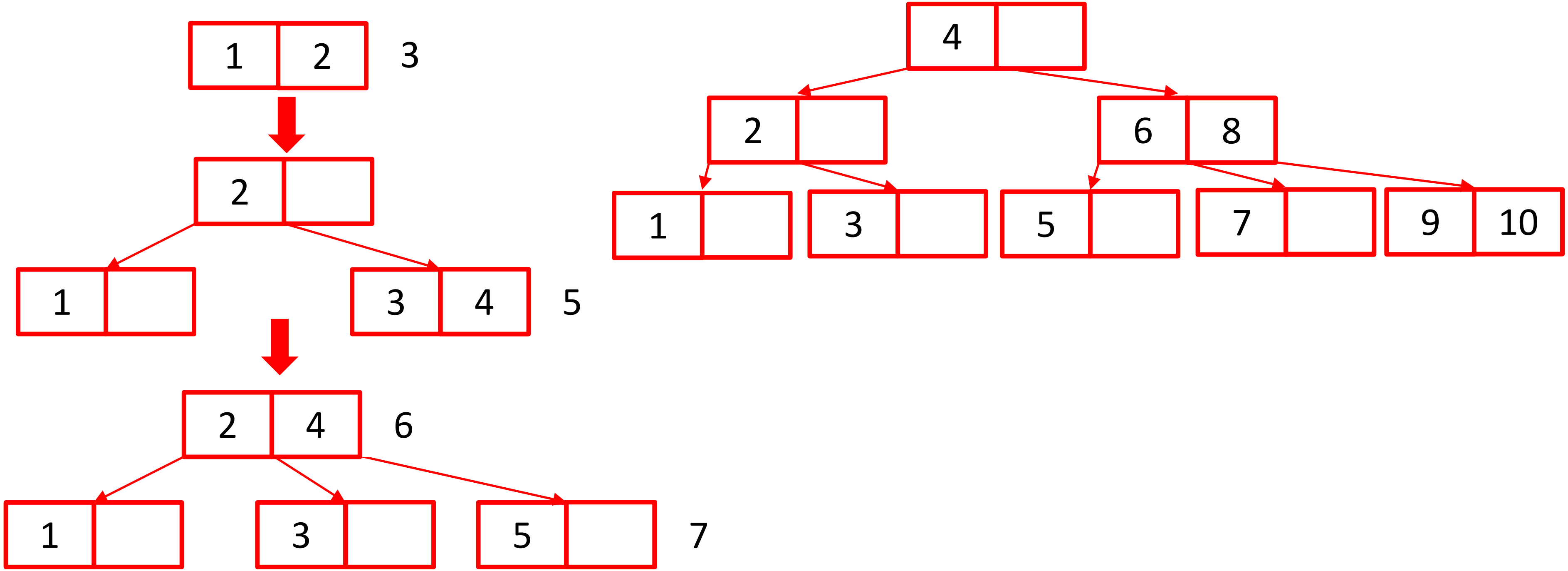
- Create a B-Tree of order 3 by inserting values from 1 to 10
- Order m=3, maximum children = 3 (m), maximum keys = 2 (m-1)



B-Tree: Exercise

- Example: 10, 20, 40, 50, 60, 70, 80, 30, 35, 5, 15
- Order m=4, maximum children = 4 (m), maximum keys = 3 (m-1)

B-Tree: Exercise

- Example: 5, 3, 21, 9, 1, 13, 2, 7, 10, 12, 4, 8
- Order m=4, maximum children = 4 (m), maximum keys = 3 (m-1)

Thank You

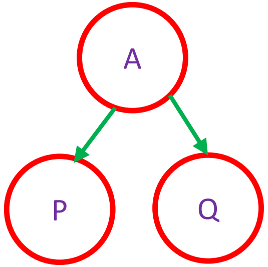
Next: 2-3 Tree

2-3 Tree : Introduction

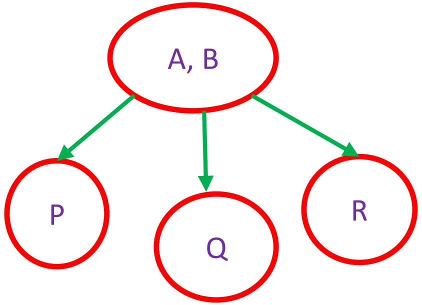
- Similar to BST where L < V < R
- It contains 3 different kinds of nodes

(1) leaf node (2) 2-node (3) 3-node

2-node: 2 Children + 1 data element



3-node: 3 Children + 2 data element



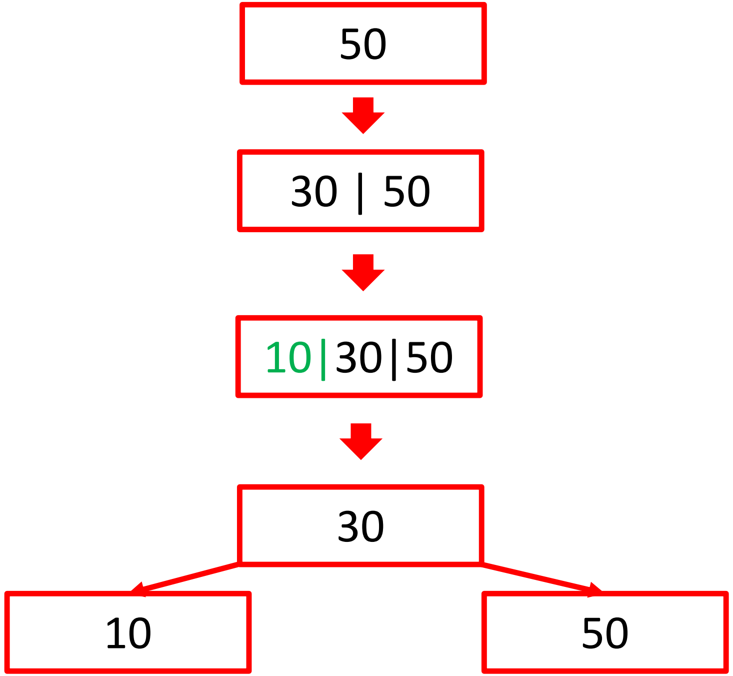
2-3 Tree : Properties

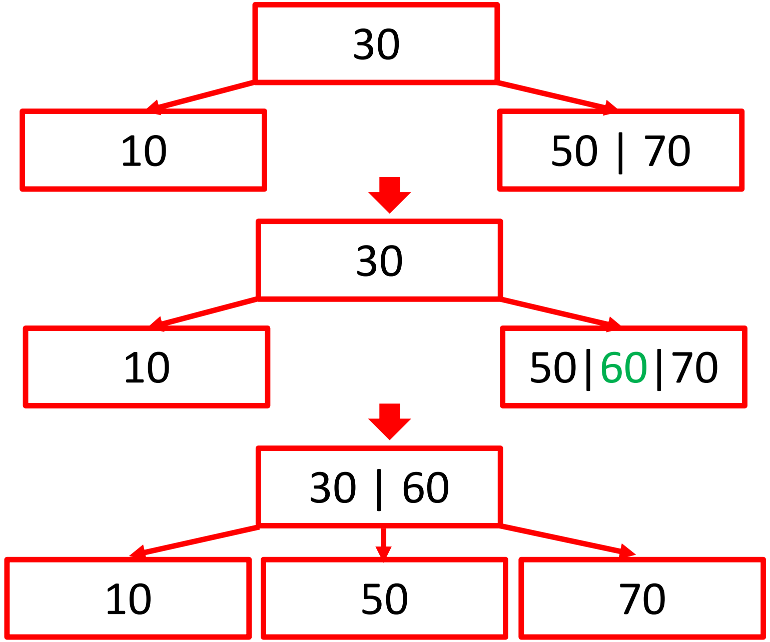
Properties of 2-3 Tree are

- It is a B-tree with order 3 (Max 2 keys and 3 children)
- Balanced tree
- Every internal node is either 2-node or 3-node
- All leaves are at same level
- Data is stored in sorted manner

2-3 Tree : Example

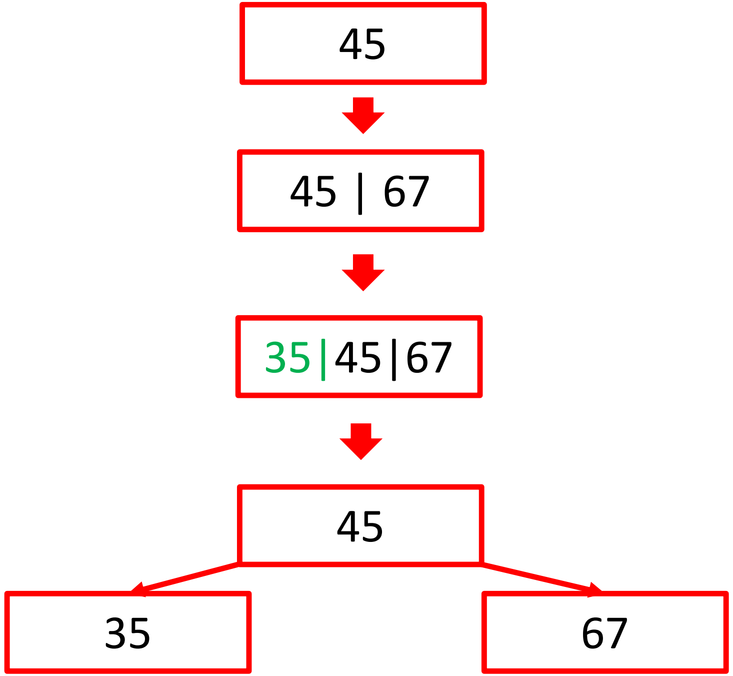
50, 30, 10, 70, 60

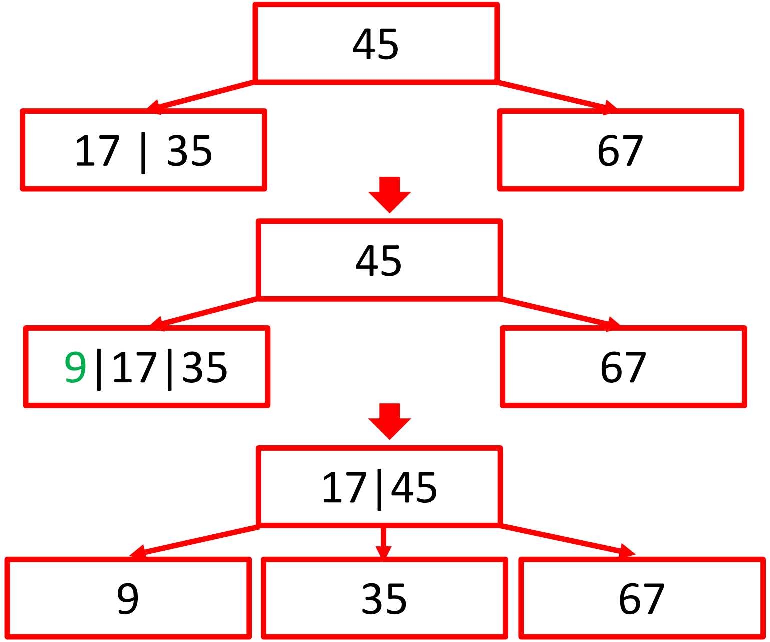




2-3 Tree : Example

45, 67, 35, 17, 9, 8 ,4, 50





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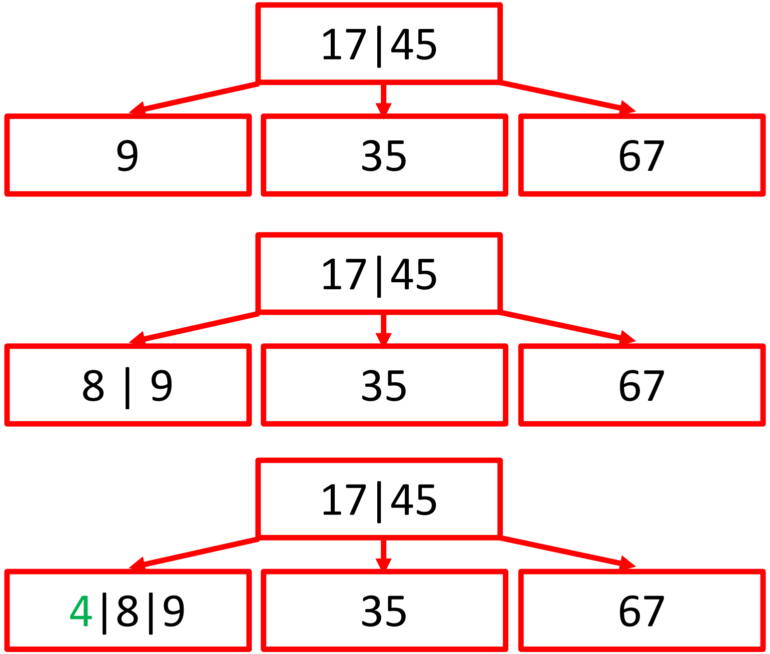
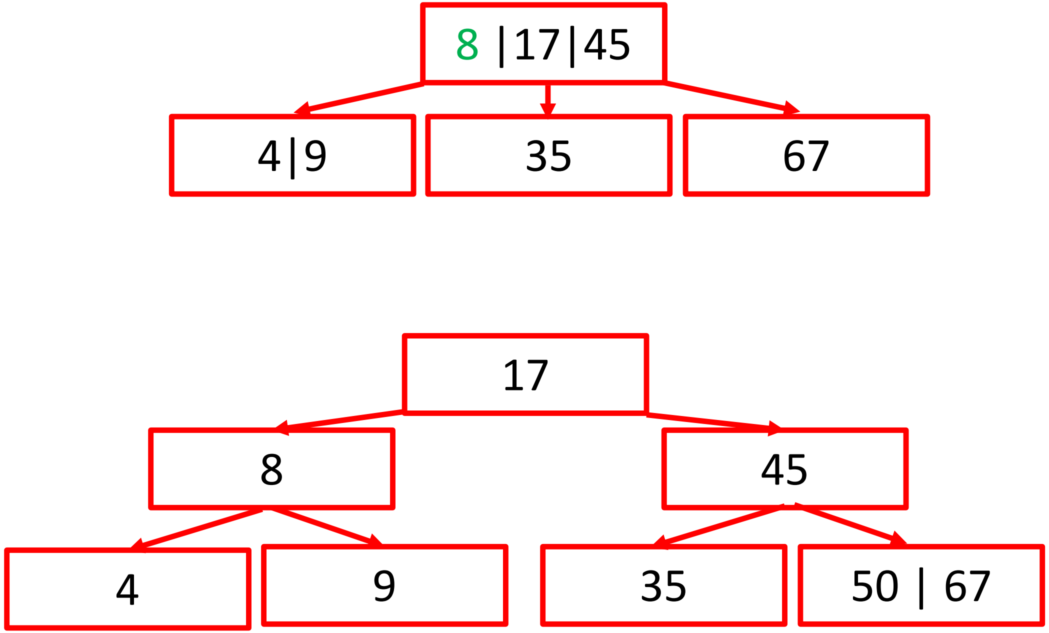
2-3 Tree : Example

45, 67, 35, 17, 9, 8 ,4, 50





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2-3 Tree : Algorithm

Step 1: If the tree is empty, create a node and put the value into it

Step 2: Find the appropriate leaf node for the value

Step 3: If the leaf node has only one value, put the value into node

Step 4: If the leaf node has more than two values, split the node and promote the median to the parent node

Step 5: If the parent node has more than two values, continue splitting & promoting for the parent node by forming a new node if necessary

