C++ for Scientific Computation

Rajeev Singh

Contents

1 Day 1: Basic input/output

1.1 aa_hello_world.c

```c
// C program to print "Hello World".
//
// Rajeev Singh
// 2013-03-27

#include <stdio.h>

int main() {
    printf("Hello World from C\n");
    return 0;
}
```

1.2 ab_hello_world.cpp

```cpp
// C++ program to print "Hello World".
//
// Rajeev Singh
// 2013-03-27

#include <iostream>

int main() {
    std::cout << "Hello World from C++";// << std::endl;
    return 0;
}
```

1.3 ac_hello_world.cpp

```
// C++ program to print "Hello World".
//
// Rajeev Singh
// 2013-03-27

#include <iostream>

using namespace std;

int main() {
    cout << "Hello World from C++" << endl;
    return 0;
}
```

1.4 ad_powers_of_integer.cpp

```cpp
// Program to calculate powers of given integer.
//
// Rajeev Singh
// 2013-03-27

#include <iostream>
#include <cmath>
using namespace std;

int main() {
    //int given_number;
    long int given_number;
    cout << "Enter an integer: ";
    cin  >> given_number;

    cout << "Given number = " << given_number << endl
         << "Square       = " << pow(given_number,2) << endl
         << "Cube         = " << pow(given_number,3) << endl
         << "Forth power  = " << pow(given_number,4) << endl;

    return 0;
}
```

1.5 ae_powers_of_real.cpp

```
// Program to calculate powers of given integer.
//
// Rajeev Singh
// 2013-03-27

#include <iostream>
#include <cmath>
using namespace std;

int main() {
    double given_number;
    //long double given_number;
    cout << "Enter a real number : ";
    cin  >> given_number;

    cout << "Given number = " << given_number << endl
         << "Square       = " << pow(given_number,2) << endl
         << "Square root  = " << pow(given_number,1./2) << endl
         << "Cube         = " << pow(given_number,3) << endl
         << "Forth power  = " << pow(given_number,4) << endl;

    return 0;
}
```

2 Day 2: Pointers/References, Arithmetic/Logical

2.1 af_pointer.cpp

```
// Program to illustrate pointers.
//
// Rajeev Singh
// 2013-03-28

#include <iostream>
using namespace std;

int main() {
    int *np = NULL;
    int n = 10;

    cout << "Initial" << endl
         << "n   = " << n   << endl
         << "np  = " << np  << endl
         << "*np = " << "since np is NULL, printing *np gives segmentation fault"
<< endl << endl;

    np = &n;
    cout << "After: np = &n" << endl
         << "n   = " << n   << endl
         << "np  = " << np  << endl
         << "*np = " << *np << endl << endl;

    *np = 22;
    cout << "After: *np = 22" << endl
         << "n   = " << n   << endl
         << "np  = " << np  << endl
         << "*np = " << *np << endl << endl;

    return 0;
}
```

2.2 ag_reference.cpp

```
// Program to illustrate the use of references (special pointers).
//
// Rajeev Singh
// 2013-03-28

#include <iostream>
using namespace std;

int main() {
    int   n = 5;
    int & r = n;
    int   m;

    cout << "Initial" << endl
         << "n = " << n << endl
         << "r = " << r << endl
         << "m = " << m << endl << endl;

    m = r + 3;     // m == n + 3
    cout << "After: m = r + 3" << endl
         << "n = " << n << endl
         << "r = " << r << endl
         << "m = " << m << endl << endl;

    r = m;         // r still points to n and n == m
    cout << "After: r = m" << endl
         << "n = " << n << endl
         << "r = " << r << endl
         << "m = " << m << endl << endl;

    m = 0;         // r and n are unchanged
    cout << "After: m = 0" << endl
         << "n = " << n << endl
         << "r = " << r << endl
         << "m = " << m << endl << endl;

    int & s = m;
    r = s;       // r still points to n and n == m (== 0)
    cout << "After: r = s where s is new reference to m" << endl
         << "n = " << n << endl
         << "r = " << r << endl
         << "m = " << m << endl << endl;

    return 0;
}
```

