SSCM 1313
C++ COMPUTER PROGRAMMING

Chapter 5:
Structure and Array Applications

Authors:
Farhana Johar
Professor Dr. Shaharuddin Salleh

Structure

- A structure groups variables into a hierarchical tree based on their common ancestral origin. Under this arrangement, a structure starts with a *parent* which includes several *children*.
- Constructed using `tydef struct`
- A structure must have a name
- Declared in the pre-processing area

Example

```
typedef  struct
{
     char  name[10];
     int  age;
     double  cpa;
}  CAMPUS;
```

members

name of structure

object of the structure

```
CAMPUS  student;
strcpy(student.name,"Michael");
student.age=35;
student.cpa=3.15;
```

assignment of values to members

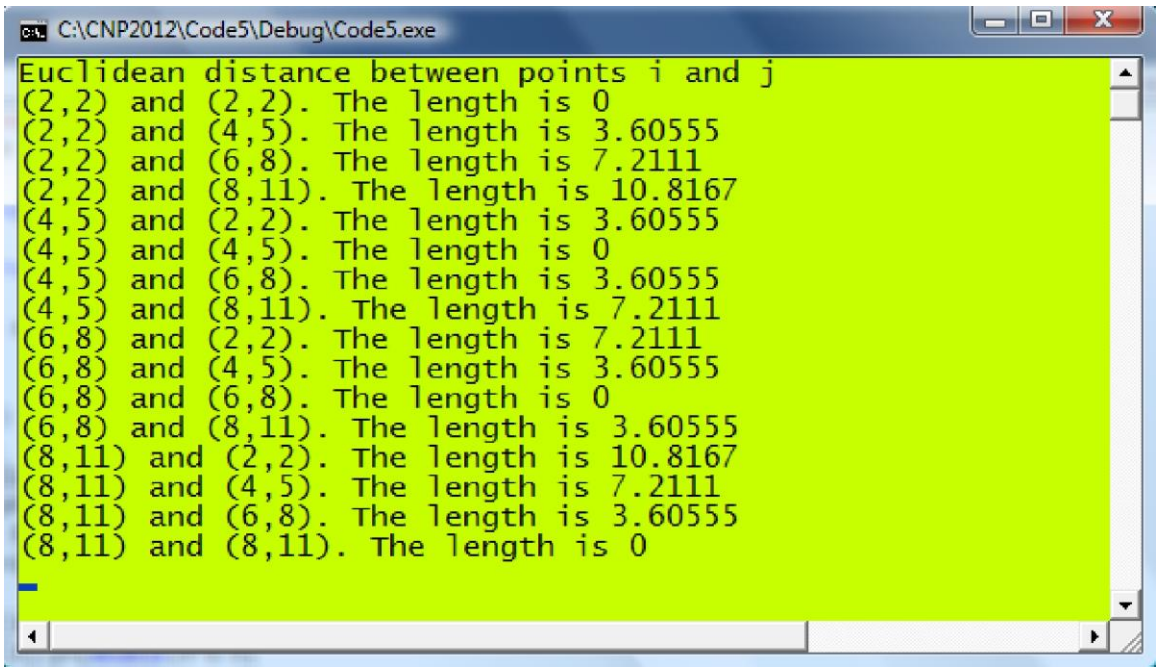
Points in Cartesian Coordinates

```
typedef struct
{
     double x,y;
} POINT;
POINT pt[10];
```

$$
\begin{aligned}
x_i &\Rightarrow pt[i].x \\
y_i &\Rightarrow pt[i].y \\
x_5 = -1 &\Rightarrow pt[5].x = -1 \\
y_5 = 4 &\Rightarrow pt[5].y = 4
\end{aligned}
$$

Code5A.cpp: Structure representing a point.

```
#include <iostream> #define n 4

using namespace  std;

void main()
{
	int i,j;
	typedef struct
	{
		double x,y;
	} POINT;
	POINT pt[n+1]; double Eu[n+1][n+1];
	for (i=1;i<=n;i++)
	{
		pt[i].x=(double)2*i;
		pt[i].y=(double)3*i-1;
	}
	cout << "Euclidean distance between points i and j" << endl;
	for (i=1;i<=n;i++)
	    for (j=1;j<=n;j++)
	    {
	    Eu[i][j]=sqrt(pow(pt[i].x-pt[j].x,2)+pow(pt[i].y-pt[j].y,2));
	    cout << "(" << pt[i].x << "," << pt[i].y << ") and ("<<pt[j].x
	         <<","<< pt[j].y <<").The  length is "<<Eu[i][j] << endl;
	    }
	cin.get();
}
```



