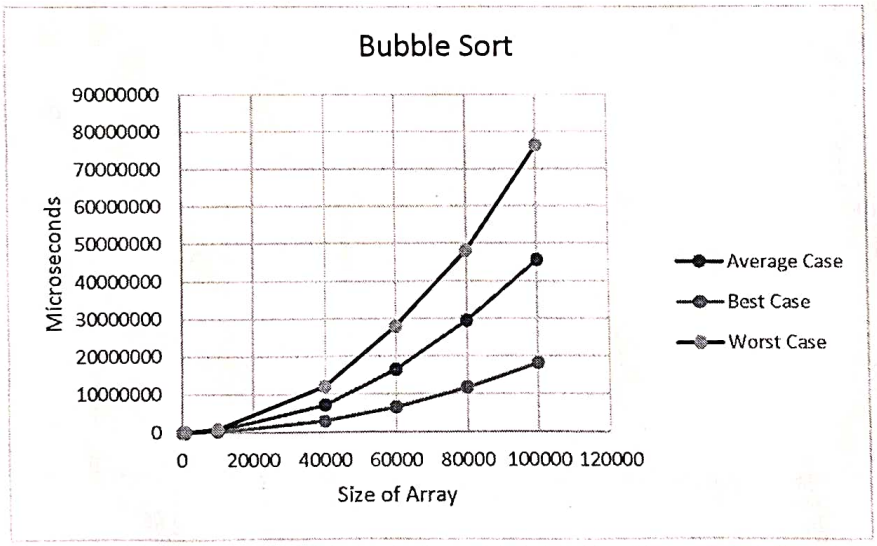
Bubble Sort
90000000
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
Microseconds
0
20000
40000
60000
80000
100000
120000
Size of Array
Average Case
Best Case
Worst Case

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Experiment-1(a)

Bubble, Selection and Insertion Sort.

Program:-

```
#include <bits/stdc++.h>
#include <chrono>
using namespace std;
using namespace std::chrono;

void printarray(int a[], int n){
    fstream file;
    file.open("output.txt", ios::out);
    for(int i=0; i<n; i++){
        file<<a[i]<<' ';
    }
    file.close();
}

void bubbleSort(int a[], int n){
    int flag = 0;
    for(int i=0; i<n; i++){
        flag = 0;
        for(int j=0; j<n-1-i; j++){
            if(a[j]>a[j+1]){
```

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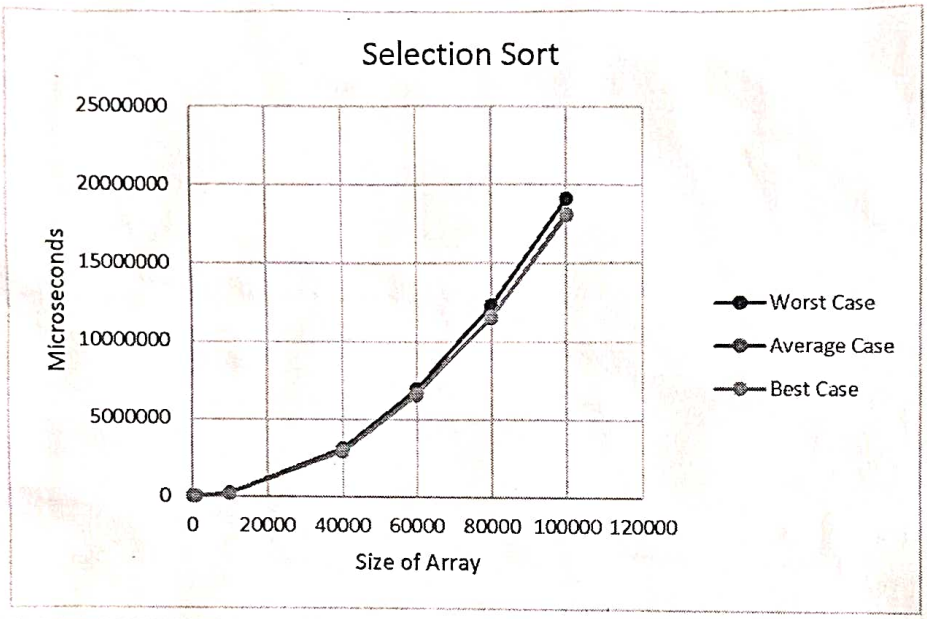
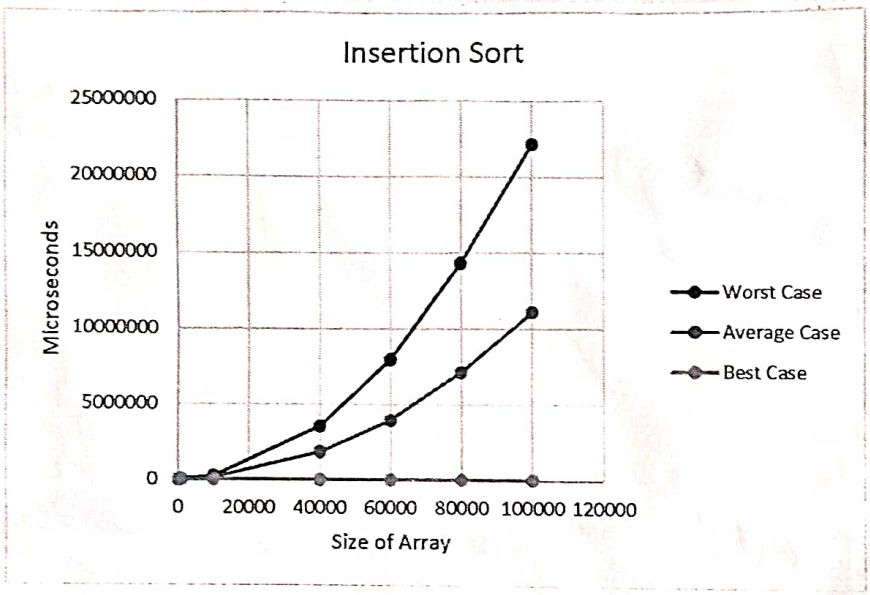