Thank You

Next: Graph

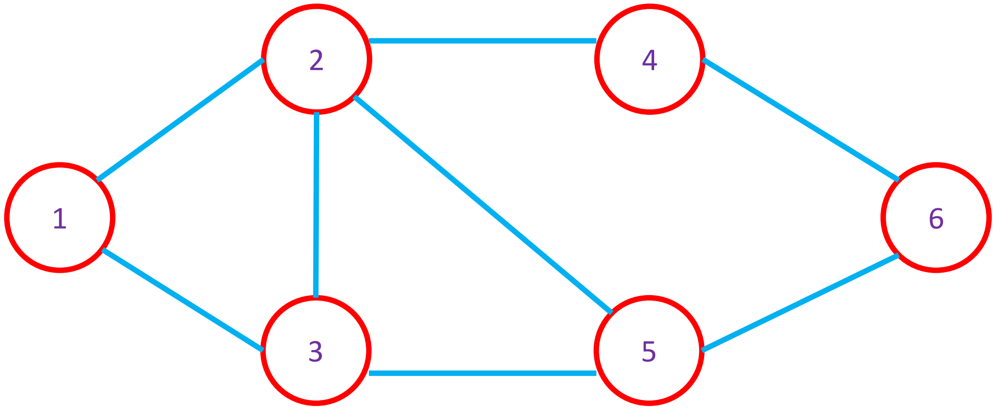
Graph

A Graph is a non-linear data structure consisting of nodes (vertices) and edges (lines or arcs)

G = {V, E}

V = {1,2,3,4,5,6}

$E = \{E_{12}, E_{13}, E_{23}, E_{24}, E_{25}, E_{35}, E_{56}, E_{46}\}$



Types of Graph

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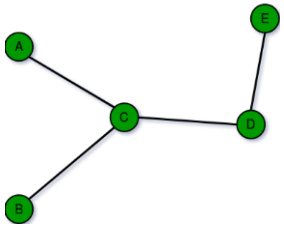
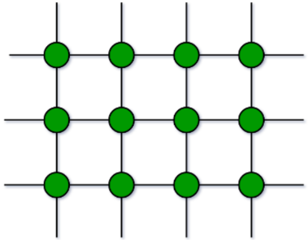
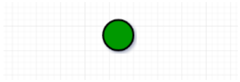
Finite Graphs: A graph is said to be finite if it has finite number of vertices and finite number of edges



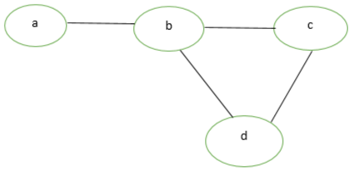
Infinite Graph: A graph is said to be infinite if it has infinite number of vertices as well as infinite number of edges.



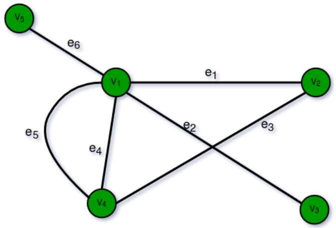
Trivial Graph: A graph is said to be trivial if a finite graph contains only one vertex and no edge.



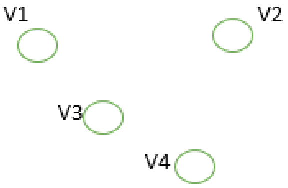
Simple Graph: A simple graph is a graph which does not contains more than one edge between the pair of vertices.



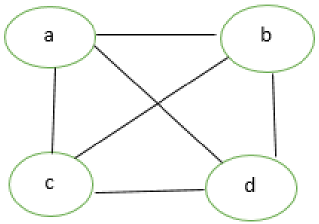
Multi Graph: Any graph which contain some parallel edges but doesn't contain any self-loop is called multi graph.



Null Graph: A graph of order n and size zero that is a graph which contain n number of vertices but do not contain any edge.



Complete/Full Graph: A simple graph with n vertices is called a complete graph if the degree of each vertex is n-1, that is, one vertex is attach with n-1 edges.



Source: www.geeksforgeeks.org

Applications of Graph

Flow of computation

Networks of communication

Data organization

Graph theory is used to find shortest path in road or a network

In Google Maps, various locations are represented as vertices or nodes and the roads are represented as edges and graph theory is used to find the shortest path between two nodes

Facebook's Graph API is perhaps the best example of application of graphs to real life problems. The Graph API is a revolution in large-scale data provision.

Flight Networks

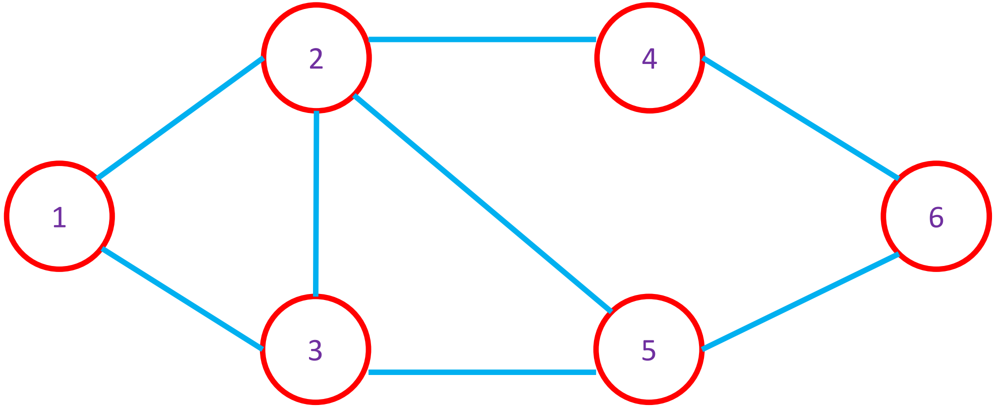
GPS Navigations Systems

Graph Representation

- Adjacency Matrix
- Adjacency List

Adjacency Matrix

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

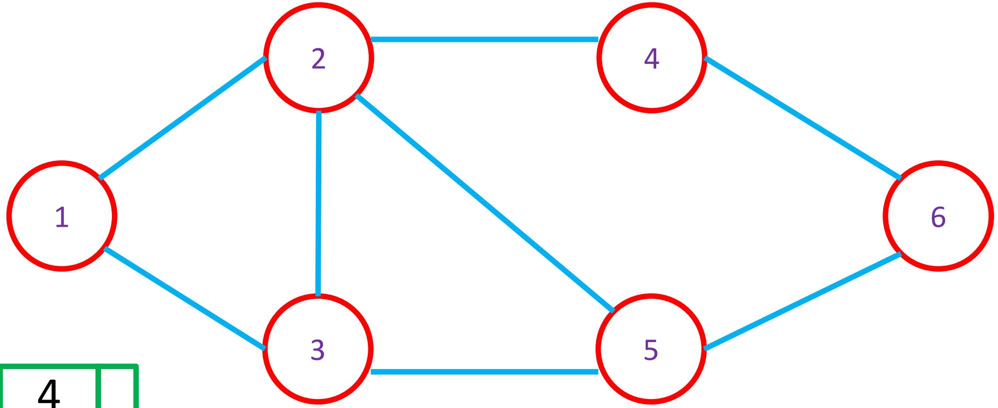


Adjacency Matrix is a matrix A[n][n] (n=number of vertices)
where,
A[i][j]=1 if i and j are adjacent
A[i][j]=0 otherwise

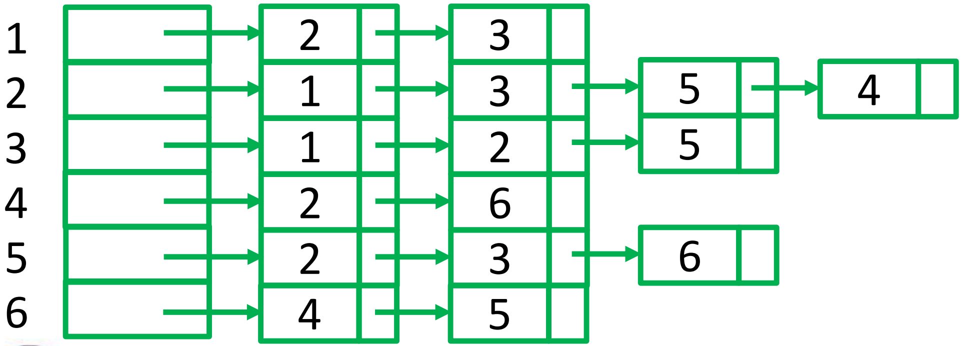
Space Complexity = $\Theta(n^2)$

Graph Representation

- Adjacency Matrix
- Adjacency List



Adjacency List



Space Complexity = Θ (n + 2e)

Graph Representation

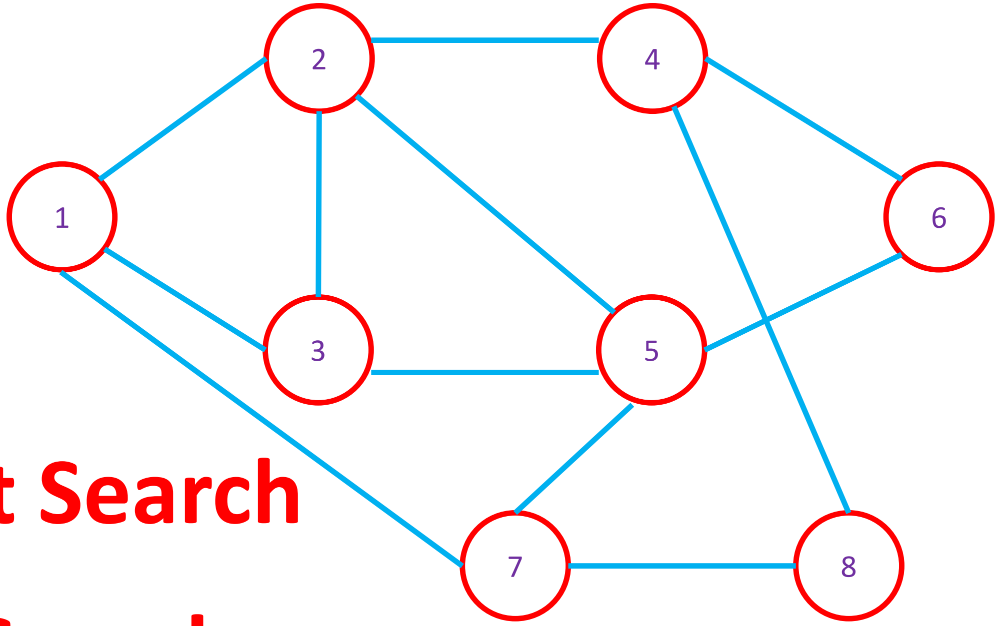
Dense Graph → Adjacency Matrix

Sparse Graph → Adjacency List

Thank You

Next: Graph Traversal (BFS/DFS)

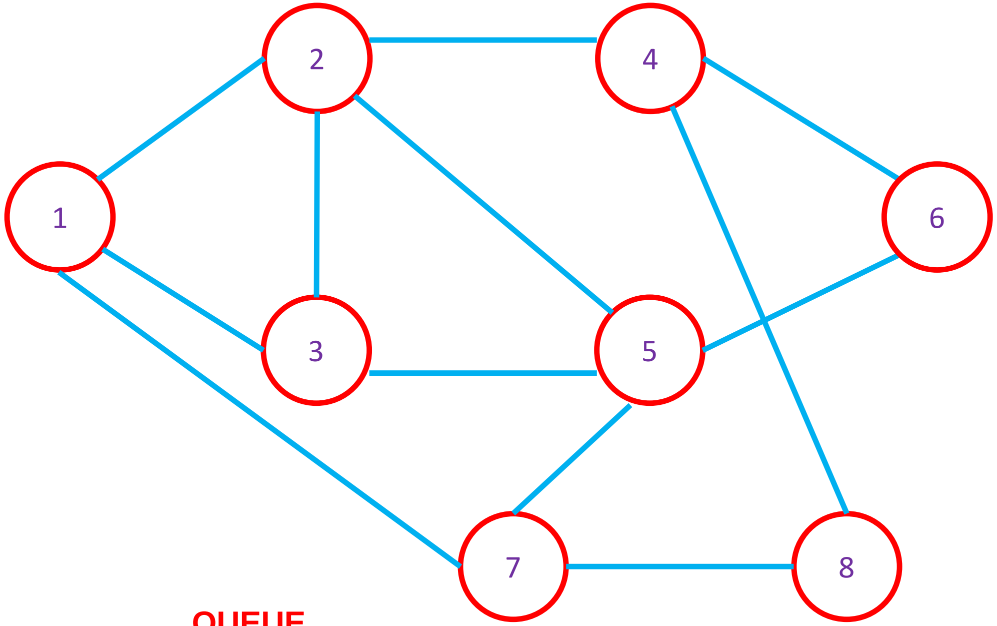
Graph Traversal



BFS : Breadth First Search

DFS : Depth First Search

BFS : Breadth First Search



Level Order Search

You can start traversing from any node. (E.g. 1 in our case)

Data Structure Used: QUEUE (FIFO)

QUEUE

~~1~~	~~2~~	~~3~~	~~7~~	~~4~~	~~5~~	~~8~~	~~6~~

OUTPUT

1	2	3	7	4	5	8	6

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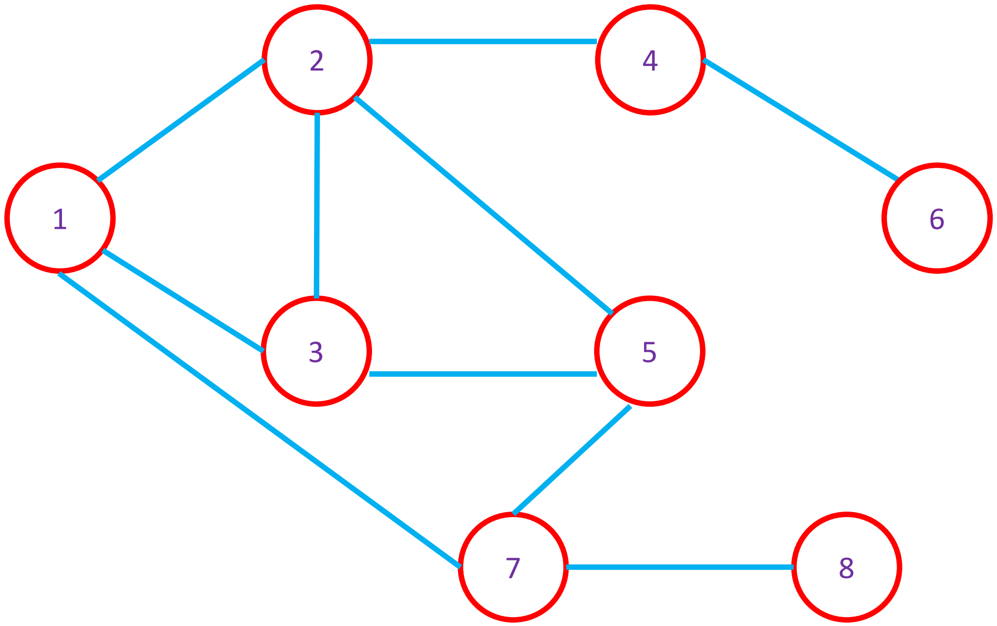
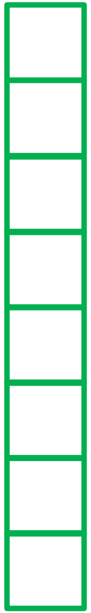
DFS : Depth First Search



You can start traversing from any node. (E.g. 1 in our case)

Data Structure Used: STACK (LIFO)



STACK

OUTPUT

1	2	3	5	7	8	4	6

Select any one unvisited adjacent vertex

Back tracking

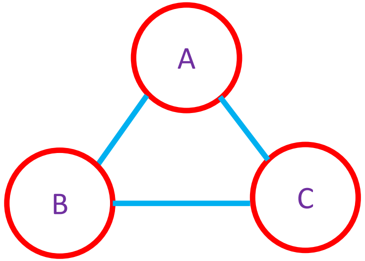
Thank You

Next: Spanning Tree

Spanning Tree

Spanning Tree: A spanning tree is a subset of Graph G, which has all the vertices covered with minimum possible number of edges.