Nested Structure

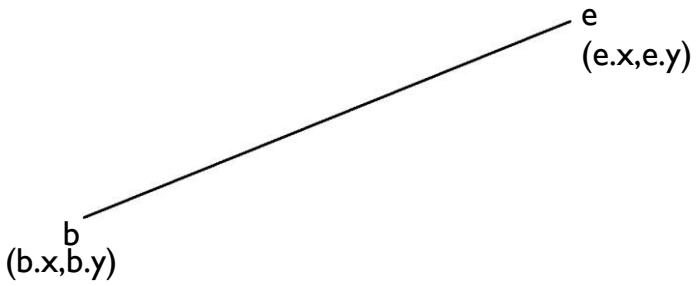
```
typedef struct
{
     double x,y;
} POINT;


typedef struct
{
    POINT b,e;
} LINE;
```

Description:

A line has two end points.

Each point in a line is represented as (x,y) coordinates.

LINE Ln;
Ln.b.x=3; Ln.b.y=-1;
Ln.e.x=7; Ln.e.y=0;



```
typedef  struct
{
    double
x,y; } POINT;

typedef  struct
{
    POINT
b,e; } LINE;

typedef  struct
{
    LINE p,q,r;
} TRIANGLE;
```

A triangle has three points.

Each line in a triangle has two end points.

Each point in a line is represented as (x,y) coordinates.

```
t.p.b.x=3; t.p.b.y=-1;
t.p.e.x=7;  t.p.e.y=0;
t.q.b.x=7;  t.q.b.y=0;
t.q.e.x=5; t.q.e.y=-8;
t.r.b.x=5; t.r.b.y=-8;
t.r.e.x=3; t.r.e.y=-1;
```

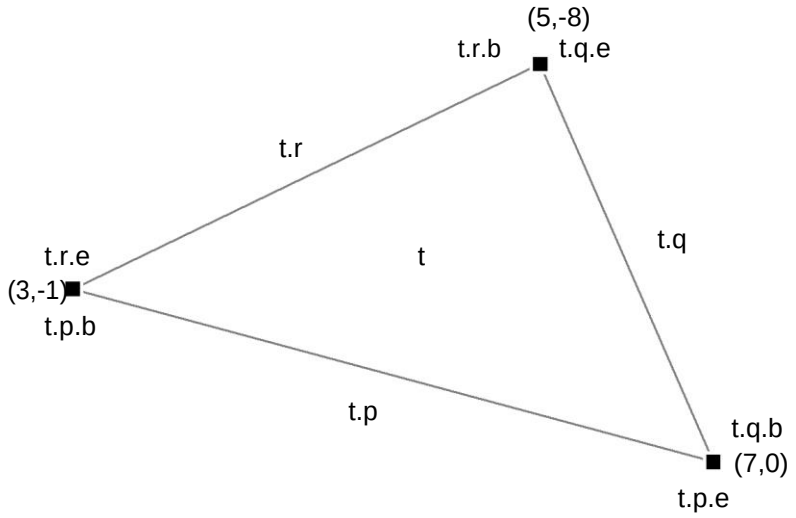
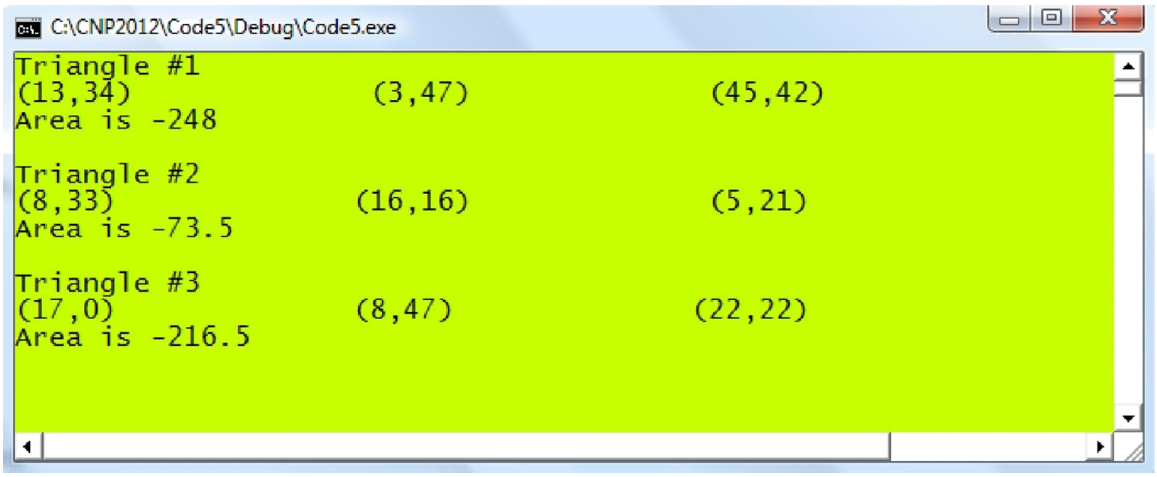


Figure 5.1. TRIANGLE and its nested structures.