Selection Sort
25000000
20000000
15000000
10000000
5000000
0
Microseconds
0
20000
40000
60000
80000
100000
120000
Size of Array
Worst Case
Average Case
Best Case

```
            swap(a[j], a[j+1]);
            flag = 1;
        }
    }
    if(flag == 0) break;
}
printarray(a,n);
}

void selectionSort(int a[], int n){
    for(int i=0; i<n; i++){
        int mi = i;
        for(int j=i+1; j<n; j++){
            if(a[mi] > a[j])
                mi = j;
            }
        }
        swap(a[i], a[mi]);
    }
    printarray(a,n);
}

void insertionSort(int a[], int n){
    for(int i=1; i<n; i++){
        int k = a[i];
```


Insertion Sort
25000000
20000000
15000000
10000000
5000000
0
Microseconds
0
20000
40000
60000
80000
100000
120000
Size of Array
Worst Case
Average Case
Best Case

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```
        int j = i-1;
        while(j>=0 && a[j] >K)
        {
            a[j+1] =a[j];
            j--;
        }
        a[j+1] = K;
    }
    printarray(a,n);
}

int main(){
    int n=100;
    int a[n+100];
    for(int i=0; i<n; i++) a[i] = i;
    auto start =high_resolution_clock::now();
    bubbleSort(a,n);
    auto stop = high_resolution_clock::now();
    auto duration = duration_cast<microseconds>(stop-start);
    cout << "Time taken by function: " << duration.count()
         << " microseconds" <<endl;
}
```

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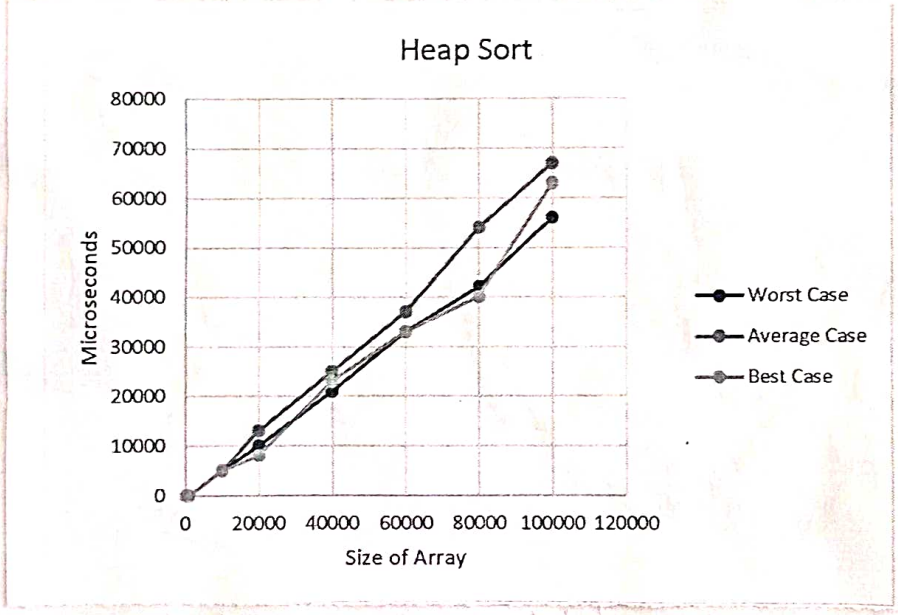
Heap Sort
80000
70000
60000
50000
40000
30000
20000
10000
0
Microseconds
0
20000
40000
60000
80000
100000
120000
Size of Array
Worst Case
Average Case
Best Case

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Experiment 1(b)

Heap Sort:-

Program:-