Graph G



Graph G = (V, E)

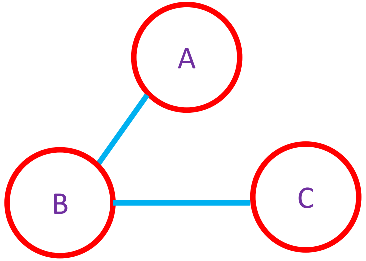
Spanning Tree G’ = (V’, E’)

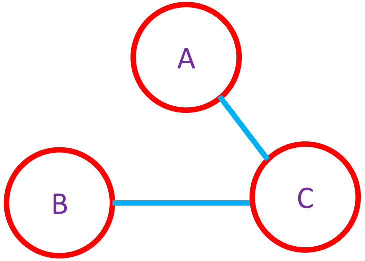
V’ = V

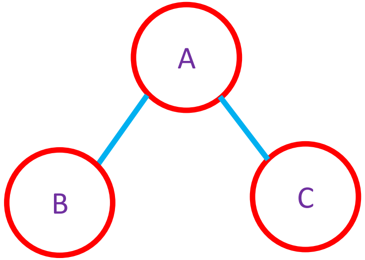
E’ C E

E’ = |V| - 1

Spanning Trees







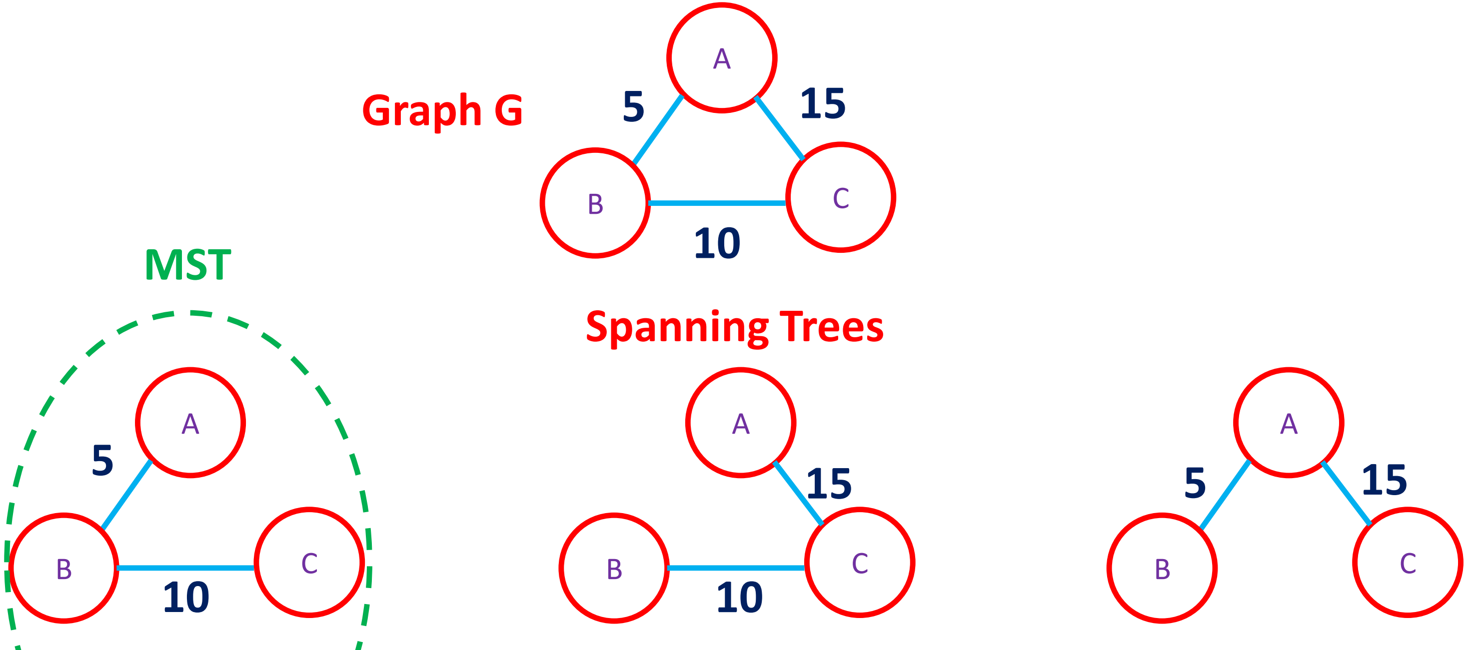
Spanning Tree

General Properties of Spanning Tree:

- A connected graph G can have more than one spanning tree.
- All possible spanning trees of graph G, have the same number of edges and vertices.
- The spanning tree does not have any cycle (loops).
- Removing one edge from the spanning tree will make the graph disconnected, i.e. the spanning tree is minimally connected.
- Adding one edge to the spanning tree will create a circuit or loop, i.e. the spanning tree is maximally acyclic.
- Maximum number of spanning tree $= n^{n-2}$ (n = number of vertices)
- From a complete graph, by removing max (e-n+1) edges, we can construct spanning a tree.

Minimum Spanning Tree

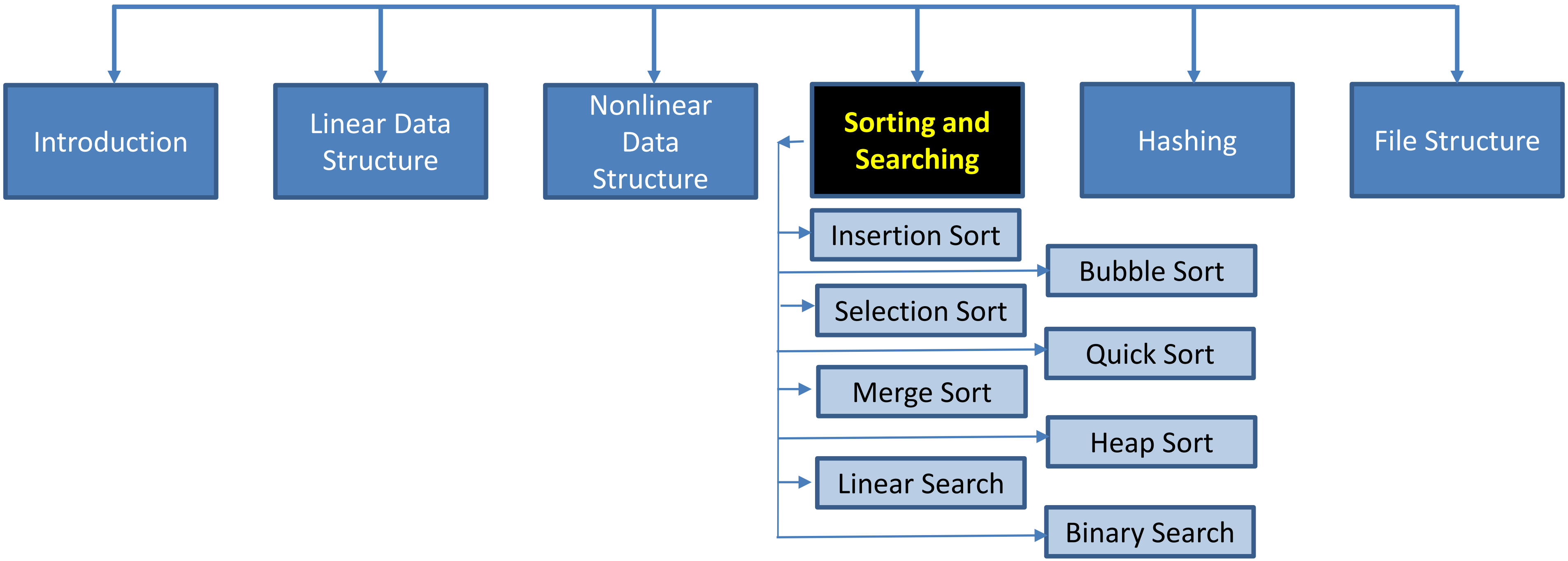
In a weighted graph, a minimum spanning tree is a spanning tree that has minimum weight than all other spanning trees of the same graph.



Thank You

Next: Sorting & Searching

DSA: Sorting and Searching



Why Sorting?

Image source: wikipedia.org

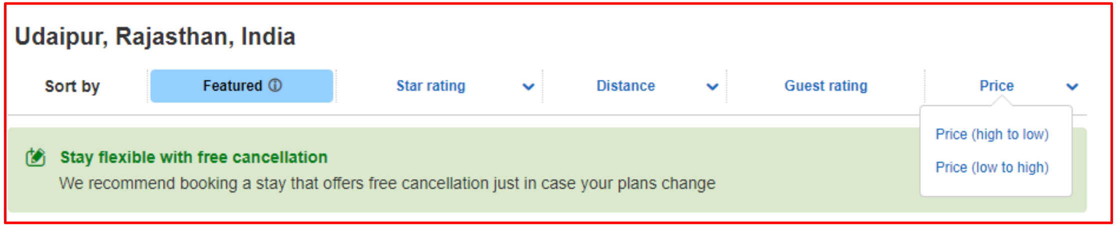
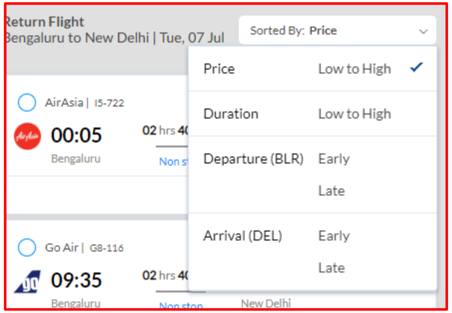


Image source: in.hotels.com



Source Image: makemytrip.com

Source image: flipkart.com

Source image: https://images.app.goo.gl/TtGsxPNaaNqUYon96

ICC Cricket World Cup 2019 - Points Table

Teams	Mat	Won	Lost	Tied	NR	Pts	NRR
India	9	7	1	0	1	**15**	+0.809
Australia	9	7	2	0	0	**14**	+0.868
England	9	6	3	0	0	**12**	+1.152
New Zealand	9	5	3	0	1	**11**	+0.175
Pakistan	9	5	3	0	1	**11**	-0.430
Sri Lanka	9	3	4	0	2	**8**	-0.919
South Africa	9	3	5	0	1	**7**	-0.030
Bangladesh	9	3	5	0	1	**7**	-0.410
West Indies	9	2	6	0	1	**5**	-0.225
Afghanistan	9	0	9	0	0	**0**	-1.322

Source image: cricbuzz.com

Source image: thycotic.com

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Data Structures and Algorithms

Selection Sort

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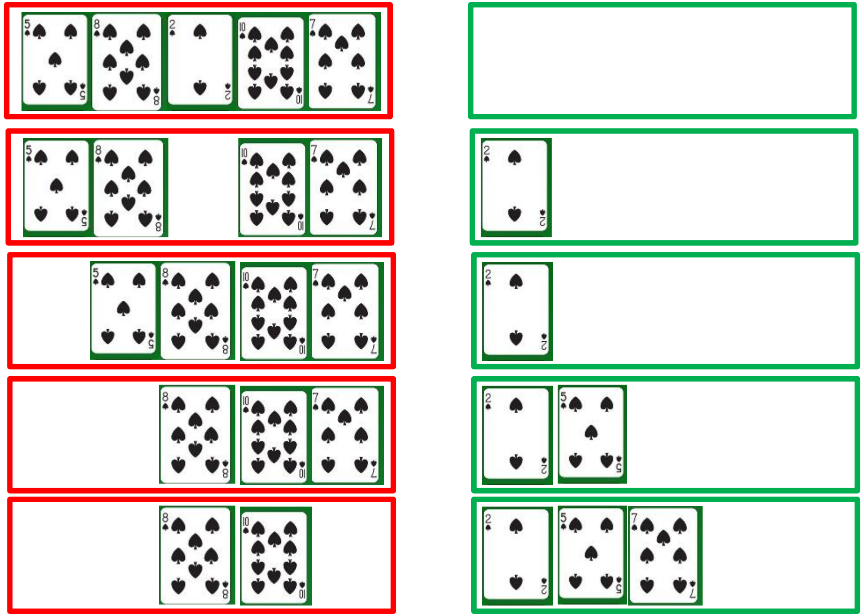
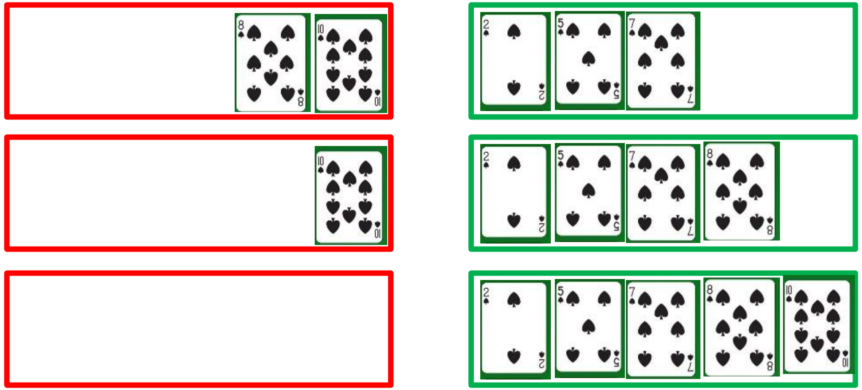
Selection Sort

- **Simplest sorting algorithm**

Unsorted (Left Hand) Sorted (Right Hand)



Unsorted (Left Hand) Sorted (Right Hand)



Selection Sort

42	23	74	11	65	58
42	23	74	11	65	58
42	23	74	11	65	58
42	23	74	11	65	58
42	23	74	11	65	58
42	23	74	11	65	58
42	23	74	11	65	58

11					
11	23				
11	23	42			
11	23	42	58		
11	23	42	58	65	
11	23	42	58	65	74

11	23	42	58	65	74

COPY ←

11	23	42	58	65	74

Selection Sort

Find the minimum and exchange with appropriate position

42	23	74	11	65	58

42	23	74	11	65	58

11	23	74	42	65	58

11	23	74	42	65	58

11	23	74	42	65	58

11	23	74	42	65	58

11	23	42	74	65	58

11	23	42	74	65	58

11	23	42	58	65	74

11	23	42	58	65	74

11	23	42	58	65	74

11	23	42	58	65	74

Selection Sort: Algorithm

```
procedure selectionSort(A:array, n: size)
for i = 0 to size(A) - 2 do:
      iMin <- I

      for j = i+1 to size(A) - 1 do:
            if (A[j] > A[iMin])
            then iMin <- j
      end for

      swap (A[i], A[iMin])
end for
end procedure
```

Selection Sort: Program

```
#include<stdio.h>
int main()
{
int i, j, iMin, temp, size=6;
int A[25]={42, 23, 74, 11, 65, 58};

for(i=0;i<=size-2;i++)
      {
      iMin = i;
      for(j=i+1; j<=size-1; ++j)
            {
            if(A[j]<A[iMin]) iMin = j;
            }
      temp=A[i];
      A[i]=A[iMin];
      A[iMin]=temp;
    }
printf("Order of Sorted elements: ");
for(i=0;i<size;i++) printf(" %d",A[i]);
return 0;
}
```

i	j	iMin	A[j]	A[iMin]	A[0]	A[1]	A[2]	A[3]	A[4]	A[5]
					42	23	74	11	65	58
0	1	0	23	42						
0	2	1	74	23						
0	3	3	11	23						
0	4	3	65	11						
0	5	3	58	11						
					11	23	74	42	65	58
1	2	1	74	23						
1	3	1	42	23						
1	4	1	65	23						
1	5	1	58	23						
					11	23	74	42	65	58
2	3	2	42	74						
2	4	3	42	65						
2	5	3	42	58						
					11	23	42	74	65	58
3	4	3	65	75						
3	5	4	65	58						
		5			11	23	42	58	65	74
4	5	4	58	75						
					11	23	42	58	65	74