2.3 ah_arithmetic_operators.cpp

```
// Program to illustrate basic arithmetic operators.
//
// Rajeev Singh
// 2013-03-28

#include <iostream>
using namespace std;

int main() {
    int m = 100,
        n = 200;

    cout << "Initial" << endl
         << "m = " << m << endl
         << "n = " << n << endl
         << "m + n = " << m + n << endl
         << "m - n = " << m - n << endl
         << "m * n = " << m * n << endl
         << "m / n = " << m / n << endl
         << "m % n = " << m % n << endl << endl;

    //m = m + 200;
    m += 200;       // both this commands are same
    cout << "After: m += 200" << endl
         << "m = " << m << endl
         << "n = " << n << endl
         << "m + n = " << m + n << endl
         << "m - n = " << m - n << endl
         << "m * n = " << m * n << endl
         << "m / n = " << m / n << endl
         << "m % n = " << m % n << endl << endl;

    m++;
    cout << "After: m++" << endl
         << "m = " << m << endl
         << "n = " << n << endl
         << "m + n = " << m + n << endl
         << "m - n = " << m - n << endl
         << "m * n = " << m * n << endl
         << "m / n = " << m / n << endl
         << "m % n = " << m % n << endl << endl;

    return 0;
}
```

2.4 ai_relational_logical.cpp

```
// program to illustrate logical and relational operators.
//
// Rajeev Singh
// 2013-03-28

#include <iostream>
using namespace std;

int main() {
    int   x = 2;
    int   y = 4;
    int   z = 4;
    bool  b;

    cout << "x = " << x << endl
         << "y = " << y << endl
         << "z = " << z << endl << endl;

    // z == 4 is not tested
    b = ( x == 2 && y == 3 && z == 4 );
    cout << "b = ( x == 2 && y == 3 && z == 4 )" << endl
         << "b = " << b << endl << endl;

    // only x == 2 is tested
    b = ( x == 2 || y == 3 || z == 4 );
    cout << "b = ( x == 2 || y == 3 || z == 4 )" << endl
         << "b = " << b << endl << endl;

    // correct, since x != 0 in "y/x"
    b = ( x != 0 && y/x > 1 );
    cout << "b = ( x != 0 && y/x > 1 )" << endl
         << "b = " << b << endl << endl;

    return 0;
}
```

3 Day 3: Scope, Conditional, Loops

3.1 aj_blocks_scope.cpp

```
// program to illustrate blocks.
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    { // block 1
        int n1 = 1;
        double f1 = 0.0;
        cout << "Block 1 "     << endl;
        cout << "n1 = " << n1 << endl;
        cout << "f1 = " << f1 << endl;
    }

    { // block 2
        int n1 = 2;
        // n1 has value 2 in this block
        cout << "Block 2 "     << endl;
        cout << "n1 = " << n1 << endl;

        //int n1 = 5; // ERROR
    }

    return 0;
}
```

3.2 ak_scope.cpp

```
// program to illustrate scope of variables
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    { // block 1
        int m, n1 = 1;
        { // block 1.1
            int n2 = 2;
            { // block 1.1.1
                m = n1 + n2;  // evaluates to m = 3
                cout << "Block 1.1.1: m = " << m << endl;
            }
        }

        { // block 1.2
            int n2 = 3;
            m = n1 + n2;       // evaluates to m = 4
            cout << "Block 1.2  : m = " << m << endl;
        }
    }

    return 0;
}
```

3.3 al_if_else.cpp

```
// program to illustrate conditional structure
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int n = 1;

    if ( n > 0 )
    {
        n = n / n;
    }

    if ( n < 0 ) {
        n += 5; // NOTE: trivial block!
        cout << "hello " << n << endl;
    }
    else if ( n %2 == 0 ) {
        n += 1;
        cout << "hello " << n << endl;
    }
    else {
        n -= 6;
        cout << "hello " << n << endl;
    }

    cout << "n = " << n << endl;

    return 0;
}
```

3.4 am_for_loop.cpp

```
// program to illustrate for loop
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int n = 1;

    for (int i=1; i<10; i++) {
        if (i>5) {
            n *= i;
            cout << "n = " << n << endl;
        }
    }

    return 0;
}
```

3.5 an_while_loop.cpp

```
// program to illustrate while loop
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int n = 1;
    int i = 1;

    while (i < 10) {
        n *= i;
        i++;
        cout << "n = " << n << endl;
    }

    return 0;
}
```