```
#include <bits/stdc++.h>
#include <chrono>
using namespace std;
using namespace std::chrono;

void heapify(int a[], int n, int i){
    int largest = i;
    int l = 2*i + 1;
    int r = 2*i + 2;
    if (l<n && a[l]>a[largest]){
        largest = l;
    }
    if (r<n && a[r] > a[largest]){
        largest = r;
    }
    if (largest != i){
        swap(a[i], a[largest]);
        heapify(a, n, largest);
    }
}
```

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```
void heapSort(int a[], int n){
    for(int n/2-1; i>=0; i--){
        heapify(a,n,i);
    }
    for(int i=n-1; i>0; i--){
        swap(a[0], a[i]);
        heapify(a,i,0);
    }
}

int main(){
    int size[] = {100, 1000, 10000, 20000, 30000, 60000, 80000, 100000};
    for(int j=0; j<8; j++){
        int n = size[j];
        int a[n+100];
        srand(time(0));
        for(int i=0; i<n; i++){
            a[i] = rand();
        }
        auto start = high_resolution_clock::now();
        heapSort(a,n);
        auto stop = high_resolution_clock::now();
        auto duration = duration_cast<microseconds>(stop - start);
        fstream file;
        file.open("output.txt", ios::out);
        for(int i=0; i<n; i++) file<<a[i]<<" ";
        file.close();
        cout<<duration.count()<<endl;
```

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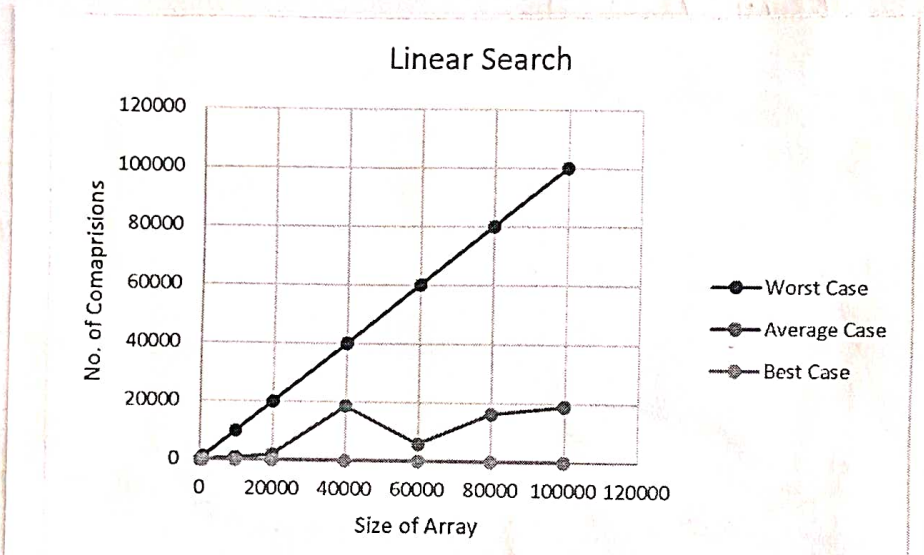
Linear Search
120000
100000
80000
60000
40000
20000
0
No. of Comaprisions
0
20000
40000
60000
80000
100000
120000
Size of Array
Worst Case
Average Case
Best Case

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Experiment 2.