OUTPUT

```
Order of Sorted elements: 11 23 42 58 65 74
```

Thank You

Next: Bubble Sort

Data Structures and Algorithms

Bubble Sort

Bubble Sort

Compare two adjacent elements and swap them if required

42	23	74	11	65	58
42	23	74	11	65	58
23	42	74	11	65	58
23	42	74	11	65	58
23	42	11	74	65	58
23	42	11	74	65	58
23	42	11	65	74	58
23	42	11	65	74	58
23	42	11	65	58	74
23	42	11	65	58	74

23	42	11	65	58	74
23	42	11	65	58	74
23	11	42	65	58	74
23	11	42	65	58	74
23	11	42	65	58	74
23	11	42	58	65	74
23	11	42	58	65	74
23	11	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74

11	23	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74
11	23	42	58	65	74

Bubble Sort: Algorithm

```
procedure bubbleSort(A : array of items, n: size of array)
for i = 0 to size(A) - 2 do:

        for j = 0 to size(A) – i - 2 do:
                if (A[j] > A[j+1])
                        swap (A[j], A[j+1])

        end for

end for
end procedure
```

Bubble Sort: Algorithm

```
procedure bubbleSort(A : array of items, n: size of
array)
for i = 0 to size(A) - 2 do:
      flag <- 0
      for j = 0 to size(A) - i - 2 do:
            if (A[j] > A[j+1])
                  swap (A[j], A[j+1])
                  flag <- 1
      end for
      if flag = 0 break
end for
end procedure
```

Bubble Sort: Program

```c
#include<stdio.h>
int main()
{
int i, j, temp, count=6;
int A[25]={42, 23, 74, 11, 65, 58};

for(i=0;i<count-1;i++)
          {
          for(j=0; j<count-i-1; ++j)
                    {
                    if(A[j]>A[j+1])
                              {
                              temp=A[j];
                              A[j]=A[j+1];
                              A[j+1]=temp;
                              }
                    }
          }
printf("Order of Sorted elements: ");
for(i=0;i<count;i++) printf(" %d",A[i]);
return 0;
}
```

i	j	j+1	A[j]	A[j+1]	A[0]	A[1]	A[2]	A[3]	A[4]	A[5]
					42	23	74	11	65	58
0	0	1	42	23	23	42				
0	1	2	42	74		42	74			
0	2	3	74	11			11	74		
0	3	4	74	65				65	74	
0	4	5	74	58					58	74
					23	42	11	65	58	74
1	0	1	23	42						
1	1	2	42	11		11	42			
1	2	3	42	65						
1	3	4	65	58				58	65	
					23	11	42	58	65	74
2	0	1	23	11	11	23				
2	1	2	23	42						
2	2	3	42	58						
					11	23	42	58	65	74
3	0	1	11	23						
3	1	2	23	42						
					11	23	42	58	65	74
4	0	1	11	12						
					11	23	42	58	65	74

Bubble Sort: Assignment

Explain the trace of bubble sort on following data. 42, 23, 74, 11, 65, 58, 94, 36, 99, 87.

42	23	74	11	65	58	94	36	99	87
42	23	74	11	65	58	94	36	99	87
23	42	74	11	65	58	94	36	99	87
23	42	74	11	65	58	94	36	99	87
23	42	11	74	65	58	94	36	99	87
23	42	11	65	74	58	94	36	99	87
23	42	11	65	58	74	94	36	99	87
23	42	11	65	58	74	94	36	99	87
23	42	11	65	58	74	36	94	99	87
23	42	11	65	58	74	36	94	99	87
23	42	11	65	58	74	36	94	87	99

23	42	11	65	58	74	36	94	87	99
23	42	11	65	58	74	36	94	87	99
23	11	42	65	58	74	36	94	87	99
23	11	42	65	58	74	36	94	87	99
23	11	42	58	65	74	36	94	87	99
23	11	42	58	65	74	36	94	87	99
23	11	42	58	65	36	74	94	87	99
23	11	42	58	65	36	74	94	87	99
23	11	42	58	65	36	74	87	94	99
23	11	42	58	65	36	74	87	94	99

Continue on next slide..

Bubble Sort: Assignment

…continued from previous slide

23	11	42	58	65	36	74	87	94	99
11	23	42	58	65	36	74	87	94	99
11	23	42	58	65	36	74	87	94	99
11	23	42	58	65	36	74	87	94	99
11	23	42	58	65	36	74	87	94	99
11	23	42	58	36	65	74	87	94	99
11	23	42	58	36	65	74	87	94	99
11	23	42	58	36	65	74	87	94	99

11	23	42	58	36	65	74	87	94	99
11	23	42	58	36	65	74	87	94	99
11	23	42	58	36	65	74	87	94	99
11	23	42	58	36	65	74	87	94	99
11	23	42	36	58	65	74	87	94	99

11	23	42	36	58	65	74	87	94	99
11	23	42	36	58	65	74	87	94	99

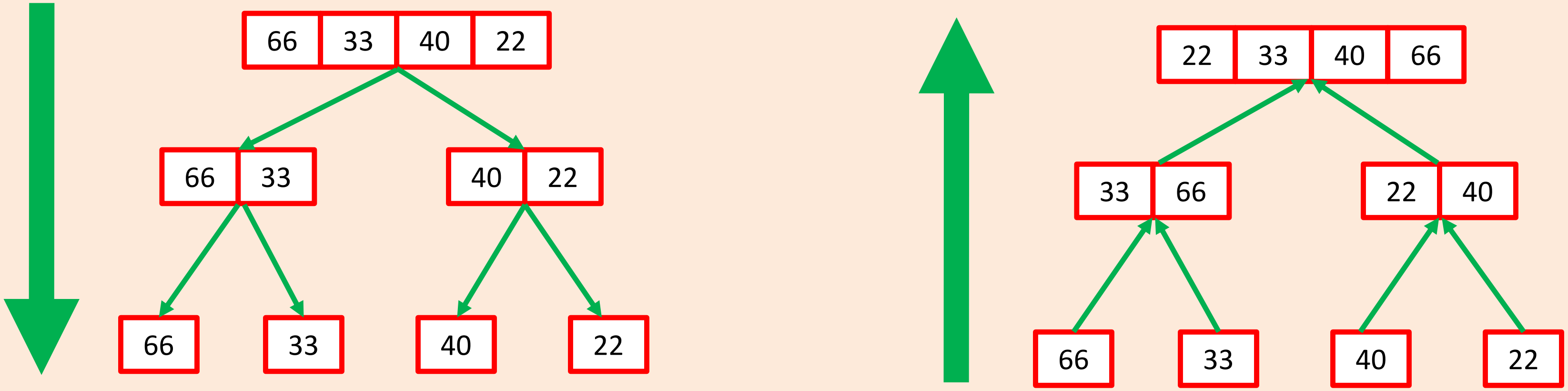
11	23	42	36	58	65	74	87	94	99
11	23	42	36	58	65	74	87	94	99
11	23	42	36	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99

11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99
11	23	36	42	58	65	74	87	94	99

Thank You

Next: Merge Sort

Merge Sort



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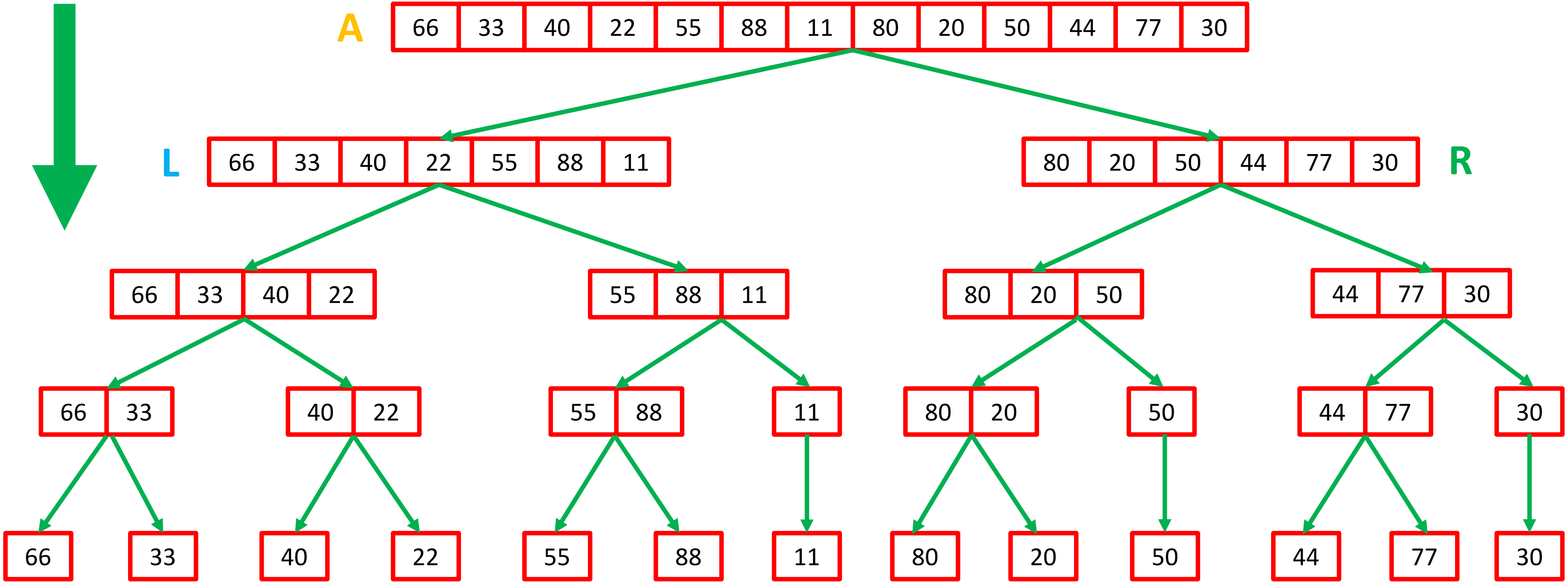
Merge Sort



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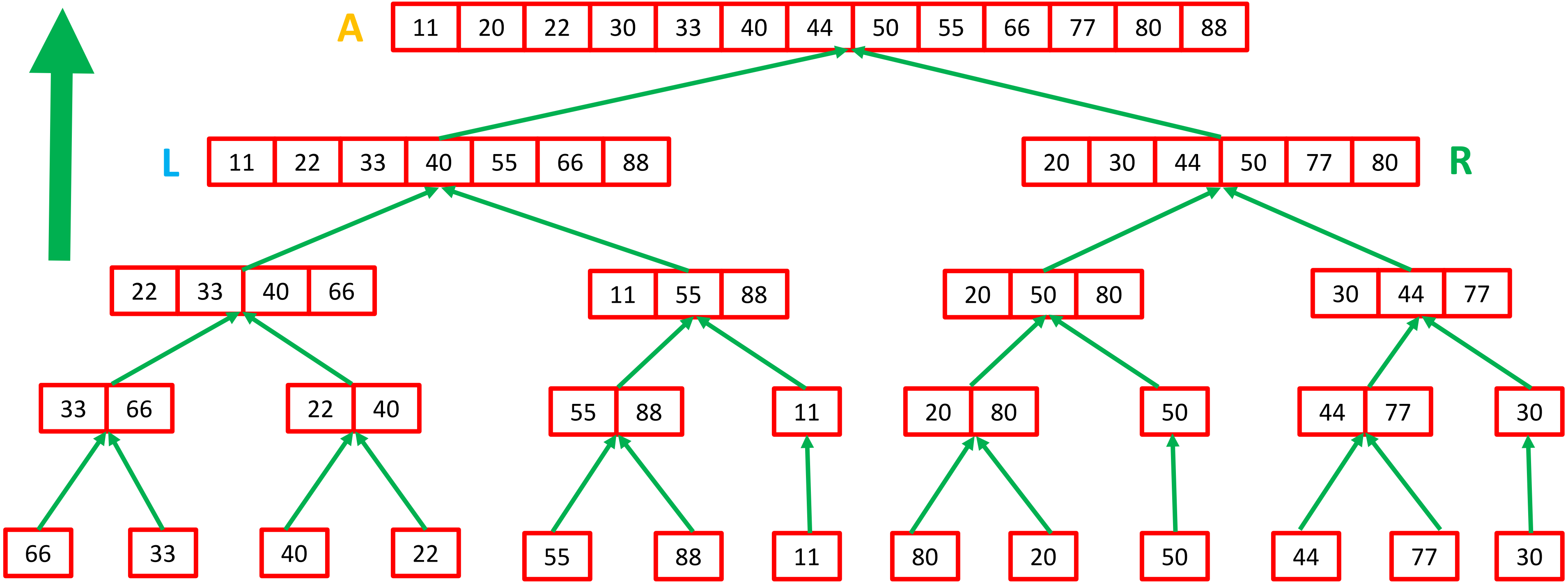
Merge Sort



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Merge Sort

A													

L	11	22	33	40	55	66	88

R	20	30	44	50	77	80

11												

	22	33	40	55	66	88

20	30	44	50	77	80

11												

	22	33	40	55	66	88

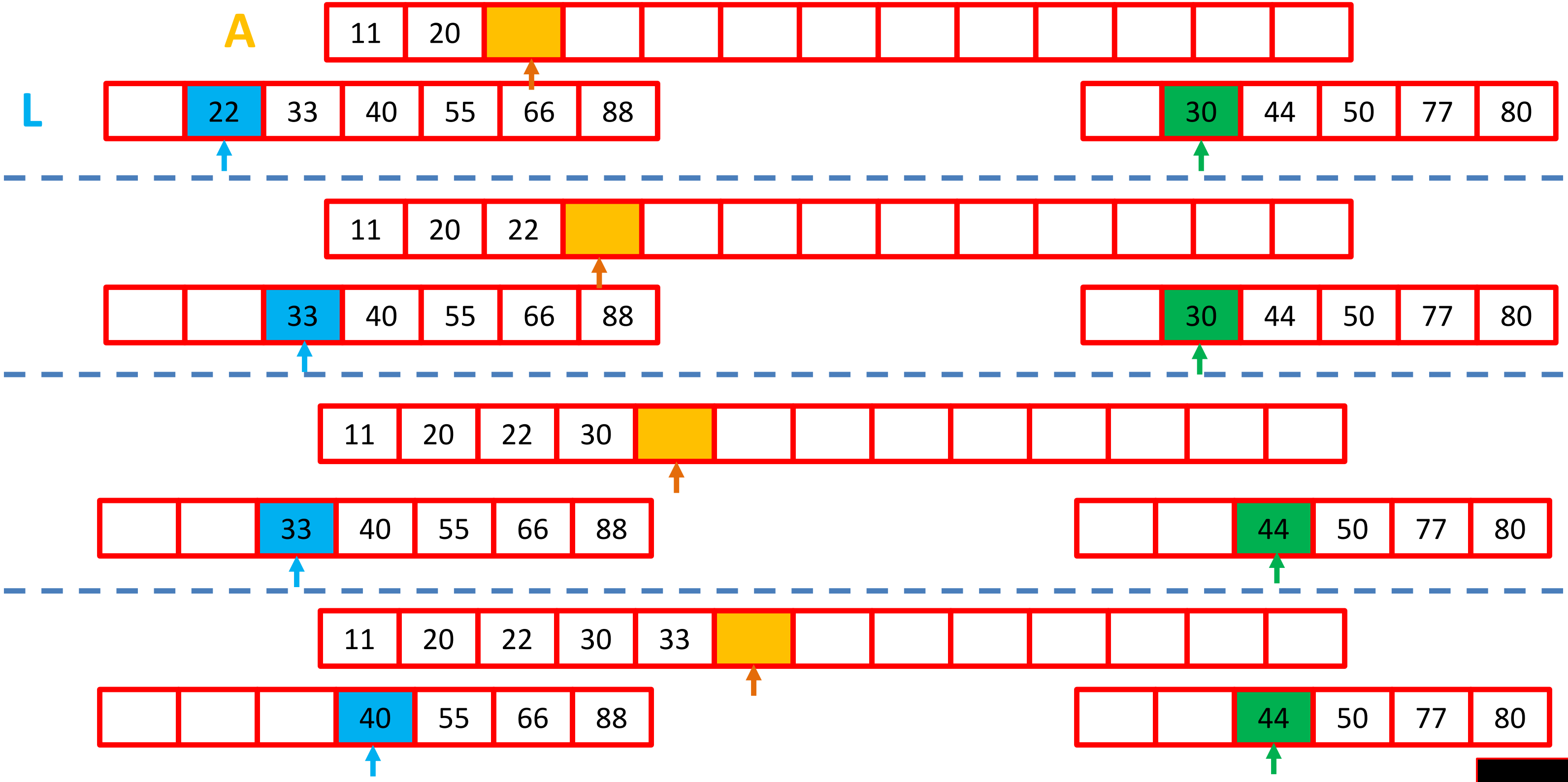
20	30	44	50	77	80

11	20											

	22	33	40	55	66	88

	30	44	50	77	80

Merge Sort


A
11 20
L
22 33 40 55 66 88
30 44 50 77 80
R
11 20 22
33 40 55 66 88
30 44 50 77 80
11 20 22 30
33 40 55 66 88
44 50 77 80
11 20 22 30 33
40 55 66 88
44 50 77 80