3.6 ao_do_while_loop.cpp

```
// program to illustrate do-while loop
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int n = 1;
    int i = 100;

    do {
        n *= i;
        i++;
        cout << "n = " << n << endl;
    } while (i < 10);

    return 0;
}
```

3.7 ap_break.cpp

```
// program to illustrate use of break
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int n = 1;

    for ( int i = 1; i < 20; i++ ) {
        // avoid overflow
        if ( n > 21474836 )
            break;
        n *= i;
        cout << "n = " << n << endl;
    }

    return 0;
}
```

3.8 aq_break_nested_loop.cpp

```
// program to illustrate behavior of break in nested loops
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    for ( int i = 1; i < 20; i++ ) {
        int n = 1;
        for ( int j = 1; j < i; j++ ) {
            if ( n > 21474836 )
                break;
            n *= j;
        }

        cout << "n = " << n << endl;
    }

    return 0;
}
```

3.9 ar_break_all_loops.cpp

```
// program to illustrate breaking all nested loops
//
// Rajeev Singh
// 2013-03-29

#include <iostream>
using namespace std;

int main() {
    int flag = 0;
    for ( int i = 1; i < 20; i++ ) {
        int n = 1;
        for ( int j = 1; j < i; j++ ) {
            if ( n > 21474836 ) {
                flag = 1;
                break;
            }
            n *= j;
        }
        if (flag == 1)
            break;

        cout << "n = " << n << endl;
    }

    return 0;
}
```

4 Day 4: Functions, Call by value/reference

4.1 as_function_square.cpp

```
// program to illustrate defining function
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

double
square (const double x) {
    return x*x;
}

int main() {
    double a = 2.5;

    cout << "a   = " << a << endl
         << "a^2 = " << square(a) << endl;

    return 0;
}
```

4.2 at_function_factorial.cpp

```
// program to illustrate defining the factorial function
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

int
factorial (const int n) {
    int f = 1;
    for (int i = 1; i <= n; i++ )
        f *= i;

    return f;
}

int main() {
    int m = 10;

    cout << "m  = " << m << endl
         << "m! = " << factorial(m) << endl;

    return 0;
}
```

4.3 au_function_call_by_value.cpp

```
// program to illustrate call by value feature
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

int
f (int n) {
    n = 10;
    return n;
}

int main() {
    int m = 5;

    cout << "m before calling = " << m    << endl;
    cout << "funtion output   = " << f(m) << endl;
    cout << "m after calling  = " << m    << endl;

    return 0;
}
```

4.4 av_function_call_by_reference.cpp

```
// program to illustrate call by reference feature
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

int
f (int & n) {
    n = 10;
    return n;
}

int main() {
    int m = 5;

    cout << "m before calling = " << m    << endl;
    cout << "funtion output   = " << f(m) << endl;
    cout << "m after calling  = " << m    << endl;

    return 0;
}
```

4.5 aw_function_call_by_reference_using_pointers.cpp

```
// program to illustrate call by reference feature using general
// pointers
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

int
f (int * n) {
    *n = 10;
    return *n;
}

int main() {
    int m = 5;

    cout << "m before calling = " << m      << endl;
    cout << "funtion output   = " << f(&m) << endl;
    cout << "m after calling  = " << m      << endl;

    return 0;
}
```

4.6 ax_function_multiple_return_values.cpp

```
// program to illustrate funtions with multiple return values using
// call by reference
//
// Rajeev Singh
// 2013-03-31

#include <iostream>
using namespace std;

void
min_max ( const int n1, const int n2,
  int & min, int & max );

int main() {
    int m1, m2, min, max;

    cout << "Enter two integers :";
    cin >> m1 >> m2;

    min_max(m1, m2, min, max);
    cout << "m1          = " << m1 << endl
         << "m2          = " << m2 << endl << endl
         << "min(m1,m2) = " << min << endl
         << "max(m1,m2) = " << max << endl;

    return 0;
}

void
min_max ( const int n1, const int n2,
  int & min, int & max ) {
    if ( n1 < n2 ) {
        min = n1;
        max = n2;
    }
    else {
        min = n2;
        max = n1;
    }
}
```