Searching Linear Search and Binary Search

Program:

```
#include <bits/stdc++.h>
using namespace std;

int co=0;

int linearSearch(int a[], int n, int k){
    for(int i=0; i<n; i++){
        if(a[i]==k){
            return i;
        }
        co++;
    }
}

int binarySearch(int a[], int n, int k){
    int l=0, h=n-1;
    while(l<=h){
        int m = l + (h-l)/2;
        if(a[m]==k){
            co++;
```

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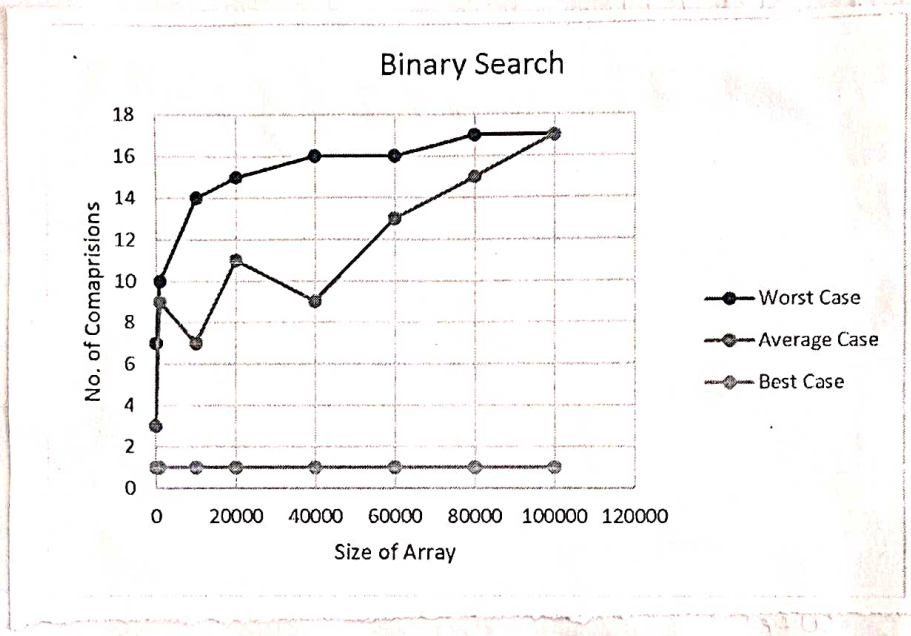
Binary Search
No. of Comaprisions
18
16
14
12
10
8
6
4
2
0
0
20000
40000
60000
80000
100000
120000
Size of Array
Worst Case
Average Case
Best Case

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```
            return k;
        }else if(a[m]<k){
            l = m+1;
            co+=2;
        }else{
            h = m-1;}
        }
}

int main(){
    int size[] = {100, 1000, 10000, 20000, 40000, 60000, 80000, 100000};
    for(int j=0; j<8; j++){
        co=0;
        int n = size[j];
        int a[n+100];
        srand(time(0));
        for(int i=0; i<n; i++){
            a[i] = i; //best case.
            a[i] = n-i-1; //worst case;
            a[i] = rand(); //average case;
        {
        sort(a, a+n);
        linearSearch(a, n, a[rand()%n]); or binarySearch(a, n, a[rand()%n]);
        cout<<co<<endl;
    }
{
```

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Experiment 3 (a)

Merge and Quick Sort.

Program :-

```
#include <bits/stdc++.h>
#include <chrono>
using namespace std;
using namespace std::chrono;

void printarray(int a[], int n){
    fstream file;
    file.open("output.txt", ios::out);
    for(int i=0; i<n; i++){
        file << a[i] << " ";
    }
    file.close();
}

void swap(int *a, int *b){
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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```
void merge(int a[], int l, int m, int h){
    int n1 = m-l+1;
    int n2 = h-m;
    int i=0, j=0, k=l;
    int a1[n1], a2[n2];
    for(i=0; i<n1; i++) a1[i] = a[l+i];
    for(j=0; j<n2; j++) a2[j] = a[m+1+j];
    i=0;
    j=0)
    while(i<n1-1 && j<n2-1){
        if(a1[i] < a2[j]){
            a[k] = a1[i];
            i++;
            k++;
        }else{
            a[k] = a2[j];
            j++;
            k++;
        }
    }
    if(i!=n1){
        for(; i<n1; i++){
            a[k] = a1[i];
            k++)
        }
}
```

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```
    if(j!=n2){
        for(; j<n2; j++){
            a[k] = a2[j];
            k++;
        }
    }
}

void mergeSort(int a[], int l, int h){
    if(l<h){
        int m = (h+l)/2;
        mergeSort(a, l, m);
        mergeSort(a, m+1, h);
        merge(a, l, m, h);
    }
}

int partition(int a[], int l, int h){
    int p = a[l];
    int i=l, j=h;
    do{
        while(a[i]<=p){i++;}
        while(a[j]>p){j--;}
        if(i<j) swap(&a[i], &a[j]);
    }while(i<j);
    swap(&a[j], &a[l]);
    return j;
}
```