Merge Sort

A

11	20	22	30	33	40							

L

				55	66	88

R

		44	50	77	80

11	20	22	30	33	40	44						

				55	66	88

			50	77	80

11	20	22	30	33	40	44	50					

				55	66	88

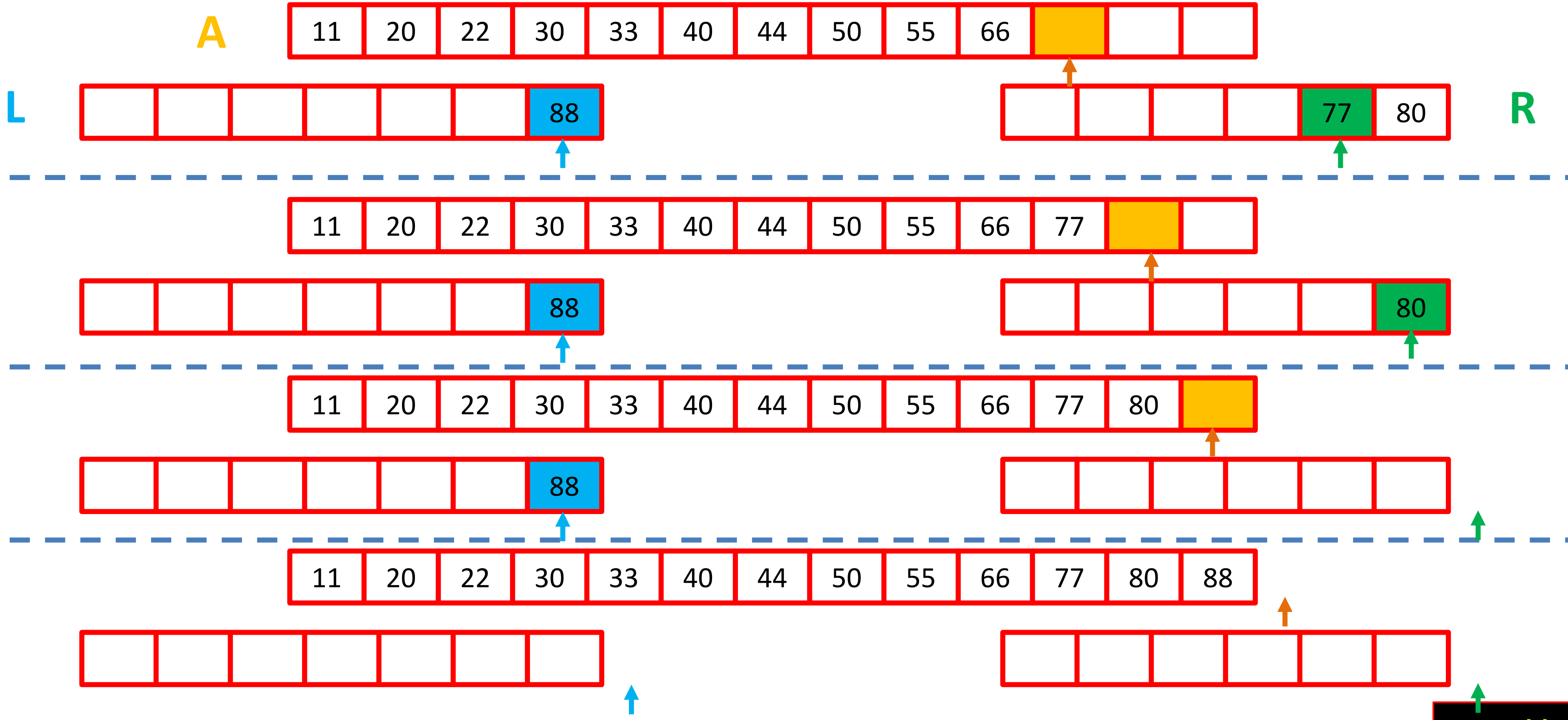
				77	80

11	20	22	30	33	40	44	50	55				

					66	88

				77	80

Merge Sort



A
11 20 22 30 33 40 44 50 55 66
L
88
77 80
R
11 20 22 30 33 40 44 50 55 66 77
88
80
11 20 22 30 33 40 44 50 55 66 77 80
88
11 20 22 30 33 40 44 50 55 66 77 80 88

Merge Sort: Algorithm

```
mergeSort (A)
n <- size(A)
if n < 2 return
mid <- n / 2
Create left array L of size(mid)
Create right array R of size (n -
mid)

for i <- 0 to mid-1
        L [i] <- A[i]

for i < mid to n - 1
        R [i-mid] <- A[i]

MergeSort (L)
MergeSort (R)
Merge(L, R, A)
```

Merge Sort: Algorithm

```
merge (L, R, A)
  nL <- size(L)
  nR <- size(R)
  i <- j <- k <- 0
  while i <nL AND j < nR do
          if L[i] <= R[j]
                    copy L[i] into A[k]
                    increment i
          else
                    copy R[j] into A[k]
                    increment j
          end if
          increment k
  end while

  while i < nL do
          copy L[i] into A[k]
          increment i and k
  end while
  while j < nR do
          copy R[j] into A[k]
          increment j and k
  end while
```

Merge Sort: Program

```
void mergeSort(int A[], int left, int right)
{
    if (left < right)
            {
            int mid = left + (right - left) / 2;
            mergeSort(A, left, mid);
            mergeSort(A, mid + 1, right);
            merge(A, left, mid, right);
            }
}
```

```
int main()
{
int i, A[] = {66, 33, 40, 22, 55, 88, 11, 80,
20, 50, 44, 77, 30}, size=13;

mergeSort(A, 0, size - 1);

for(i=0; i<size; ++i)printf("%d ",A[i]);
return 0;
}
```

Merge Sort: Program

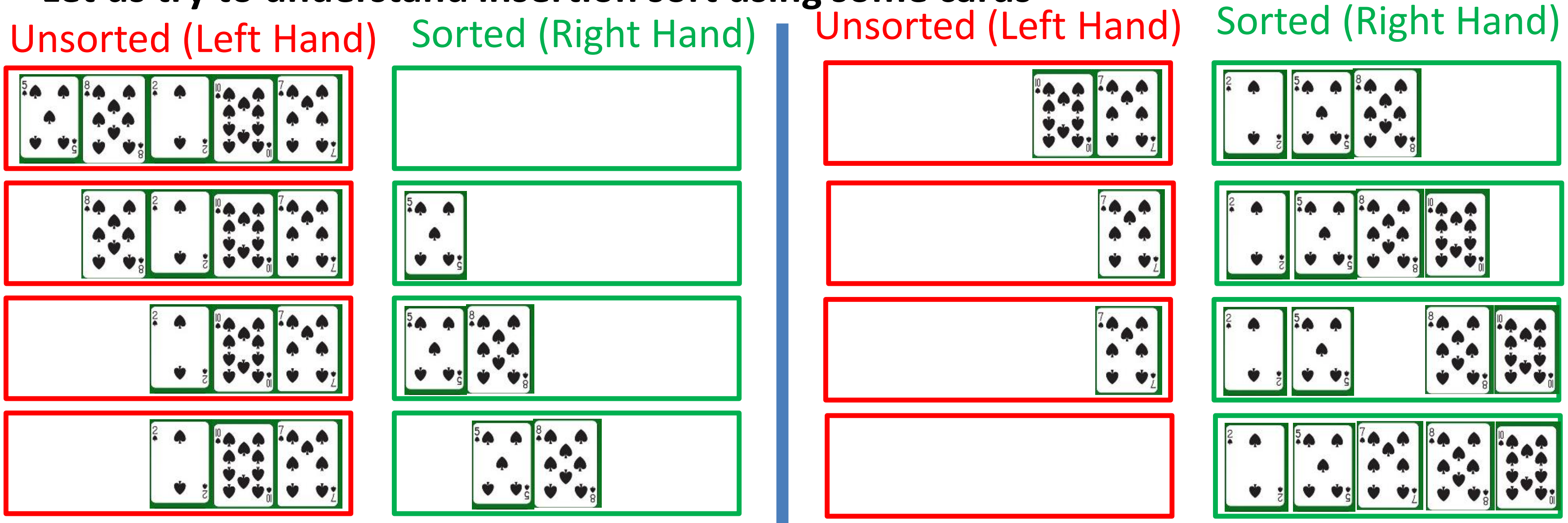
```
void merge(int A[], int left, int mid, int right)
{
    int i, j, k;
    int nL = mid - left + 1;
    int nR = right - mid;
    int L[nL], R[nR];
    for (i = 0; i < nL; i++) L[i] = A[left + i];
    for (j = 0; j < nR; j++) R[j] = A[mid + 1 + j];

    i = 0; j = 0; k = left;
    while (i < nL && j < nR)
        {
        if (L[i] <= R[j]) {A[k] = L[i]; i++;}
        else {A[k] = R[j]; j++;}
        k++;
        }
    while (i < nL) {A[k] = L[i]; i++; k++;}
    while (j < nR) {A[k] = R[j]; j++; k++;}
}
```

Thank You

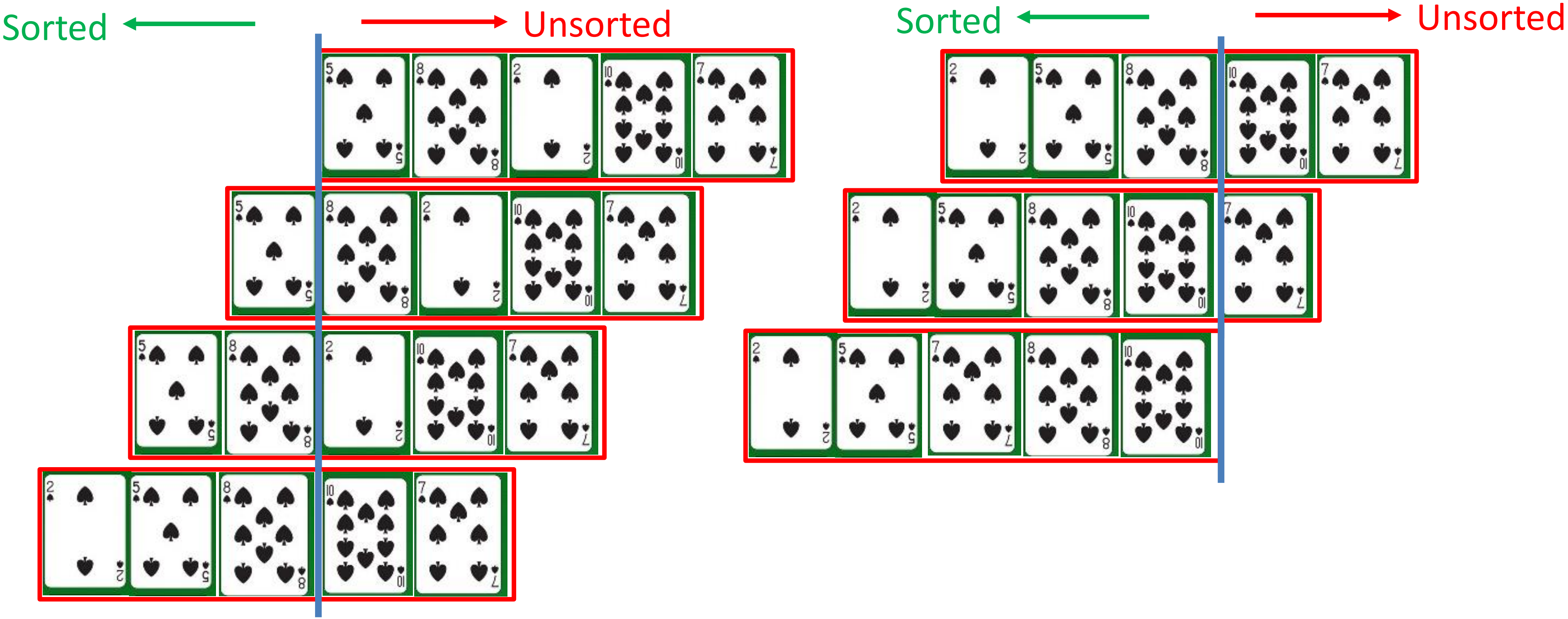
Next: Insertion Sort

Insertion Sort

- Not a best sorting algorithm
- But, better than selection and bubble sort
- Let us try to understand insertion sort using some cards



Insertion Sort



Insertion Sort

42	23	74	11	65	58	
42	23	74	11	65	58	
42		74	11	65	58	Value <- 23

Hole

	42	74	11	65	58	Value <- 23
23	42	74	11	65	58	Value <- 23

23	42	74	11	65	58	Value <- 74
23	42		11	65	58	Value <- 74
23	42	74	11	65	58	

23	42	74		65	58	Value <- 11
23	42		74	65	58	Value <- 11
23		42	74	65	58	Value <- 11

	23	42	74	65	58	Value <- 11
11	23	42	74	65	58	

11	23	42	74		58	Value <- 65
11	23	42		74	58	Value <- 65

11	23	42	65	74	58	
11	23	42	65	74		Value <- 58
11	23	42	65		74	Value <- 58
11	23	42		65	74	Value <- 58

11	23	42	58	65	74

Insertion Sort: Psudocode

Step 1: If it is the first element, it is already sorted. return 1;
Step 2: Pick next element
Step 3: Compare with all elements in the sorted sub-list
Step 4: Shift all the elements in the sorted sub-list that is greater than the value to be sorted
Step 5: Insert the value
Step 6: Repeat until list is sorted

Insertion Sort: Algorithm

```
procedure insertionSort( A : array of items )
int hole
int value
for i = 1 to size(A) do:
        /* select value to be inserted */
        value = A[i]
        hole = i

        /*locate hole position for the element to be inserted */
        while hole > 0 and A[hole-1] > value do:
                A[hole] = A[hole-1]
                hole = hole -1
        end while

        /* insert the A at hole position */
        A[hole] = value
end for
end procedure
```