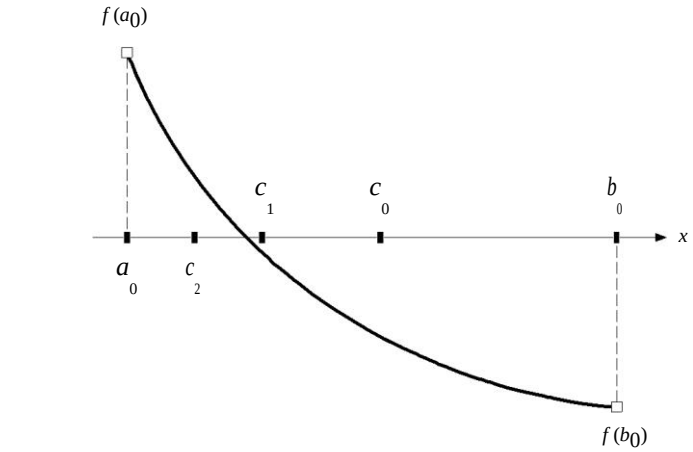
Code5B.cpp: Structure representing a triangle.

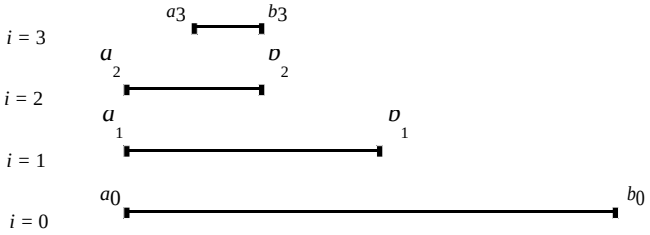
```
#include <iostream>
#include <iomanip>
#include <time.h>
#define n 3
using  namespace  std;

void  main()
{
       int i;
       srand(time(0));
       typedef struct
       {
              double
       x,y; } POINT;

       typedef  struct
       {
              POINT b,e;
              double length;
       }  LINE;

       typedef  struct
       {
              LINE p,q,r;
              double area;
       } TRIANGLE;
       TRIANGLE t[n+1];

       for  (i=1;i<=n;i++)
       {
              t[i].p.b.x=(double)(rand()%50); t[i].p.b.y=(double)(rand()%50);
              t[i].p.e.x=(double)(rand()%50); t[i].p.e.y=(double)(rand()%50);
              t[i].q.e.x=(double)(rand()%50); t[i].q.e.y=(double)(rand()%50);
              t[i].q.b.x=t[i].p.e.x; t[i].q.b.y=t[i].p.e.y;
              t[i].r.b.x=t[i].q.e.x; t[i].r.b.y=t[i].q.e.y;
              t[i].r.e.x=t[i].p.b.x; t[i].r.e.y=t[i].p.b.y; t[i].area=0.5*(-
              t[i].p.e.x*t[i].p.b.y+t[i].q.e.x*t[i].p.b.y
                           +t[i].p.b.x*t[i].p.e.y-t[i].q.e.x*t[i].p.e.y -
                           t[i].p.b.x*t[i].q.e.y+ t[i].p.e.x*t[i].q.e.y);
              cout  <<  "Triangle  #"  <<  i  <<  endl;
              cout << "(" << t[i].p.b.x << "," << t[i].p.b.y << ")" << setw(15);
              cout << "(" << t[i].q.b.x << "," << t[i].q.b.y << ")" << setw(15);
              cout << "(" << t[i].r.b.x << "," << t[i].r.b.y << ")" << endl;
              cout << "Area is " << t[i].area << endl << endl;
       }
       cin.get();
}
```


C:\CNP2012\Code5\Debug\Code5.exe
Triangle #1
(13,34) (3,47) (45,42)
Area is -248
Triangle #2
(8,33) (16,16) (5,21)
Area is -73.5
Triangle #3
(17,0) (8,47) (22,22)
Area is -216.5

CS1 (Case Study 1): Finding the root of a function

Given $f(x) = 0$, *find the value of* x, *assuming the value exists.*





Algorithm 5.1. Bisection Method.