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```
void quickSort(int a[], int l, int h){
    if (l<h){
        int p = partition (a, l, h);
        quickSort (a, l, p-1);
        quickSort (a, p+1, h);
    }
    return;
}

int main(){
    int size[] = {100, 1000, 10000, 20000, 40000, 60000, 80000, 100000};
    for(int j=0; j<8; j++){
        int n = size[j];
        int a[n+100];
        srand(time(0));
        for(int i=0; i<n; i++){
            a[i] = i; or a[i] = n-i-1; or a[i] = rand();
        }
        auto start = high_resolution_clock::now();
        insertionSort(a,n); mergeSort(a,n); or quickSort(a,n);
        auto stop = high_resolution_clock::now();
        auto duration = duration_cast<microseconds>(stop-start);
        cout << "Time taken by function: " << duration.count() <<
            " microseconds" << endl;
```

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Experiment 3 (b)

Strassen's Matrix multiplication

Program:-

```
#include <bits/stdc++.h>
#include <chrono>
using namespace std;
Using namespace std::chrono;
typedef long long ll;

inline ll** MatrixMultiply(ll** a, ll **b, int n, int l, int m) {
    ll** c = new ll*[n];
    for(int i=0; i<n; i++)
        c[i] = new ll[m];

    for(int i=0; i<n; i++){
        for(int j=0; j<m; j++){
            c[i][j]=0;
            for(int k=0; k<l; k++){
                c[i][j] += a[i][k] * b[k][j];
            }
        }
    }
```

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```
    return c;
}

inline ull** Strassen(ull** a, ull** b, int n, int l, int m) {
    if (n==1 || l==1 || m==1)
        return MatrixMultiply(a,b,n,l,m);

    ull** c = new ull*[n];
    for(int i=0; i<n; i++){
        c[i] = new ull[m];

    int adjN = (n>>1) + (n&1);
    int adjL = (l>>1) + (l&1);
    int adjM = (m>>1) + (m&1);

    ull**** As = new ull***[2];
    for(int x=0; x<2; x++) {
        As[x] = new ull**[2];
        for(int y=0; y<2; y++){
            As[x][y] = new ull*[adjN];
            for(int i=0; i<adjN; i++){
                As[x][y][i] = new ull[adjL];
                for(int j=0; j<adjL; j++){
                    int I = i + (x&1)*adjN;
                    int J = j + (y&1)*adjL;
                    As[x][y][i][j] = (I<n && J<l) ? a[I][J] : 0;
```

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```
            }
        }
    }
}

Ud**** Bs = new Ud***[2];
for(int x=0; x<2; x++){
    Bs[x] = new Ud**[2];
    for(int y=0; y<2; y++){
        Bs[x][y] = new Ud*[adjN];
        for(int i=0; i<adjL; i++){
            Bs[x][y][i] = new Ud[adjM];
            for(int j=0; j<adjM; j++){
                int I = i+(x&1)*adjL;
                int J = j+(y&1)*adjM;
                Bs[x][y][i][j] = (I<l && J<m)? b[I][J] : 0;
            }
        }
    }
}

Ud*** s = new Ud**[10];
for(int i=0; i<10; i++){
    switch(i){
    case 0:
        s[i] = new Ud*[adjL];
```

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```
        for(int j=0; j<adjL; j++){
            s[i][j] = new ld [adjM];
            for(int k=0; k<adjM; k++){
                s[i][j][k] = Bs[0][1][j][k] - Bs[1][1][j][k];
            }
        }
        break;
    case 1:
        s[i] = new ld* [adjN];
        for(int j=0; j<adjN; j++){
            s[i][j] = new ld [adjL];
            for(int k=0; k<adjL; k++){
                s[i][j][k] = As[0][0][j][k] + As[0][1][j][k];
            }
        }
        break;
    case 2:
        s[i] = new ld* [adjN];
        for(int j=0; j<adjN; j++){
            s[i][j] = new ld [adjL];
            for(int k=0; k<adjL; k++){
                s[i][j][k] = As[1][0][j][k] + As[1][1][j][k];
            }
        }
        break;
```