Insertion Sort: Program

```
#include<stdio.h>
int main()
{int i, hole, size=6, value;
int A[25]={42,23,74,11,65,58};
for(i=1; i<size; i++)
  {
  value=A[i];
  hole=i-1;
  while((value<A[hole]) && (hole>=0))
          {A[hole+1]=A[hole];
          hole=hole-1;
          }
  A[hole+1]=value;
  }
printf("Order of Sorted elements: ");
for(i=0;i<size;i++) printf(" %d",A[i]);
return 0;
}
```

i	Value= A[i]	hole	A[hole]	Value<A[hole]	hole>=0	A[0]	A[1]	A[2]	A[3]	A[4]	A[5]
						42	23	74	11	65	58
1	23	0	42	(23<42?) True	True		42				
1		-1			False	23					
						23	42	74	11	65	58
2	74	1	42	(74<42?) False	True	23	42	74	11	65	58
3	11	2	74	(11<74?) True	True				74		
3		1	42	(11<42?) True	True			42			
3		0	23	(11<23?) True	True		23				
3		-1			False	11					
						11	23	42	74	65	58
4	65	3	74	(65<74?) True	True					74	
4		2	42	(65<42) False	True				65		
						11	23	42	65	74	58
5	58	4	74	(58<75?) True	True						74
5		3	65	(58<65?) True	True					65	
5		2	42	(58<42?) False	True				58		
						11	23	42	58	65	74

OUTPUT

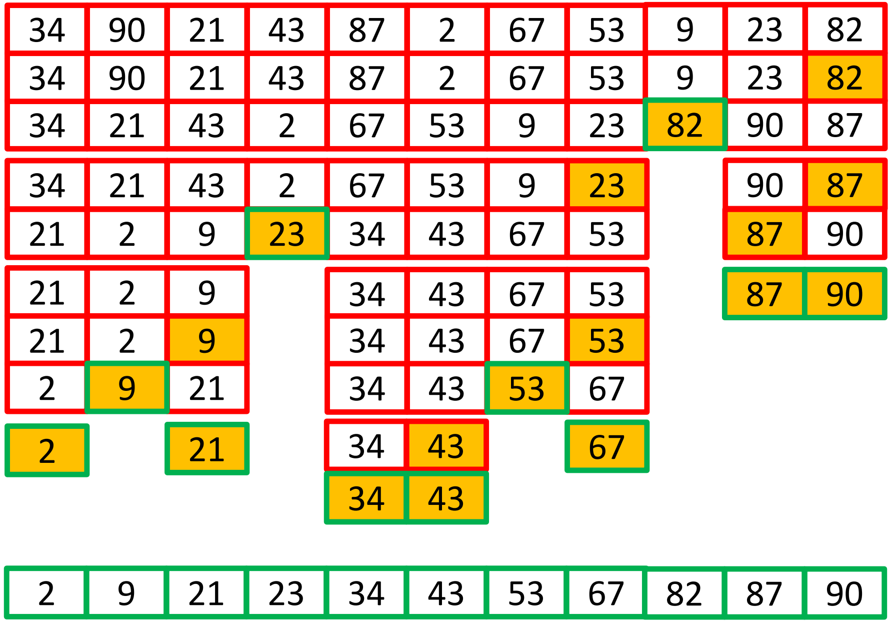
```
Order of Sorted elements: 11 23 42 58 65 74
```

Thank You

Next: Quick Sort

Quick Sort

- **Divide and conquer strategy, In-place sorting algorithm, Fast and efficient in practical situation**



Quick Sort: Partitioning

Partition Index ← Start   Pivot ← A[end]   i index

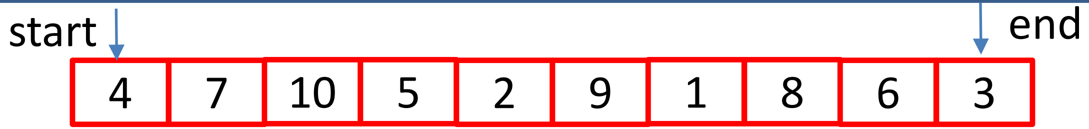
34	90	21	43	87	2	67	53	9	23	82
34	90	21	43	87	2	67	53	9	23	82
34	90	21	43	87	2	67	53	9	23	82
34	90	21	43	87	2	67	53	9	23	82
34	21	90	43	87	2	67	53	9	23	82
34	21	90	43	87	2	67	53	9	23	82
34	21	43	90	87	2	67	53	9	23	82
34	21	43	90	87	2	67	53	9	23	82
34	21	43	90	87	2	67	53	9	23	82
34	21	43	2	87	90	67	53	9	23	82

if(A[i]<pivot) then swap A[i] and A[PartitionIndex]

34	21	43	2	87	90	67	53	9	23	82
34	21	43	2	67	90	87	53	9	23	82
34	21	43	2	67	90	87	53	9	23	82
34	21	43	2	67	53	87	90	9	23	82
34	21	43	2	67	53	87	90	9	23	82
34	21	43	2	67	53	87	90	9	23	82
34	21	43	2	67	53	9	90	87	23	82
34	21	43	2	67	53	9	90	87	23	82
34	21	43	2	67	53	9	23	87	90	82
34	21	43	2	67	53	9	23	82	90	87

Quick Sort: Algorithm

```
QuickSort (A, start, end)
{
if (start < end)
          {
          pIndex <- Partition (A,start, end)
          QuickSort (A, start, pIndex-1)
          QuickSort (A, pIndex+1, end)
          }
}
```




```
Partition (A, start, end)
{
pivot <- A[end]
pIndex <- start
for i <- start to end-1 do
          if A[i] <= pivot
                    swap A[i] with A[partiionIndex]
                    increment pIndex
          end if
end for
}
```

Quick Sort: Program

```
int QuickSort (int *A, int start, int end)
{if(start < end)
          {int pIndex = Partition (A, start, end);
          QuickSort (A, start, pIndex-1);
          QuickSort (A, pIndex+1, end);
          }
          return 0;
}

int Partition (int *A, int start, int end)
{int i, temp, pivot = A[end], pIndex = start;
for (i=start; i<end; ++i)
          {if(A[i]<pivot)
                    {temp = A[i]; A[i] = A[pIndex];A[pIndex] = temp;
                    pIndex++;
                    }
          }
temp = A[end]; A[end] = A[pIndex]; A[pIndex] = temp;
return pIndex;
}
```

```
int main()
{
int A[] = {5,7,10,5,2,9,1,8,6,3}, i;
QuickSort (A, 0, 9);
for(i=0; i<10; ++i) printf("%d ",A[i]);
return 0;
}
```

Thank You

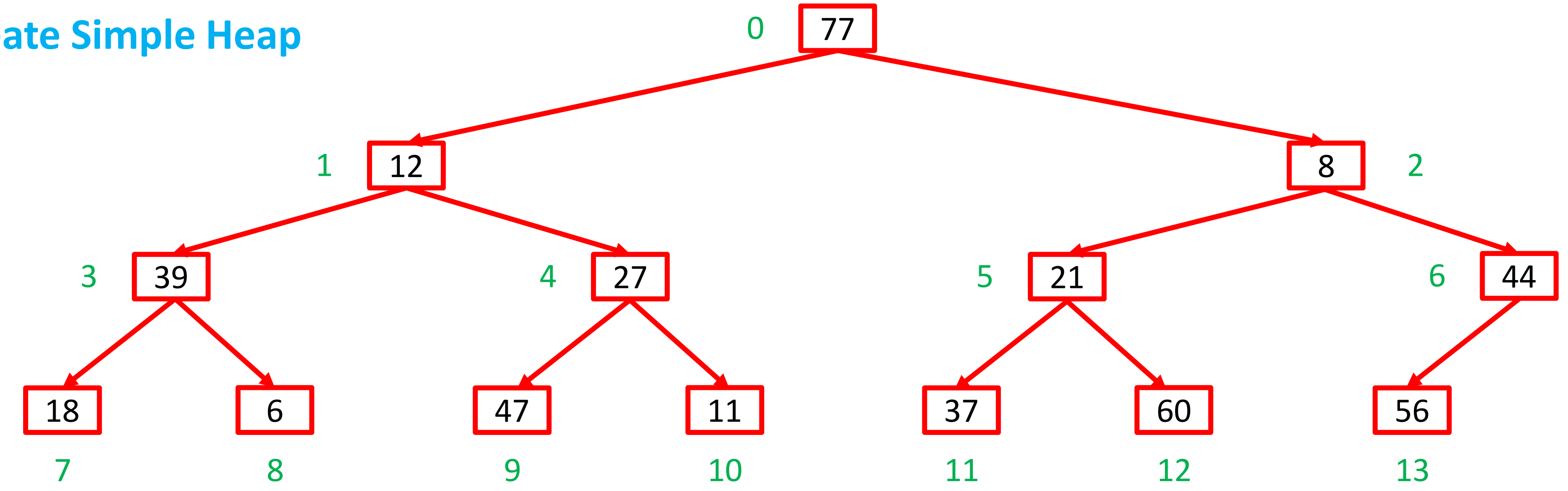
Next: Heap Sort

Heap Sort

77	12	8	39	27	21	44	18	6	47	11	37	60	56
0	1	2	3	4	5	6	7	8	9	10	11	12	13

Heap: Ordered binary tree

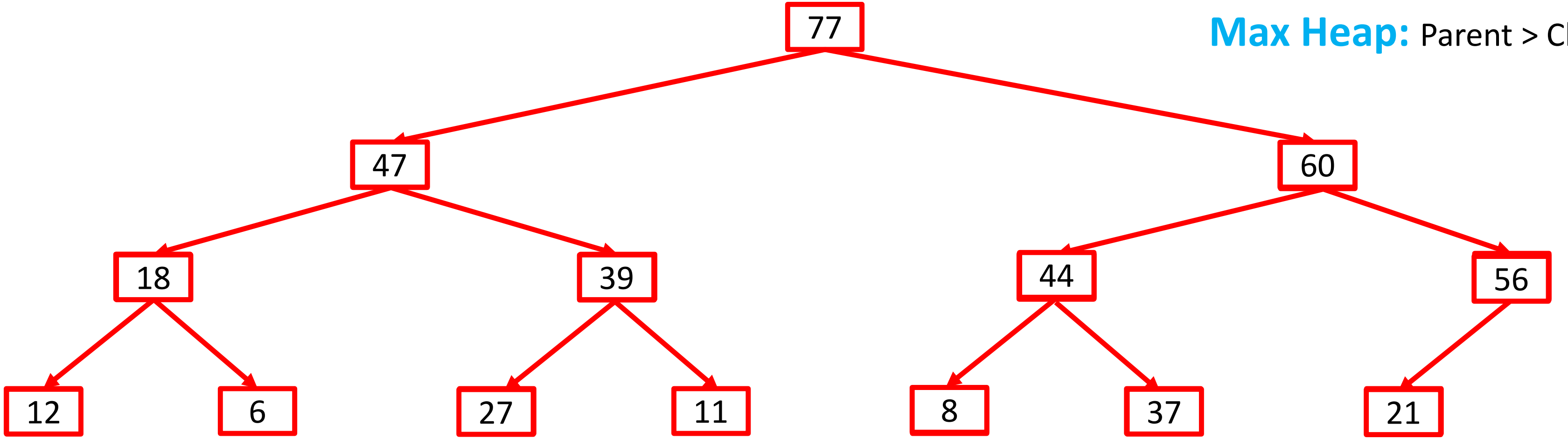
Create Simple Heap



Create Max Heap

77	12	8	39	27	21	44	18	6	47	11	37	60	56
0	1	2	3	4	5	6	7	8	9	10	11	12	13

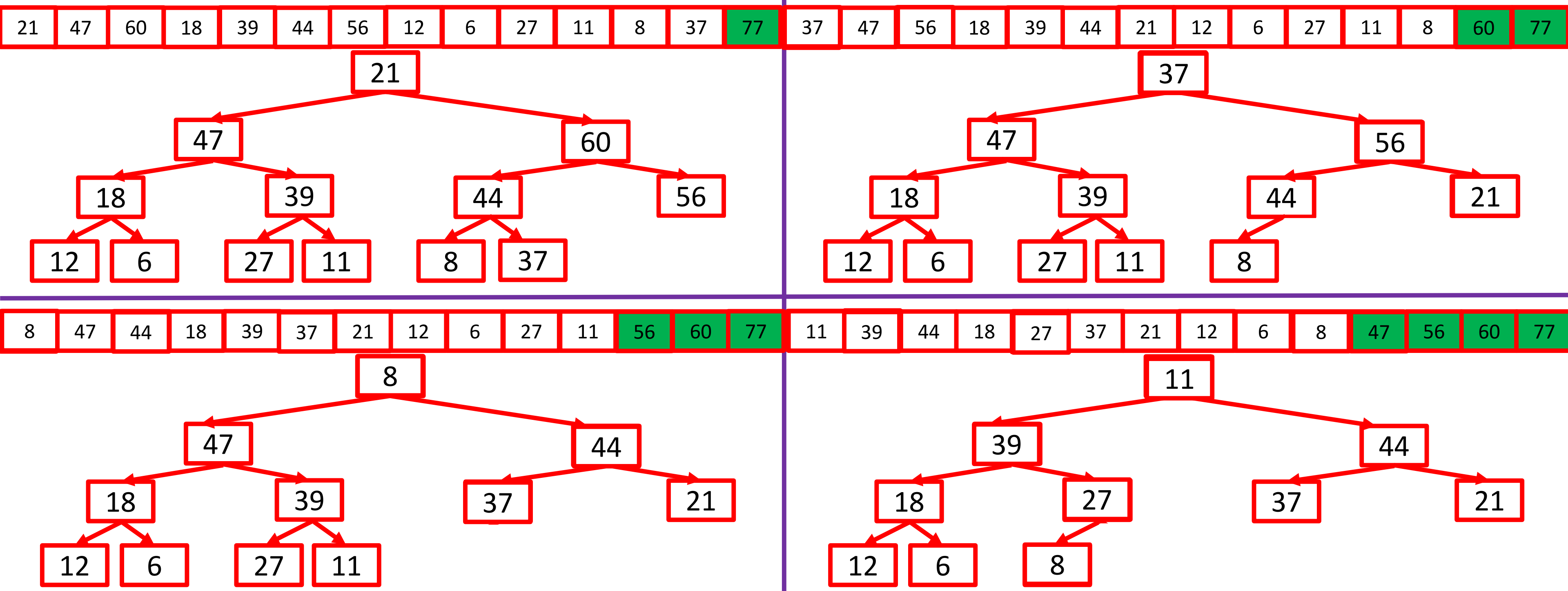
Max Heap: Parent > Child



77	47	60	18	39	44	56	12	6	27	11	8	37	21
0	1	2	3	4	5	6	7	8	9	10	11	12	13

Heapify

- parent > child
- Swap maximum element (root) with the last element
- Remove the maximum element



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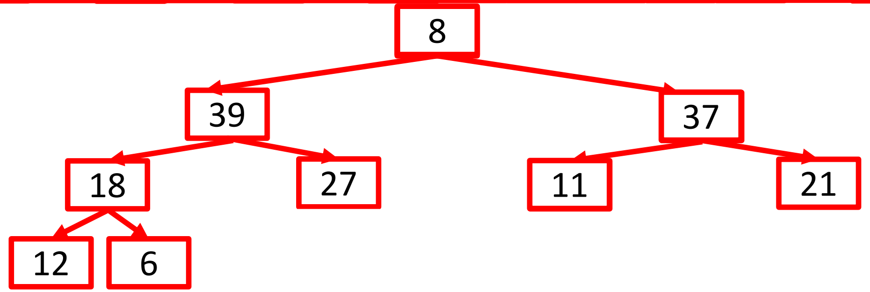
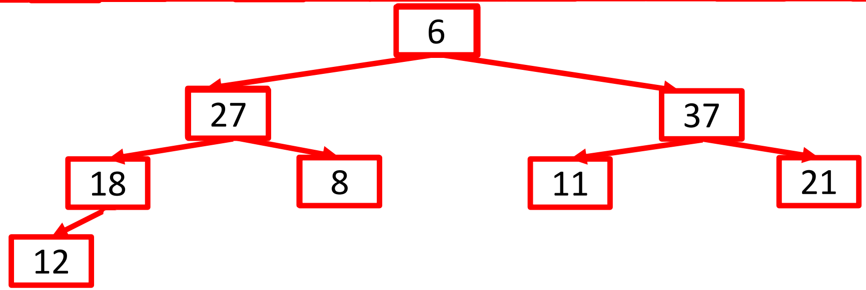
Heapify