Given $f(x) = 0$, ε and the initial end-points $[a_0, b_0]$ where $f(a_0) f(b_0) < 0$;
Given *max* =maximum number of iterations;
For $i = 0$ to *max*

Compute $c_i = \frac{a_i + b_i}{2}$;

If $f(a_i) f(c_i) < 0$

Update $b_{i+1} = c_i$ and $a_{i+1} = a_i$;

If $f(a_i) f(c_i) > 0$

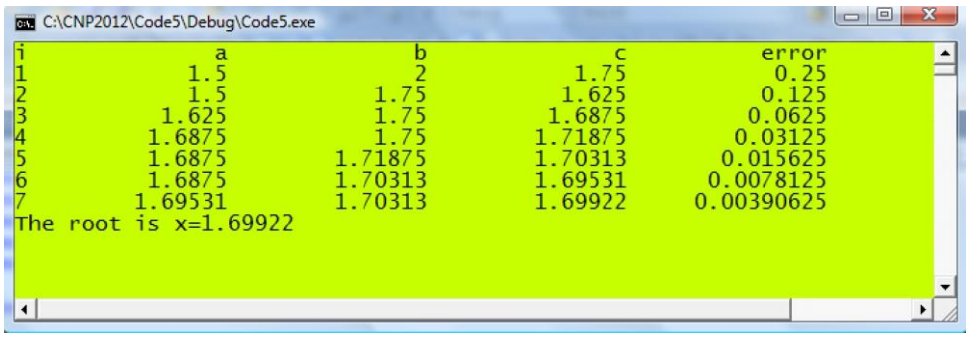
Update $a_{i+1} = c_i$ and $b_{i+1} = b_i$;

If $|c_i - c_{i-1}| < \varepsilon$

Solution= c_i;
Stop the iterations;
Endfor

Code5C.cpp: Finding the root of a function.

```
#include
<iostream>
#include <iomanip>
#define f(x) (pow(x,3)-pow(x,2)-2)
#define N 20
#define EPSILON  0.005

using namespace std;

void main()
{
	double *a, *b, *c;
	a=new double
	[N+1]; b=new
	double [N+1];
	c=new double
	[N+1]; a[0]=1;
	b[0]=2;
	cout<<"i"<<setw(15)<<"a"<<setw(15)<<"b"<<setw(15)<<"c"<<setw(15)<<"error
	"<<endl;
	for (int i=0;i<=N;i++)
	{
		c[i]=(a[i]+b[i])/2;
		if  (f(a[i])*f(c[i])>0)
			a[i+1]=c[i];  b[i+1]=b[i];  //  update  a
		else
			b[i+1]=c[i];  a[i+1]=a[i];  //  update  b
		if  (i>0)
		{
			double StopError = fabs(c[i]-c[i-1]);
			cout << i << setw(15)<< a[i]<<setw(15)<< setw(15)
				<< b[i] << setw(15) << c[i] << setw(15) << StopError
			<< endl;
			if (StopError<EPSILON)
				cout << "The root is x=" << c[i] <<
				endl; break;
		}
	}
	delete
	a,b,c;
	cin.get();
}
```



CS2: Sorting Numbers

Swapping numbers

```
if  (p>q)
{
   tmp=p;
   p=q;
   q=tmp;
}
```

```
Example:  p=72,  q=50

if  (p>q)
{
    tmp=p;      // p=72, tmp=72
    p=q;        // q=50, p=50
    q=tmp;      // tmp=72, q=72
}

        p=50,  q=72
```

Example 5.1. Sort the numbers in the list given by 60, 74, 43, 57 and 45 in ascending order. The numbers are fully sorted after $k = 3$. The final order from the given list is 43, 45, 57, 60 and 74.

Solution

Applying the sorting algorithm above with $k = 1$:

	old	new
w[1]	60	60
w[2]	74	43
w[3]	43	57
w[4]	57	45
w[5]	45	74

i=1: 60<74, no change with w[1]=60, w[2]=74.
i=2: 74>43, swap with w[2]=43, w[3]=74.
i=3: 74>57, swap with w[3]=57, w[4]=74.
i=4: 74>45, swap with w[4]=45, w[5]=74.

Continue with $k = 2$:

	old	new
w[1]	60	43
w[2]	43	57
w[3]	57	45
w[4]	45	60
w[5]	74	74

i=1: 60>43, swap with w[1]=43, w[2]=60.
i=2: 60>57, swap with w[2]=57, w[3]=60.
i=3: 60>45, swap with w[3]=45, w[4]=60.
i=4: 60<74, no change with w[4]=60, w[5]=74.