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```
case 3;
    s[i] = new ull* [adjL];
    for(int j=0; j< adjL; j++){
        s[i][j] = new ull [adjM];
        for(int k=0; k<adjM; k++){
            s[i][j][k] = Bs[1][0][j][k] - Bs[0][0][j][k];
        }
    }
    break;
case 4;
    s[i] = new ull* [adjN];
    for (int j=0; j<adjN; j++){
        s[i][j] = new ull [adjL];
        for(int k=0; k<adjL; k++){
            s[i][j][k] = As[0][0][j][k] + As[1][1][j][k];
        }
    }
    break;
case 5;
    s[i] = new ull* [adjL];
    for(int j=0; j<adjL; j++){
        s[i][j] = new ull[adjM];
        for(int k=0; k<adjM; k++){
            s[i][j][k] = Bs[0][0][j][k] + Bs[1][1][j][k];
        }
    }
    break;
```

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```
case 6:
    s[i] = new ld*[adjN];
    for(int j=0; j<adjN; j++){
        s[i][j] = new ld[adjL];
        for(int k=0; k<adjL; k++)
            s[i][j][k] = As[0][i][j][k] - As[1][i][j][k];
    }
}
break;
case 7:
    s[i] = new ld*[adjL];
    for(int j=0; j<adjL; j++){
        s[i][j] = new ld[adjM];
        for(int k=0; k<adjM; k++){
            s[i][j][k] = Bs[1][0][j][k] + Bs[1][i][j][k];
        }
    }
}
break;
case 8:
    s[i] = new ld*[adjN];
    for(int j=0; j<adjN; j++){
        s[i][j] = new ld[adjL];
        for(int k=0; k<adjL; k++){
            s[i][j][k] = As[0][0][j][k] - As[1][0][j][k];
        }
    }
}
break;
```

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```
        case 9:
            S[i] = new Ud* [adjL];
            for(int j=0; j<adjL; j++){
              S[i][j] = new Ud [adjM];
              for(int k=0; k<adjM; k++){
                S[i][j][k] = Bs[0][0][j][k] + Bs[0][1][j][k];
              }
            }
        break;
      }
    }

Ud*** p = new Ud** [7];
p[0] = Strassen(As[0][0], S[0], adjN, adjL, adjM);
p[1] = Strassen(S[1], Bs[1][1], adjN, adjL, adjM);
p[2] = Strassen(S[2], Bs[0][0], adjN, adjL, adjM);
p[3] = Strassen(As[1][1], S[3], adjN, adjL, adjM);
p[4] = Strassen(S[4], S[5], adjN, adjL, adjM);
p[5] = Strassen(S[6], S[7], adjN, adjL, adjM);
p[6] = Strassen(S[8], S[9], adjN, adjL, adjM);

for(int i=0; i<adjN; i++){
  for(int j=0; j<adjM; j++){
    C[i][j] = p[4][i][j] + p[3][i][j] - p[1][i][j] + p[5][i][j];
    if(j+adjM < m)
      C[i][j+adjM] = p[0][i][j] + p[1][i][j];
```

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```
        if (i+adjN < n){
            c[i+adjN][j] = p[2][i][j] + p[3][i][j];
        if (i+adjN<n && j+adjM<m)
            c[i+adjN][j+adjM] = p[4][i][j] + p[6][i][j] - p[2][i][j]
                                - p[6][i][j])
    }
}

for( int x = 0; x<2; x++){
    for (int y=0; y<2; y++){
        for (int i=0; i<adjN; i++)
            delete[] As[x][y][i];
        }
        delete[] As[x][y];
    }
    delete[] As[x];
}
delete[] As;

for(int x=0; x<2; x++){
    for(int y=0; y<2; y++){
        for(int i=0; i<adjL; i++){
            delete Bs[x][y][i];
        }
        delete[]Bs[x][y];
    }
    delete[] Bs[x];
}
delete[] Bs;
```

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```
for (int i=0; i<10; i++) {
    switch (i) {
    case 0:
    case 3:
    case 5:
    case 7:
    case 9:
        for (int j=0; j<adj[i]; j++) {
            delete[] s[i][j];
        }
        break;
    case 1:
    case 2:
    case 4:
    case 6:
    case 8:
        for (int j=0; j<adjN; j++) {
            delete[] s[i][j];
        }
        break;
    }
    delete[] s[i];
}
delete[] s;

for(int i=0; i<7; i++) {
```

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```
    for (int j=0; j<(n>>1); j++){
        delete [] p[i][j];
    }
    delete [] p[i];
}
delete [] p;

return C;
}

int main(){
    ull** matA;
    matA = new ull*[2];
    for(int i=0; i<2; i++)
        matA[i] = new ull[3];
    srand(time(0));
    for(int i=0; i<2; i++){
        for(int j=0; j<3; j++){
            matA[i][j] = rand();
        }
    }
    ull** matB;
    matB = new ull*[3];
    for(int i=0; i<3; i++)
        matB[i] = new ull[2];
```

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```
for(int i=0; i<3; i++){
    for(int j=0; j<2; j++){
        matB[i][j] = rand();

ll** matC = Strassen(matA, matB, 2, 3, 2);
for (int i=0; i<2; i++){
    for (int j=0; j<2; j++){
        printf("%lld", matC[i][j]);
    }
    printf("\n");
}
return 0;
}
```

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Experiment No- 9

Sorting in linear time : Counting Sort, Radix Sort.