- parent > child
- Swap maximum element (root) with the last element
- Remove the maximum element

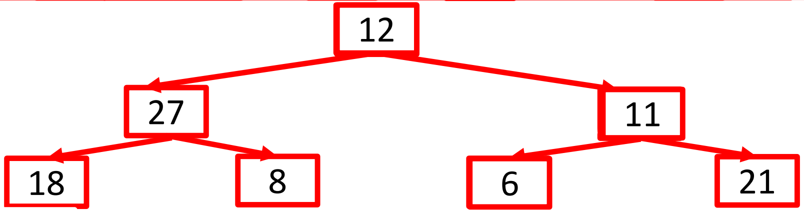
8	39	37	18	27	11	21	12	6	44	47	56	60	77



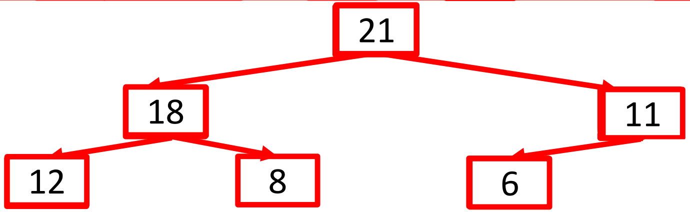
6	27	37	18	8	11	21	12	39	44	47	56	60	77



12	27	11	18	8	6	21	37	39	44	47	56	60	77



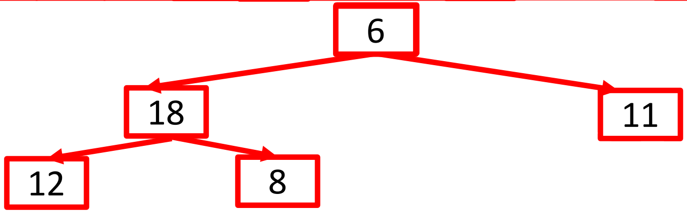
21	18	11	12	8	6	27	37	39	44	47	56	60	77



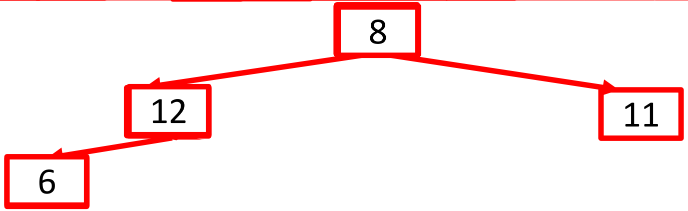
Heapify

- parent > child
- Swap maximum element (root) with the last element
- Remove the maximum element

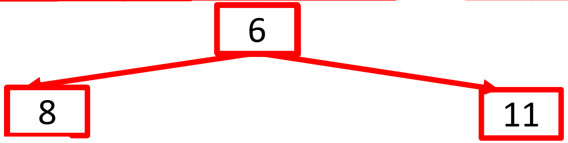
6	18	11	12	8	21	27	37	39	44	47	56	60	77



8	12	11	6	18	21	27	37	39	44	47	56	60	77



6	8	11	12	18	21	27	37	39	44	47	56	60	77



6	8	11	12	18	21	27	37	39	44	47	56	60	77

Sorted !! ☺

Linear Search

11	58	6	77	18	21	39	37	27	44	47	8	60	12
0	1	2	3	4	5	6	7	8	9	10	11	12	13

Does exist in array?	Result?	At which position?
21	Yes	5
41	No	-
60	Yes	12
88	No	-

How do we search?

Simplest option is Linear Search !

searchLinear

Best case: Find the x at first place, hence only 1 comparison

Worst case: Find the x at last place (or x does not exist), hence n comparisons

Array does not need to be sorted

Linear Search: Algorithm & Program

```
#include<stdio.h>

int main()
{
int A[]={77,12,8,39,27,21,44,18,6,47,11,37,60,56}
int n=14, x=39;
int searchLinear (int[],int,int);
int searchResult = searchLinear (A,n,x);
if (searchResult == -1)printf("Element does not exist");
else printf("Element %d found at poistion %d",x,searchResult);
return 0;
}

int searchLinear (int A[], int n, int x)
{
int i;
for(i=0; i<n; ++i){if (A[i]==x)return i;}
return -1;
}
```

```
searchLinear (A, n, x)
for each i from 0 to n-1 do
          if A[i] is equal to x
                    then return i
          end if
end for
return -1
```

Binary Search

Start=0 Middle = (Start + End) /2 = 6 End=13

6	8	11	12	18	21	27	37	39	44	47	58	60	77
0	1	2	3	4	5	6	7	8	9	10	11	12	13

Let us try to find out whether the number x=39 exists in the array or not !

We compare x with A[Middle] and there are three possibilities

Possibility 1: x is equal to A[Middle]. Our search is over as we have found the element.

Possibility 2: x is less than A[Middle]. We need to search between Start and Middle-1. That means End becomes Middle-1.

Possibility 3: x is greater than A[Middle]. We need to search between Middle+1 to End. That means Start becomes Middle+1.

Binary Search

Middle=8

Start=7

End=9

6	8	11	12	18	21	27	37	39	44	47	58	60	77
0	1	2	3	4	5	6	7	8	9	10	11	12	13

x 39

X=39	A[Middle]=27	Compare x with A[Middle]	Start=0	End=13	Middle = 6
39	27	39 > 27	7	13	10
39	47	39 < 47	7	9	8
39	39	39 = 39		FOUND ! ☺	

Binary Search: Algorithm

```
searchBinary (A, n, x)
start <- 0
end <- n-1
while start <= end do
       middle <- (start + end) / 2
       if A[Middle] is equal to x then
              return Middle
       else if A[Middle] is greater than x then
              end <- Middle - 1
       else
              start <- Middle + 1
       end if
end while
return -1
```

Binary Search: Program

```
/* binary search */
#include<stdio.h>
int main()
{           int A[]={6,8,11,12,18,21,27,37,39,44,47,58,60,77}, n=14, x=39;
            int searchBinary (int[],int,int);
            int searchResult = searchBinary (A,n,x);
            if (searchResult == -1)printf("Element does not exist");
            else printf("Element %d found at poistion %d",x,searchResult);
            return 0;
}
int searchBinary (int A[], int n, int x)
{           int i, start=0, end=n-1, middle;
            while (start <= end)
            {           middle = (start + end)/2;
                        if (A[middle]==x)return middle;
                        else if (A[middle]>x) end=middle-1;
                        else start=middle+1;
            }
return -1;
}
```

Thank You

Next: Hashing

DSA: Hashing

- Introduction
- Linear Data Structure
- Nonlinear Data Structure
- Sorting and Searching
- **Hashing**
  - Hashing Techniques
  - Symbol Table
  - Collision Resolution
- File Structure

Hashing

Hashing is a technique that is used to uniquely identify/search/retrive a specific object from a group of similar objects.

For example, using Enrolment number of a student, one can fetch other information about him/her.

As an another example, using accession number on a book, one can find the exact location of the book in library.

Hashing

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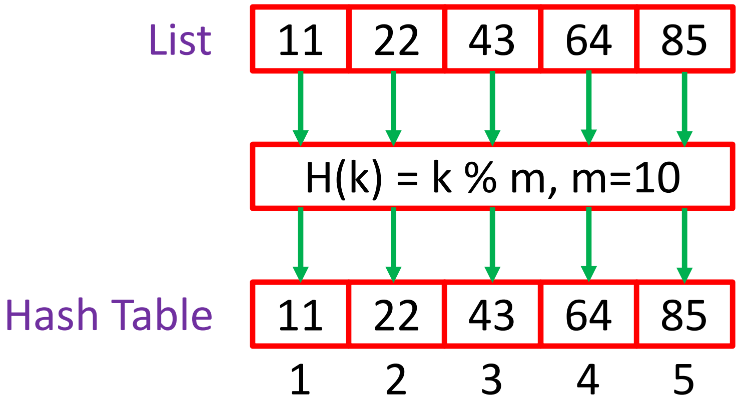
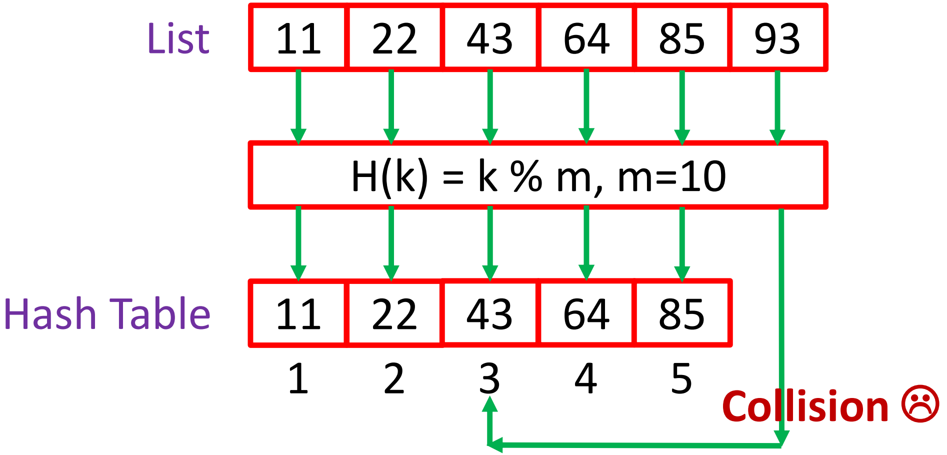
Let H(k) be a hash function that maps the value V at the index k%m, where k is the key and m is the size of hash table.

For example, we have a list L = {11, 22, 43, 64, 85}, it will be stored at position {1,2,3,4,5} in an array or hash table, respectively.





Collision Resolution

(1) Open Hashing (Closed Addressing)
(2) Closed Hashing (Open Addressing)

(1) Open Hashing (Closed Addressing)
- Chaining

(2) Closed Hashing (Open Addressing)
- Linear Probing
- Quadratic Probing
- Double Hashing

Collision can not be avoided but can be minimized.

Collision Resolution: Chaining

(1) Open Hashing (Closed Addressing) - Chaining

List L(k) = {3, 2, 9, 6, 11, 13, 7, 12}

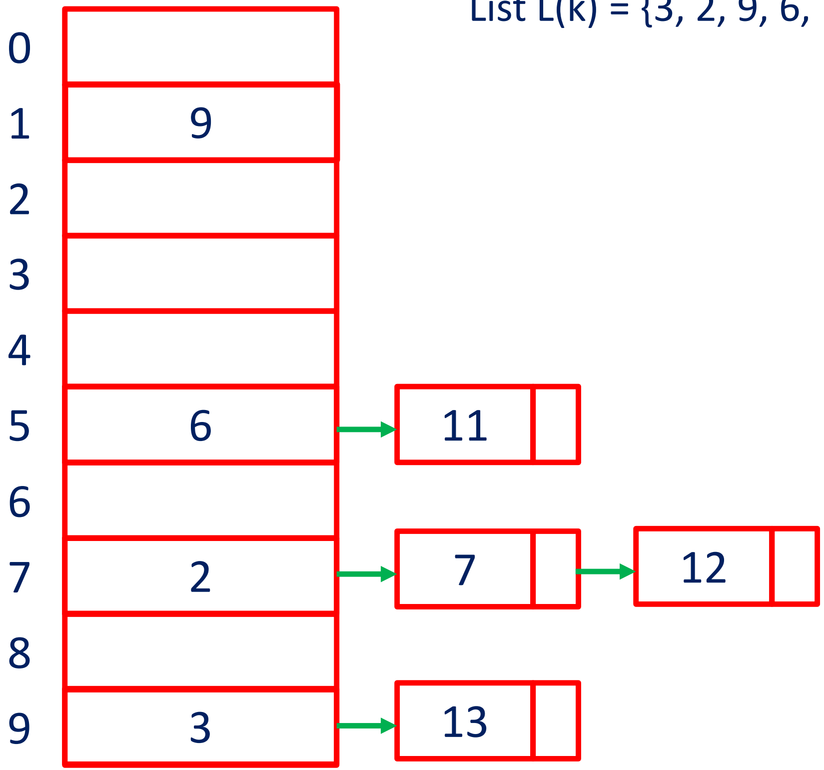
Hash Function H(k) = 2k + 3

Size of hash table = m = 10

Collision Resolution Technique to be used = Division Method AND Open Hashing (Closed Addressing) - Chaining

Collision Resolution: Chaining

List L(k) = {3, 2, 9, 6, 11, 13, 7, 12}



k	Location=(2k+3)%m
3	(2x3+3)%10 → 9
2	(2x2+3)%10 → 7
9	(2x9+3)%10 → 1
6	(2x6+3)%10 → 5
11	(2x11+3)%10 → 5
13	(2x13+3)%10 → 9
7	(2x7+3)%10 → 7
12	(2x12+3)%10 → 7

Collision Resolution: Chaining

```
#include <stdio.h>
#define m 10
#define size 20
struct hashing
{
        int data;
        struct hashing *next;
};
void main()
{
        struct hashing *hash[m], *newnode, *temp;
        int list[size]={23,54,10,55,67,32,44,77,2,9,53,94,30,15,167,352,434,767,27,98}, i, pos;

        for(i=0; i<m; ++i) hash[i]=NULL;
```

Collision Resolution: Chaining

```
for (i=0; i<size; ++i)
        {
                pos = (2 * list[i] + 3) % m;
                if(hash[pos]==NULL)
                {
                        newnode =  (struct hashing *) malloc (sizeof(newnode));
                        newnode->data = list[i];
                        newnode->next = NULL;
                        hash[pos]=newnode;
                }
                else
                {---
                }
        }
```

Collision Resolution: Chaining

```
for (i=0; i<size; ++i)
        {
                pos = (2 * list[i] + 3) % m;
                if(hash[pos]==NULL)            {--}
                else
                {
                        temp=hash[pos];
                        while(temp->next!=NULL) {temp=temp->next;}
                        newnode =  (struct hashing *) malloc (sizeof(newnode));
                        newnode->data = list[i];
                        newnode->next = NULL;
                        temp->next=newnode;
                }
        }
```

Collision Resolution: Chaining

```
for(i=0; i<m; ++i)
        {
                temp=hash[i];
                printf("Hash Index : %d ->", i);
                while(temp!=NULL)
                {
                        printf("%d\t",temp->data);
                        temp=temp->next;
                }
                printf("\n");
        }
}
```

Collision Resolution: Chaining

```
Hash Index : 0 ->
Hash Index : 1 ->54     44      9       94      434
Hash Index : 2 ->
Hash Index : 3 ->10     55      30      15
Hash Index : 4 ->
Hash Index : 5 ->
Hash Index : 6 ->
Hash Index : 7 ->67     32      77      2       167     352     767     27
Hash Index : 8 ->
Hash Index : 9 ->23     53      98
```

Collision Resolution

(1) Open Hashing (Closed Addressing)
(2) Closed Hashing (Open Addressing)

(1) Open Hashing (Closed Addressing)
- Chaining

(2) Closed Hashing (Open Addressing)
- Linear Probing
- Quadratic Probing
- Double Hashing