5 Day 5: Functions- default args, function pointers; Arrays

5.1 ay_function_default_arguments.cpp

```
// program to illustrate function with default arguments
//
// Rajeev Singh
// 2013-04-01

#include <iostream>
using namespace std;

double
square (const double x = 10.0) {
    return x*x;
}

int main() {
    double a = 2.5;

    cout << "a         = " << a << endl;
    cout << "a^2       = " << square(a) << endl;
    cout << "square()  = " << square() << endl;

    return 0;
}
```

5.2 az_function_inline.cpp

```
/* program to illustrate inline functions
 *
 * WARNING: do not inline functions with large bodies. it can cause
 *          the final executable to be very large in size and decrease
 *          performance.
 *
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

inline double
square (const double x = 10.0) {
    return x*x;
}

int main() {
    double a = 2.5;

    cout << "a         = " << a << endl;
    cout << "a^2       = " << square(a) << endl;
    cout << "square()  = " << square() << endl;

    return 0;
}
```

5.3 ba_function_pointers.cpp

```
/* program to illustrate function pointers
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

double
square (const double x) {
    return x*x;
}

int main() {
    double a = 2.5;
    double (* pf) (const double x);
    pf = square;

    cout << "a          = " << a << endl;
    cout << "square(a) = " << square(a) << endl;
    cout << "pf(a)      = " << pf(a) << endl;

    return 0;
}
```

5.4 bb_function_pointers_as_arguments.cpp

```
/* program to illustrate funtion pointers as arguments
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

double
square (const double x) {
    return x*x;
}

double
cube (const double x) {
    return x*x*x;
}

double
f ( double ( * func ) ( const double x ),
  const double x ) {
    return func( x );
}


int main() {
    double a = 2.5;

    cout << "a             = " << a << endl;
    cout << "f(square, a) = " << f(square, a) << endl;
    cout << "f(cube,   a) = " << f(cube,   a) << endl;

    return 0;
}
```

5.5 bc_static_variables.cpp

```
/* program to illustrate static variables
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

double
f ( const double x, long & cnt ) {
    static long counter = 0; // allocated and initialised
                             // once per program
    cnt = ++counter;
    return 2.0*x*x - x;
}


int main() {
    long cnt = 0;

    for ( double x = -10; x <= 10.0; x += 0.1 )
        f( x, cnt );

    cout << "num times f called = " << cnt << endl;

    return 0;
}
```

5.6 bd_array.cpp

```
/* program to illustrate array
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

int main() {
    double f[5];

    for ( int i = 0; i < 5; i++ )
        f[i] = 2*i;

    cout << "f = " << f << endl;
    for ( int i = 0; i < 5; i++ )
        cout << "f[" << i << "] = " << f[i] << endl;

    cout << "f[5] = " << f[5] << endl; // bug but program still compiles
    // if you lucky such bugs will be detected by segmentation fault

    return 0;
}
```

5.7 be_function_with_array_argument.cpp

```
/* program to illustrate arrays as function arguments
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

void
copy ( const double x[3], double y[3] ) {
    for ( int i = 0; i < 3; i++ )
        y[i] = x[i];
}

void
add ( const double x[3], double y[3] ) {
    for ( int i = 0; i < 3; i++ )
        y[i] += x[i];
}


int main() {
    double a[3],
           b[] = {0, 0, 0}; // b is automaticall of size 3

    for ( int i = 0; i < 3; i++ )
        a[i] = 2*i;

    cout << "Intial a and b:" << endl;
    for ( int i = 0; i < 3; i++ )
        cout <<   "a[" << i << "] = " << a[i]
             << "  b[" << i << "] = " << b[i]<< endl;

    copy( a, b );
    cout << endl << "After calling copy funtion:" << endl;
    for ( int i = 0; i < 3; i++ )
        cout <<   "a[" << i << "] = " << a[i]
             << "  b[" << i << "] = " << b[i]<< endl;

    add( a, b );
    cout << endl << "After calling sum funtion:" << endl;
    for ( int i = 0; i < 3; i++ )
        cout <<   "a[" << i << "] = " << a[i]
             << "  b[" << i << "] = " << b[i]<< endl;

    return 0;
}
```