```
# include <bits/stdc++.h>
# include < chrono >
using namespace std;
using namespace std::chrono;

void printarray(int a[], int n){
    fstream file;
    file.open("Output.txt", ios::out);
    for( int i=0; i<n; i++){
        file << a[i] << " ";
    }
    file.close()
}

void countSort(int a[], int n) {
    int maxe = a[0];
    for( int i=0; i<n; i++) {
        maxe = max(maxe, a[i]);
    }
    int h[maxe+1] = {0};
    for( int j=0; j<n) j++){
        h[a[j]]++;
    }
    int i=0
```

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```
for (int K=0; K<maxe; K++){
        while (h[K] >0){
            a[i] = K;
            i++;
            h[K]--;
        }
    }
    printarray(a,n);
    return 0;
}

void radixSort( char a[], int n){
    int h[26] = {0};
    for(int i=0; i<n; i++){
        h[a[i]-'a']++;
    }
    for( int i=0; i<n; i++){
        while(h[i] >0){
            a[i] = i+'a';
        }
    }
    printArray(a,n);
}

int main(){
    int n=100000;
    int a[n+100];
```

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```
srand(time(0));
for(int i=0; i<n; i++){
    a[i] = i;
}
auto start = high_resolution_clock::now();
countingSort(a,n); or radixSort(a,n);
auto stop = high_resolution_clock::now();
auto duration = duration_cast<microseconds>(stop-start);
cout<<"Time taken by function: "<<duration.count()<<
"microseconds"<<endl;
}
```

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Experiment 5

Maximum / Minimum element, K^{th} Smallest Element :-

Program :-

```
#include <bits/stdc++.h>
using namespace std;

Struct Pair
{
    int min;
    int max;
}

Struct Pair getMinMax(int arr[], int low, int high){
    struct Pair minmax, mml, mmr;
    int mid;

    if (low == high)
    {
        minmax.max = arr[low];
        minmax.min = arr[low];
        return minmax;
    }

    if (high == low + 1) {
```

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```
        if (arr[low] > arr[high])
        {
            minmax.max = arr[low];
            minmax.min = arr[high];
        }else{
            minmax.max = arr[high];
            minmax.min = arr[low];
        }
        return minmax;
    }
    mid = (low + high)/2;
    mml = getMinMax(arr, low, mid);
    mmr = getMinMax(arr, mid+1, high);

    if(mml.min < mmr.min)
        minmax.min = mml.min;
    else
        minmax.min = mmr.min;

    if (mml.max > mmr.max)
        minmax.max = mml.max;
    else
        minmax.max = mmr.max;

    return minmax;
}
```

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```
int KthSmallest(int arr[], int n, int K){

    sort(arr, arr+n);
    return arr[K-1];
}

int main(){
    int n = 100000;
    int a[n+100];
    srand(time(0));
    for(int i=0; i<n; i++){
        a[i] = i;  or  a[i] = n-i-1;  or  a[i] = rand();
    }

    auto start = high_resolution_clock::now();
    getMinMax(a, n);
    auto stop = high_resolution_clock::now();
    auto duration = duration_cast<microseconds>(stop - start);
    cout << "Time taken by function: " << duration.count() <<
     "microseconds" << endl;
}
```

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Experiment 6

Minimum Spanning Tree using Prim's and Kruskal's Algorithm.

Program:-

```
int minKey(int key[], bool mstSet[]) {
    int min = INT_MAX, min_index;
    for (int v = 0; v < 5; v++) {
        if (mstSet[v] == false && key[v] < min)
            min = key[v];
            min_index = v;
    }
    return min_index;
}

void printMST(int parent[], int graph[5][5]){
    cout << "Edge \t weight \n";
    for(int i=1; i<V; i++)
        cout<<parent[i]<<" - "<<i<<" \t"<<graph[i][parent[i]]<<
        "\n";
}

void primMST( int graph[5][5]) {
    int parent[5];
    int key[5])
```

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```
bool mstSet[V];
for (int i=0; i<5; i++)
    Key[i] = INT_MAX, mstSet[i] = false;
key[0] = 0;
parent[0] = -1;
for(int count = 0; count < V-1; count++)
{
    int u = minKey(Key, mstSet);
    mstSet[u] = true;
    for (int v=0; v<5; v++)
        if (graph[u][v] && mstSet[v] == false && graph[u][v]
                                                < key[v])
            parent[v] = u, key[v] = graph[u][v];
}
printMST(parent, graph);
}

// Kruskal Algorithm.

class DSU{
    int *parent;
    int *rank;
public:
    DSU(int n){
        parent = new int[n];
        rank = new int[n];
```