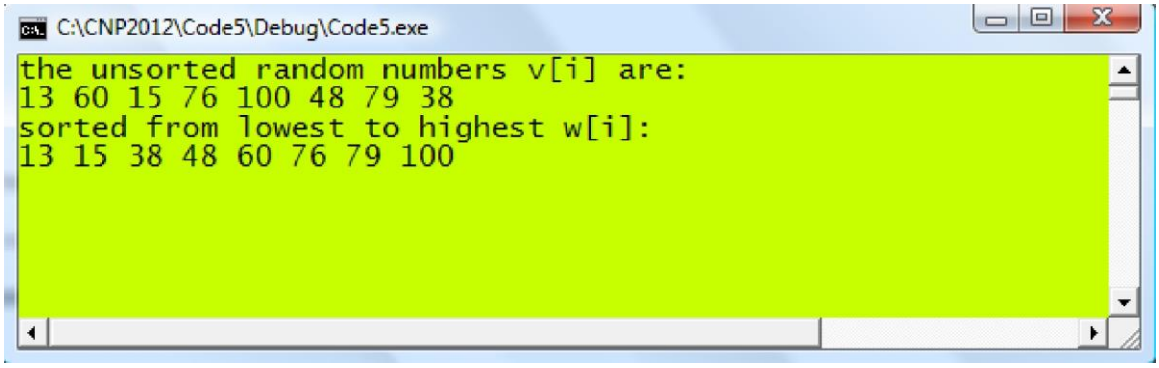
Next iteration with $k = 3$:

	old	new
w[1]	43	43
w[2]	57	45
w[3]	45	57
w[4]	60	60
w[5]	74	74

i=1:43<57, no change with w[1]=43, w[2]=57.
i=2: 57>45, swap with w[2]=45, w[3]=57.
i=3:57<60, no change with w[3]=57, w[4]=60.
i=4: 60<74, no change with w[4]=60, w[5]=74.

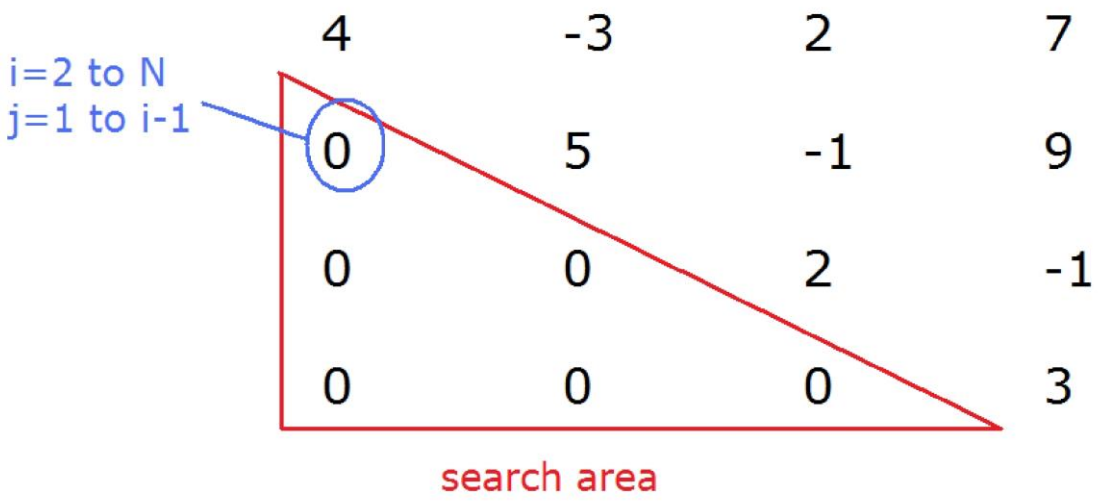
Code5D.cpp: Sorting numbers

```
#include <iostream>
#include <time.h>
#define N 8

using namespace std;

void main()
{
	int v[N+1], w[N+1],tmp, i;
	srand(time(0));
	for (int  i=1;i<=N;i++)
	{
		v[i]=1+rand()%100; // random numbers from 1 to 100
		w[i]=v[i];
	}
	for (int k=1;k<=N;k++)
		for (i=1;i<=N-1;i++)
			if (w[i]>w[i+1]) // swap for low to high
			{
				tmp=w[i];
				w[i]=w[i+1];
				w[i+1]=tmp;
			}
	cout << "the unsorted random numbers v[i] are:" << endl;
	for (i=1;i<=N;i++)
		cout  <<  v[i]  <<  "  ";
	cout<<endl<<"sorted from lowest to highest w[i]:"<<endl; for
	(i=1;i<=N;i++)
		cout << w[i] << " ";
	cout << endl;
	cin.get();
}
```