5.8 bf_multidimensional_arrays.cpp

```
/* program to illustrate multidimensional arrays
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

void
mulvec ( const double M[3][3],
         const double x[3],
               double y[3] ) {
    for ( int i = 0; i < 3; i++ ) {
        y[i] = 0.0;

        for ( int j = 0; j < 3; j++ )
            y[i] += M[i][j] * x[j];
    }
}


int main() {
    double M[3][3],
           x[3], y[3];

    for ( int i = 0; i < 3; i++ ) {
        x[i] = 2*i;
        for ( int j = 0; j < 3; j++ )
            M[i][j] = 3*i+j;
    }

    mulvec(M, x, y);

    cout << "M:" << endl;
    for ( int i = 0; i < 3; i++ ) {
        for ( int j = 0; j < 3; j++ )
            cout << " " << M[i][j];
    cout << endl;
    }

    cout << "x:" << endl;
    for ( int j = 0; j < 3; j++ )
        cout << " " << x[j] << endl;

    cout << "y = M*x:" << endl;
    for ( int j = 0; j < 3; j++ )
        cout << " " << y[j] << endl;

    return 0;
}
```

5.9 bg_array_and_pointer.cpp

```
/* program to illustrate pointers as arrays
 *
 * in C/C++ there is NO distinction between a pointer and an array.
 *
 * Rajeev Singh
 * 2013-04-01
 *
 */

#include <iostream>
using namespace std;

int main() {
    int   n[5] = { 2, 3, 5, 7, 11 };
    int * p    = n;
    int * q    = &n[1];

    cout << "n:" << endl;
    for ( int j = 0; j < 5; j++ )
        cout << " " << n[j] << endl;

    cout << "p:" << endl;
    for ( int j = 0; j < 5; j++ )
        cout << " " << p[j] << endl;

    cout << "q:" << endl;
    for ( int j = 0; j < 5; j++ )
        cout << " " << q[j] << endl;


    return 0;
}
```

6 Day 6: Dynamic memory, Multidimensional Array, BLAS

6.1 bh_dynamic_memory.cpp

```
/* program to illustrate dynamic memory
 *
 * this example shows the C++ way of doing the job. this will not work
 * for C.
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int      n = 10;
    double * v = new double[n];

    for ( int i = 0; i < n; i++ )
        v[i] = double( i*i );

    cout << "n = " << n << endl;
    cout << "v:" << endl;
    for ( int j = 0; j < n; j++ )
        cout << " " << v[j] << endl;

    delete[] v;
    return 0;
}
```

6.2 bi_dynamic_array_size_input.cpp

```
/* program to illustrate dynamic memory
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int n;

    cout << "Enter the size of the array: ";
    cin >> n;

    double * v = new double[n];

    for ( int i = 0; i < n; i++ )
        v[i] = double( i*i );

    cout << "n = " << n << endl;
    cout << "v:" << endl;
    for ( int j = 0; j < n; j++ )
        cout << " " << v[j] << endl;

    delete[] v;
    return 0;
}
```

6.3 bj_multidimensional_array_with_pointer.cpp

```
/* program to illustrate dynamic memory
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int n1[4], n2[4], n3[4], n4[4];
    int * p1 = n1;                  // p1 -> pointer
    int * p2 = n2;
    int * p3 = n3;
    int * p4 = n4;

    int *p[4] = {p1, p2, p3, p4}; // p -> pointer of pointers

    for (int i = 0; i < 4; i++ )
        for (int j = 0; j < 4; j++ )
            p[i][j] = 4*i+j;

    cout << "p:" << endl;
    for (int i = 0; i < 4; i++ ) {
        for (int j = 0; j < 4; j++ )
            cout << " " << p[i][j];
        cout << endl;
    }

    return 0;
}
```

6.4 bk_multidimensional_dynamic_array.cpp

```
/* program to illustrate dynamic memory
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int * p1 = new int[4];
    int * p2 = new int[4];
    int * p3 = new int[4];
    int * p4 = new int[4];

    int **p =  new int*[4];

    p[0] = p1;
    p[1] = p2;
    p[2] = p3;
    p[3] = p4;

    for (int i = 0; i < 4; i++ )
        for (int j = 0; j < 4; j++ )
            p[i][j] = 4*i+j;

    cout << "p:" << endl;
    for (int i = 0; i < 4; i++ ) {
        for (int j = 0; j < 4; j++ )
            cout << " " << p[i][j];
        cout << endl;
    }

    return 0;
}
```