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```
for(int i=0; i<n; i++){
    parent[i] = -1;
    rank[i] = 1; }
}

int find(int i){
    if(parent[i] == -1)
        return i;
    return parent[i] = find(parent[i]);
}

void unite(int x, int y){
    int s1 = find(x);
    int s2 = find(y);

    if(s1 != s2){
        if(rank[s1] < rank[s2]){
            parent[s2] = s2;
            rank[s2] += rank[s1];
        }else{
            parent[s2] = s1;
            rank[s1] += rank[s2]; }
    }

class Graph {
    vector<vector<int>> edgelist;
    int V;
```

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```
public:
    Graph(int v){
        this -> V = v;
    }
    void addEdge(int x, int y, int w){
        edgelist.push_back({w,x,y});
    }
    int kruskals_mst(){
        sort(edgelist.begin(), edgelist.end());
        DSU s(v);
        int ans = 0;
        for(auto edge : edgelist)
        {
            int w = edge[0];
            int x = edge[1];
            int y = edge[2];
            if (s.find(x) != s.find(y)){
                s.unite(x,y);
                ans += w;
            }
        }
    }   return ans;
};
```

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Experiment 7

Dynamic Programming: Matrix Chain Multiplication:

```
int matrixChainOrder(int p[], int n)
    int dp[n][n];
    for(int i=1; i<n; i++){
        dp[i][i]=0
    for(int L=1; L<n-1; L++){
        for(int i=1; i<n-L; i++){
            dp[i][i+L] = min(dp[i+1][i+L] + p[i-1]*p[i]*p[i+L],
            dp[i][i+L-1] + p[i-1]*p[i+L-1]*p[i+L]);
        }
    }
    return dp[1][n-1];
}
```

Longest Common Subsequence:-

```
int lcs( char *X, char *Y, int m, int n) {
    int L[m+1][n+1];
    int i, j;
    for( i=0; i<=m; i++){
        for( j=0; j<=n ) j++) {
            if(i==0 || j==0) {
                L[i][j] = 0;
```

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```
        else if (X[i-1] == Y[j-1])
            L[i][j] = L[i-1][j-1] + 1;
        else
            L[i][j] = max(L[i-1][j], L[i][j-1]);
        }
    }
    return L[m][n];
}
```

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Experiment 8

Case study of P, NP, NP- complete and NP Hard Problems.

In computer science, the problem are basically divided into the following parts -

Optimization Problems :- Optimization problem are those for which the objective is to maximize or minimize some values.

Decision Problems :- There are many problems for which the answer is a Yes or No. These kind of problems are known as decision problem.

Below are the major classes of the problems :-

P - class :- The class P consist of those problems that are solvable in polynomial time i.e. these problems can be solved in time $O(n^k)$ in worst case where k is a constant.

Example :- "String Matching Problem".
We are given two string S and T (& Length(S) > Length(T)) and we need to check is any substring of S matches with T or not.

We can solve this problem by iterating in S and if any character matches with the first letter of T match the next letter until the string matched or any unmatched character found.

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Time Complexity = $O(m.n)$ is the worst case.

NP class:- The class consist of those problems that are verifiable in polynomial time. Every problem in this class can be solved in exponential time using exhaustive search.
Eg:- "Travelling Salesman problem".

The decision version of travelling salesman problem is NP. The verification can be clearly be done in is polynomial time. It simply adds the matrix entries ~~corresponding~~ corresponding to the paths between the cities.

NP Complete Problems:- In computational complexity theory, a problem is NP complete when -

1) A non deterministic Turing Machine can solve it in polynomial time.
2) A deterministic Turing Machine can solve it in a large time complexity.
3) It can be used to simulate any other problem with similar solvability.

Eg. "Knapsack problem"

NP Hard Problems:- In computational theory, NP hardness (non-deterministic polynomial time hardness) is the defining property of a class of problems that are informally "at least as hard as the hardest problem in NP."

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Example:- "Longest Path Problem"

Given an undirected graph G and two vertices u and v, find the longest simple path from u to v.

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