Collision Resolution: Linear Probing

(2) Closed Hashing (Open Addressing) – Linear Probing

List L(k) = {3, 2, 9, 6, 11, 13, 7, 12}

Hash Function H(k) = 2k + 3

Size of hash table = m = 10

Collision Resolution Technique to be used = Division Method AND Closed Hashing (Open Addressing) – Linear Probing

Collision Resolution: Linear Probing

Insert K_i at first free location from (loc + i) % m where i=0 to m-1

0	13
1	9
2	12
3	
4	
5	6
6	11
7	2
8	7
9	3

Problem: Congestion due to Clustering

k	Location=(2k+3)%m	Probes
3	(2x3+3)%10 → 9	1
2	(2x2+3)%10 → 7	1
9	(2x9+3)%10 → 1	1
6	(2x6+3)%10 → 5	1
11	(2x11+3)%10 → 5	2
13	(2x13+3)%10 → 9	2
7	(2x7+3)%10 → 7	2
12	(2x12+3)%10 → 7	6

Order of Elements: 13, 9, 12, -, -, 6, 11, 2, 7, 3

Collision Resolution

(1) Open Hashing (Closed Addressing)
(2) Closed Hashing (Open Addressing)

(1) Open Hashing (Closed Addressing)
- Chaining

(2) Closed Hashing (Open Addressing)
- Linear Probing
- Quadratic Probing
- Double Hashing

Collision Resolution: Quadratic Probing

(3) Closed Hashing (Open Addressing)

List L(k) = {3, 2, 9, 6, 11, 13, 7, 12}

Hash Function H(k) = 2k + 3

Size of hash table = m = 10

Collision Resolution Technique to be used = Division Method AND Closed Hashing (Open Addressing)- Quadratic Probing

Collision Resolution: Quadratic Probing

Insert K_i at first free location from $(loc + i^2) \% m$ where i=0 to m-1

0	13
1	9
2	
3	12
4	
5	6
6	11
7	2
8	7
9	3

k	Location=(2k+3)%m	Probes
3	(2x3+3)%10 → 9	1
2	(2x2+3)%10 → 7	1
9	(2x9+3)%10 → 1	1
6	(2x6+3)%10 → 5	1
11	(2x11+3)%10 → 5	2
13	(2x13+3)%10 → 9	2
7	(2x7+3)%10 → 7	2
12	(2x12+3)%10 → 7	5

Order of Elements: 13, 9, -, 12, -, 6, 11, 2, 7, 3

Collision Resolution

(1) Open Hashing (Closed Addressing)
(2) Closed Hashing (Open Addressing)

(1) Open Hashing (Closed Addressing)
- Chaining

(2) Closed Hashing (Open Addressing)
- Linear Probing
- Quadratic Probing
- Double Hashing

Collision Resolution: Double Hashing

(4) Closed Hashing (Open Addressing)

List L(k) = {3, 2, 9, 6, 11, 13, 7, 12}

Hash Function H(k) = 2k + 3

Size of hash table = m = 10

Collision Resolution Technique to be used = Division Method AND Closed Hashing (Open Addressing)- Double Hashing

Collision Resolution: Double Hashing

$H_1(k) = 2k + 3$, $H_2(k) = 3k + 1$

Insert Ki at first free place from (loc1 + loc2 x i) % m, where i={0 to m-1}

0	
1	9
2	
3	11
4	12
5	6
6	
7	2
8	
9	3

k	Loc1=(2k+3)%m	Loc2=(3k+1)%m	Probes
3	(2x3+3)%10 → 9	-	1
2	(2x2+3)%10 → 7	-	1
9	(2x9+3)%10 → 1	-	1
6	(2x6+3)%10 → 5	-	1
11	(2x11+3)%10 → 5	(3x11+1)%10 → 4	3
13	(2x13+3)%10 → 9	(3x13+1)%10 → 0	m*
7	(2x7+3)%10 → 7	(3x7+1)%10 → 2	m*
12	(2x12+3)%10 → 7	(3x12+1)%10 → 7	2

Order of Elements: -,9, -,11, 12,6,-,2,-, 3

* Poor hash function

Symbol Table

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```
int a;
int fun1()
{
int b, c;
            {
            int d, e;
            }
int f, g;
            {
            int h, i;
            }
}
void fun2()
{
int j, k;
            {
            int l, m;
            }
int n;
}
```

Symbol Table (Global)

Name	Type	Data type
a	var	int
fun1	fun	int
fun2	fun	void

Symbol Table (fun1)

Name	Type	Data type
b	var	int
c	var	int
f	var	int
g	var	int

Symbol Table (fun2)

Name	Type	Data type
j	var	int
k	var	int
n	var	int

Symbol Table (Inner Scope - I)

Name	Type	Data type
d	var	int
e	var	int

Symbol Table (Inner Scope - II)

Name	Type	Data type
h	var	int
i	var	int

Symbol Table (Inner Scope - III)

Name	Type	Data type
l	var	int
m	var	int

Symbol Table

It is an important **data structure** created and maintained by the compiler in order to keep track of semantics of variable i.e. it stores information about scope and binding information about names, information about instances of various entities such as variable and function names, classes, objects, etc.

Items stored in Symbol table:

- Variable names and constants
- Procedure and function names
- Literal constants and strings
- Compiler generated temporaries
- Labels in source languages

Information used by compiler from Symbol table:

- Data type and name
- Declaring procedures
- Offset in storage
- If structure or record then, pointer to structure table.
- For parameters, whether parameter passing by value or by reference
- Number and type of arguments passed to function
- Base Address

Symbol Table

Following are commonly used data structure for implementing symbol table :

- List / Arrays
- Linked List
- Hash Table
- Binary Search Tree

Thank You

Next: File Structures

DSA: File Structure

- Introduction
- Linear Data Structure
- Nonlinear Data Structure
- Sorting and Searching
- Hashing
- **File Structure**
  - File Structure: Concepts of fields, records and files
  - Sequential, Indexed and Relative/Random File Organization
  - Indexing structure for index files
  - Hashing for direct files
  - Multi-Key file organization and access methods

File Structures

File organization ensures that records are available for processing. It is used to determine an efficient file organization for each base relation.

For example, if we want to retrieve students records in alphabetical order of name. Sorting the file by student name is a good option for file organization. However, if we want to retrieve all students whose CPI are in a certain range, a file is ordered by student name would not be a good file organization.

File organization indicates how the records are organized in a file.

File Structures

Basic Terminology

- A file is a collection of data.
- The data is subdivided into records
- Each record contains a number of fields
- One (or more) field is the key field

Database: collection of related files
File: collection of related records
Record: collection of related data fields
Key Fields: It uniquely identifies the record

Enrolment No	Name	CPI	Address
19CE201	Jaivik	8.9	Kadi
19IT301	Yash	7.8	Gandhinagar
19CSE401	Priyam	8.7	Ahmedabad

Storing the files in certain order is called file Organization

File Structures

Issue: How to organize the records such that it provides convenient access to us?

Various methods have been introduced to Organize files.

- Sequential File Organization
- Direct Access File Organization
- Indexed File Organization
- Relative File Organization
- Random File Organization

Access Methods:

- Sequential
  - Sequential file
- Random
  - Direct Access file
  - Indexed file
  - Hashed file

Sequential File Organization

Records are conceptually organized in a sequential list and can only be accessed sequentially

- The actual storage may/may-not be sequential. For example, on a tape, mostly it is sequential, but on hard disk, it may be distributed across sectors/track
- Suitable for applications that requires sequential processing of the file
- Originally designed to operate for magnetic tapes
- Records can only be accesses sequentially, one after another, from beginning to end
- It is not possible to add a record in the middle of the file without rewriting the file.

Image Source: archive.indianexpress.com

Image Source: www.123rf.com

Sequential File Organization

1. Pile File Method

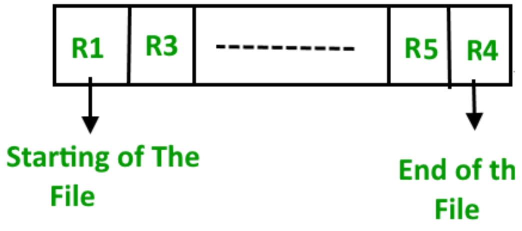
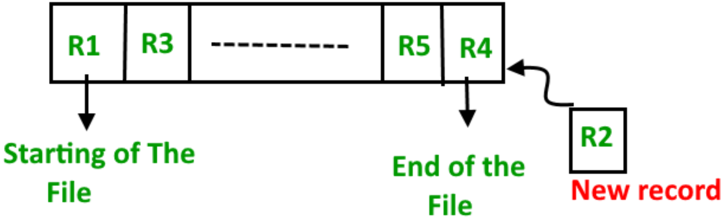
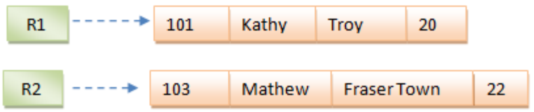
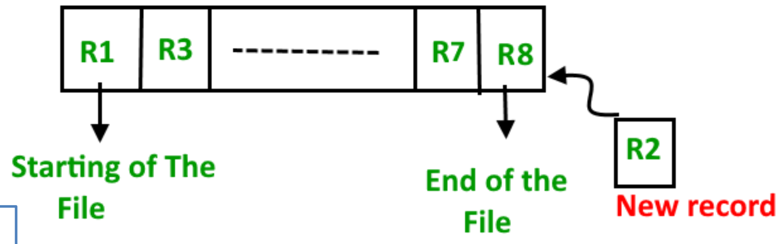


Image source: **www.geeksforgeeks.org**





2. Sorted File Method



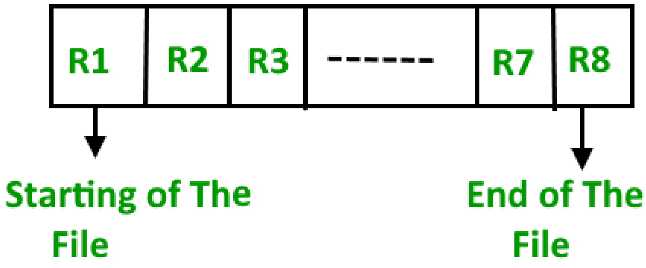


Image source: **www.tutorialcup.com**

Sequential File Organization

Advantage:

- Simple design. Easy to store the data.
- Fast and efficient for large data for similar type of tasks. (E.g. Generating marksheets, Salary slips etc.)
- Good for report generation or statistical calculations.
- E.g. magnetic tapes

Disadvantage:

- Sorting/Arranging records is cumbersome (time & space consumption).
- Becomes slow as it tries to sort the data after every insert/delete/update.
- Accessing a random/specific data

Direct Access File Organization

- Direct access file is also known as random access or relative file organization.
- In direct access file, all records are stored in direct access storage device (DASD), such as hard disk. The records are randomly placed throughout the file.
- The records does not need to be in sequence because they are updated directly and rewritten back in the same location.
- This file organization is useful for immediate access to large amount of information. It is used in accessing large databases.
- It is also called as hashing.

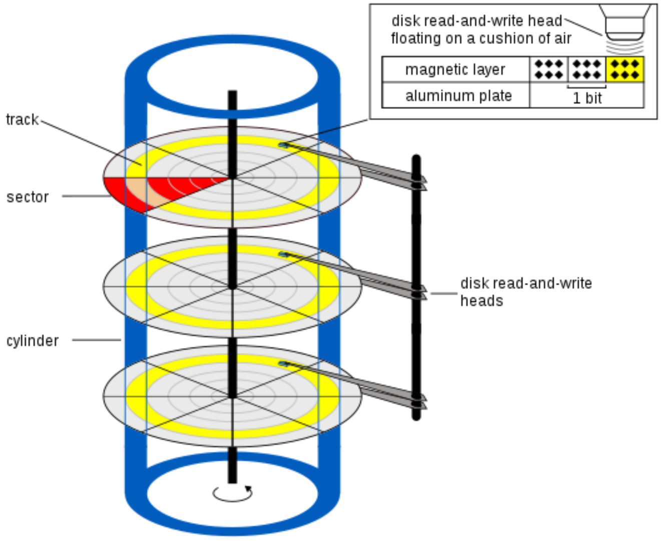


Image Source: www.wikipedia.org

Direct Access File Organization

Advantages:

- Direct access file helps in online transaction processing system (OLTP) like online railway reservation system.
- In direct access file, sorting of the records are not required.
- It accesses the desired records immediately.
- It updates several files quickly.
- It has better control over record allocation.

Disadvantages:

- It is expensive.

Indexed Sequential File Organization

- Indexed sequential access file combines both **sequential** file and **direct access** file organization.
- It consists of two parts: **Data File** contains records in sequential scheme. **Index File** contains the primary key and its address in the data file.

Apartment
A
B
C
D
E
F
G

Block No	Name	Maintenance	Mobile
A-101	---	---	---
D-101	---	---	---
D-102	---	---	---
G-101	---	---	---
G-102	---	---	---

Indexed Sequential File Organization

- In indexed sequential access file, records are stored randomly on a direct access device such as magnetic disk by a primary key.
- This file have multiple keys. These keys can be alphanumeric in which the records are ordered is called primary key.
- The data can be access either sequentially or randomly using the index. The index is stored in a file and read into memory when the file is opened.

Indexed Sequential File Organization

Advantage:

- In indexed sequential access file, sequential file and random file access is possible.
- It accesses the records very fast if the index table is properly organized.
- The records can be inserted in the middle of the file.
- It provides quick access for sequential and direct processing.
- It reduces the degree of the sequential search.

Disadvantage:

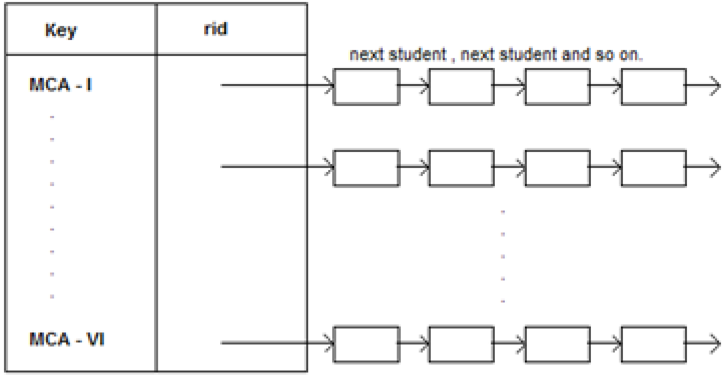
- Indexed sequential access file requires unique keys and periodic reorganization.
- Indexed sequential access file takes longer time to search the index for the data access or retrieval.
- It requires more storage space.
- It is expensive because it requires special software.
- It is less efficient in the use of storage space as compared to other file organizations.

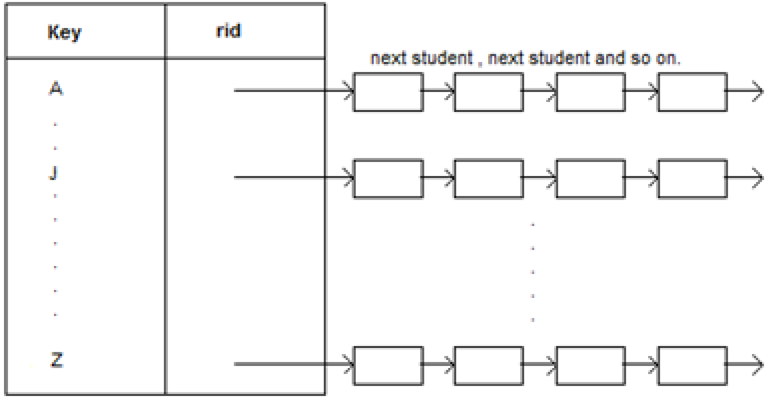
Multi-Key File Organization

Why?

- When you need to access a file by multiple keys
- For example, I wish to access the student data using (i) enrolment number (ii) name (iii) city etc

Example





Images Source: http://techmightsolutions.blogspot.com/

Thank You