CS3: Detecting the Upper Triangular Matrix

$$U = \begin{bmatrix} * & * & * & * \\ 0 & * & * & * \\ 0 & 0 & * & * \\ 0 & 0 & 0 & * \end{bmatrix} \qquad L = \begin{bmatrix} * & 0 & 0 & 0 \\ * & * & 0 & 0 \\ * & * & * & 0 \\ * & * & * & * \end{bmatrix}$$




```
bool flag;
flag=1;
for (i=2;i<=N;i++)
    for (j=1;j<=i-1;j++)
        if (a[i][j]!=0)
        {
            flag=0;
            break;
        }
```

The following code segment determines whether a given matrix is upper triangular method for detection:

If `flag` *is* 0 *then the matrix is not upper triangular.*
If `flag` *is* 1 *then the matrix is upper triangular.*

This code below showing how the input data is read.

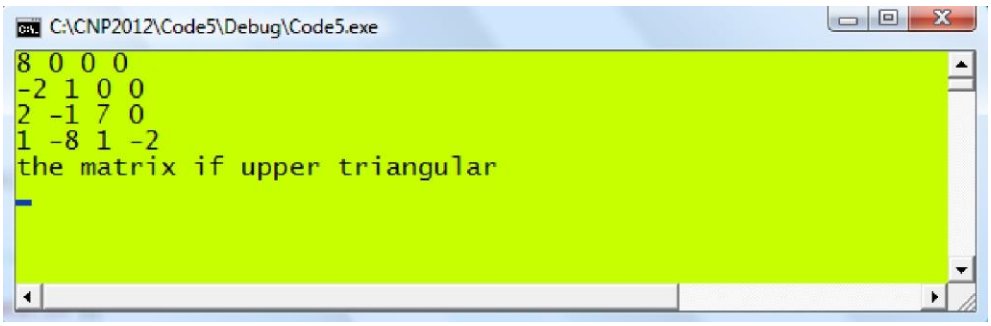
```
ifstream InFile;

InFile.open("Code5E.in");

for (i=1;i<=N;i++)
{
    for (j=1;j<=N;j++)
    {
        InFile >> a[i][j]);
        cout << a[i][j] << " ";
    }
    cout << endl;
 }
```

Code5E.cpp: Detecting upper triangular matrix

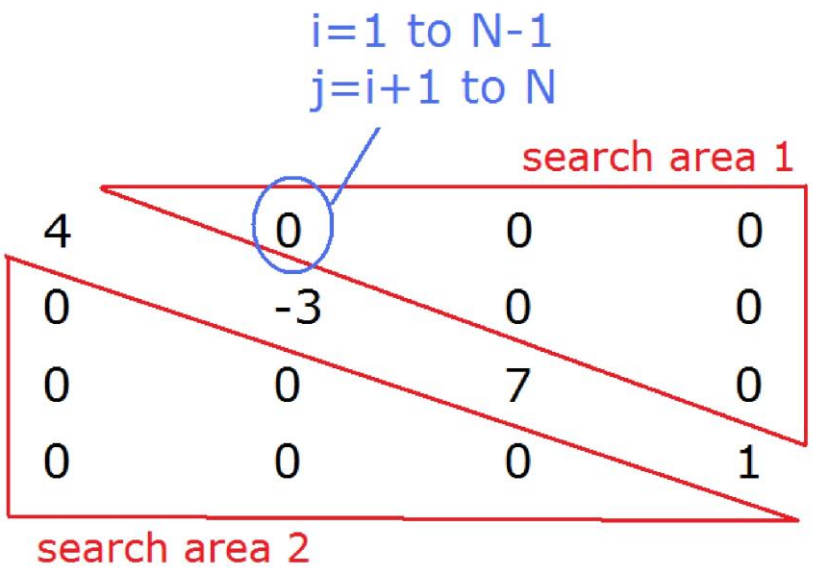
```
#include <iostream>
#include <fstream>
#define N 4

using namespace  std;

void main()
{
	bool flag=1;
	double a[N+1][N+1];
	int i,j;

	// read matrix A values and display them to confirm
	ifstream InFile;
	InFile.open("Code5E.in");
	for (i=1;i<=N;i++)
	{
		for (j=1;j<=N;j++)
		{
			InFile >> a[i][j];
			cout << a[i][j]  <<  "   ";
		}
		cout << endl;
	}
	InFile.close();

	// detect the presence of a non-zero
	for (i=2;i<=N;i++)
	{
		for (int j=1;j<i;j++)
		if (a[i][j]!=0)
			{
				flag=0;
				break;
			}
		if (!flag)
			break;
	}
	if (flag)
		cout<< "the  matrix  is  upper  triangular"<<endl;
	else
		cout<< "the matrix is not upper triangular"<< endl;
	cin.get();
}
```

Code5E.in

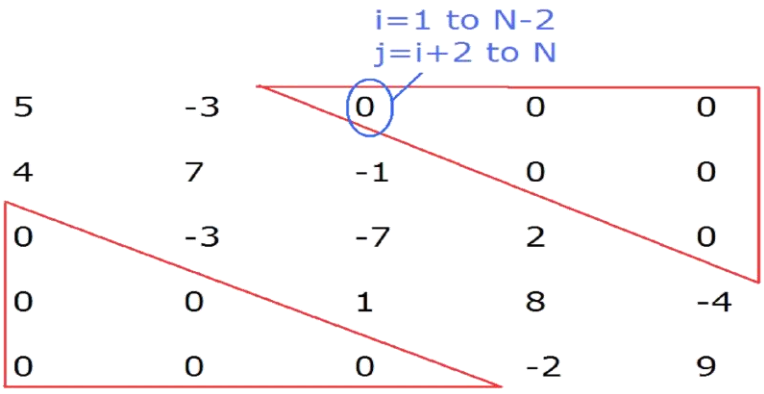
```
8	0	0	0
-2	1	0	0
2	-1	7	0
1	8	1	-2
```



Detecting a diagonal matrix



Detecting a tridiagonal matrix



CS4: Matrix Reduction into an Upper Triangular Form

Method: Row Operations through Gaussian Elimination Method

Example 5.2. Find the upper triangular matrix U of the following matrix:

$$A = \begin{bmatrix} 8 & 2 & -1 & 2 \\ -2 & 1 & -3 & -8 \\ 2 & -1 & 7 & -1 \\ 1 & -8 & 1 & -2 \end{bmatrix}$$

8.000	2.000	-1.000	2.000	
0.000	1.500	-3.250	-7.500	$m = a_{21} / a_{11}$, $a_{2j} \leftarrow a_{2j} - m * a_{1j}$
0.000	-1.500	7.250	-1.500	$m = a_{31} / a_{22}$, $a_{3j} \leftarrow a_{3j} - m * a_{1j}$
0.000	-8.250	1.125	-2.250	$m = a_{41} / a_{22}$, $a_{4j} \leftarrow a_{4j} - m * a_{1j}$

Operations with respect to the second row.

8.000	2.000	-1.000	2.000	
0.000	1.500	-3.250	-7.500	
0.000	0.000	4.000	-9.000	$m = a_{32} / a_{22}$, $a_{3j} \leftarrow a_{3j} - m * a_{2j}$
0.000	0.000	-16.750	-43.500	$m = a_{42} / a_{22}$, $a_{4j} \leftarrow a_{4j} - m * a_{2j}$

Operations with respect to the third row.

8.000	2.000	-1.000	2.000	
0.000	1.500	-3.250	-7.500	
0.000	0.000	4.000	-9.000	
0.000	0.000	0.000	-81.188	$m = a_{43} / a_{33}$, $a_{4j} \leftarrow a_{4j} - m * a_{3j}$

General Algorithm for the Row Operations: $n = 4$

$$m = \frac{a_{ik}}{a_{kk}}, \quad a_{ij} \leftarrow a_{ij} - m * a_{kj}, \; b_i \leftarrow b_i - m * b_k$$

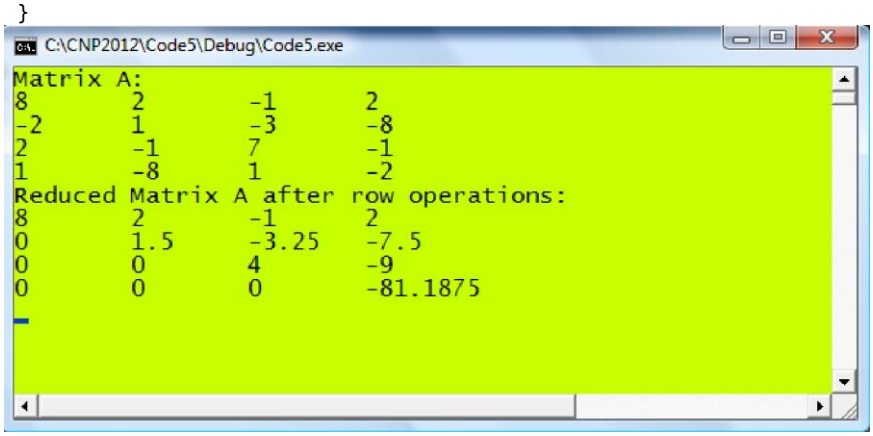
for $k = 1,2,...,n-1,$ followed by $i = k+1, k+2,...,n$ and $j = 1,2,...,n$

Row operations on A produce U

$$U = \begin{bmatrix} 8 & 2 & -1 & 2 \\ 0 & 1.5 & -3.25 & -7.5 \\ 0 & 0 & 4 & -9 \\ 0 & 0 & 0 & -81.188 \end{bmatrix}$$

Code5F.cpp: Finding the upper triangular matrix

```
#include <fstream>
#include <iostream>
#define N 4
using namespace std;
void main()
{
     int i,j,k;
        double **a;
        a=new double *[N+1];
        for (i=0;i<=N;i++)
                a[i]=new double [N+1];
        ifstream InFile;
        InFile.open("Code5F.in",ios::in); for
        (i=1;i<=N;i++)
                for (j=1;j<=N;j++)
                        InFile >> a[i][j];
        InFile.close();
        cout << "Matrix A:" << endl;
        for (i=1;i<=N;i++)
        {
                for (j=1;j<=N;j++)
                        cout << a[i][j] << "\t";
                cout << endl;
        }
        // row operations
        double m;
        for (k=1;k<=N-1;k++)
                for (i=k+1;i<=N;i++)
                {
                        m=a[i][k]/a[k][k];
                        for (j=1;j<=N;j++)
                                a[i][j]-= m*a[k][j];
                }
        cout << "Reduced Matrix A after row operations:" << endl; for
        (i=1;i<=N;i++)
        {
                for  (j=1;j<=N;j++)
                        cout << a[i][j] << "\t";
                cout << endl;
        }
        cin.get();
}
```



CS5: Computing the Determinant of a Matrix

Theorem 5.1. If a square matrix is reducible to its triangular matrix, the determinant of this matrix is the product of the diagonal elements of its reduced upper or lower triangular matrix.

The above theorem states that if a square matrix $A=[a_{ij}]$ is reducible toits upper triangular matrix $U=[u_{ij}]$ then

$$|A|=|U|=\prod_{i=1}^{N}u_{ii}=u_{11}.u_{22}...u_{NN}. \quad (5.3)$$

```
double Product, m;
for (k=1;k<=N-1;k++)
    for  (i=k+1;i<=N;i++)
    {
        m=a[i][k]/a[k][k];
        for (j=1;j<=N;j++)
            a[i][j]  -=  m*a[k][j];
    }
Product=1;
for (i=1;i<=N;i++)
    Product *= a[i][i];
```

Code5G.cpp: Computing the determinant of a matrix

```
#include <iostream>
#include <fstream>
#include <iomanip>
#define N 4
Using namespace std;

void main()
{
	int  i,j,k;
	double A[N+1][N+1] Product=1,m;
	cout.setf(ios::fixed); cout.precision(5);
	cout << "Input matrix A: " << endl;
	ifstream InFile("Code5F.in");
	for (i=1;i<=N;i++)
	{
		for (j=1;j<=N;j++)
		{
			InFile >> A[i][j];
			cout << setw(10) << A[i][j];
		}
		cout << endl;
	}
	InFile.close();
	for (k=1;k<=N-1;k++)
		for (i=k+1;i<=N;i++)
		{
			m=A[i][k]/A[k][k];
			for (j=1;j<=N;j++)
				A[i][j]-=m*A[k][j];
		}
	cout << endl << "Matrix U:" << endl;
	for (i=1;i<=N;i++)
	{
		for  (j=1;j<=N;j++)
			cout << setw(10) << A[i][j];
		cout << endl;
	}
	for (i=1;i<=N;i++)
		Product *= A[i][i];
	cout << endl << "det(A)=" << Product << endl;
	cin.get();
}
```

```
C:\CNP2012\Code5\Debug\Code5.exe
Input matrix A:
   8.00000   2.00000  -1.00000   2.00000
  -2.00000   1.00000  -3.00000  -8.00000
   2.00000  -1.00000   7.00000  -1.00000
   1.00000  -8.00000   1.00000  -2.00000

Matrix U:
   8.00000   2.00000  -1.00000   2.00000
   0.00000   1.50000  -3.25000  -7.50000
   0.00000   0.00000   4.00000  -9.00000
   0.00000   0.00000   0.00000 -81.18750

det(A)=-3897.00000
```

MAIN REFERENCE:

Shaharuddin Salleh (2012), C++ Numerical Programming.