6.5 bl_multidimensional_dynamic_array_size_input.cpp

```
/* program to illustrate dynamic memory
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int m, n;
    cout << "Enter the size of the matrix: ";
    cin >> m >> n;

    int **p =  new int*[m];

    for (int i = 0; i < m; i++ )
        p[i] = new int[n];

    for (int i = 0; i < m; i++ )
        for (int j = 0; j < n; j++ )
            p[i][j] = n*i+j;

    cout << "p:" << endl;
    for (int i = 0; i < m; i++ ) {
        for (int j = 0; j < n; j++ )
            cout << " " << p[i][j];
        cout << endl;
    }

    return 0;
}
```

6.6 bm_multidimensional_array_with_mapping.cpp

```
/* program to illustrate dynamic memory
 *
 * NOTE: using pointer of pointers can be slower than using mappings
 * for big arrays for the following reason:
 *
 * pointer of pointers -> two access to RAM to get an element
 * mapping             -> single access to RAM for the same
 *
 * accessing RAM is much more expensive than simple integer
 * multiplication and addition
 *
 * Rajeev Singh
 * 2013-04-02
 *
 */

#include <iostream>
using namespace std;

int main() {
    int m, n;
    cout << "Enter the size of the matrix: ";
    cin >> m >> n;

    int *p =  new int[m*n];

    for (int i = 0; i < m; i++ )
        for (int j = 0; j < n; j++ )
            p[n*i+j] = n*i+j;

    cout << "p:" << endl;
    for (int i = 0; i < m; i++ ) {
        for (int j = 0; j < n; j++ )
            cout << " " << p[n*i+j];
        cout << endl;
    }

    return 0;
}
```

GO TO THE TALK TO DISCUSS BLAS

7 Day 7: String, Advanced Datatypes, BLAS, Sparse Matrices

7.1 bn_strings.cpp

```
/* program to illustrate strings as array of characters
 *
 * Rajeev Singh
 * 2013-04-03
 *
 */

#include <iostream>
using namespace std;

int main() {
    char str1[] = { 'S', 't', 'r', 'i', 'n', 'g', '\0' };
    char str2[] = "String"; // '\0' is appended automatically
    char str3[] = "This is a very long \
string";

    cout << str1 << endl;
    cout << str2 << endl;
    cout << str3 << endl;

    return 0;
}
```

7.2 bo_typedef.cpp

```
/* program to illustrate renaming datatypes using typedef
 *
 * Rajeev Singh
 * 2013-04-03
 *
 */

#include <iostream>
using namespace std;

int main() {
    typedef char * string_t;
    string_t str2 = "String"; // '\0' is appended automatically
    string_t str3 = "This is a very long \
string";

    cout << str2 << endl;
    cout << str3 << endl;

    return 0;
}
```

7.3 bp_struct.cpp

```
/* program to illustrate defining new datatypes using struct
 *
 * Rajeev Singh
 * 2013-04-03
 *
 */

#include <iostream>
using namespace std;

typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;
};

void
add_vec ( const vector_t &  x,
          const vector_t &  y,
          vector_t &        z ) {
    for ( int i = 0; i < x.size; i++ )
        z.coeffs[i] = x.coeffs[i] + y.coeffs[i];
}


int main() {
    int      n = 10;
    vector_t a, b, c;
    a.size = n;
    b.size = n;
    c.size = n;

    a.coeffs = new real_t[n];
    b.coeffs = new real_t[n];
    c.coeffs = new real_t[n];

    for ( int i = 0; i < n; i++ ) {
        a.coeffs[i] = i;
        b.coeffs[i] = 2*i;
    }

    add_vec( a, b, c );

    cout << "a:" << endl;
    cout << "a.size = " << a.size << endl;
    cout << "a.coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << a.coeffs[i] << endl;

    cout << "b:" << endl;
    cout << "b.size = " << b.size << endl;
    cout << "b.coeffs:" << endl;
```

```
    for ( int i = 0; i < n; i++ )
        cout << "         " << b.coeffs[i] << endl;

    cout << "c:" << endl;
    cout << "c.size = " << c.size << endl;
    cout << "c.coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "         " << c.coeffs[i] << endl;

    delete[] a.coeffs;
    delete[] b.coeffs;
    delete[] c.coeffs;
    return 0;
}
```

7.4 bq_struct_pointer.cpp

```
/* program to illustrate using pointers to struct
 *
 * Rajeev Singh
 * 2013-04-03
 *
 */

#include <iostream>
using namespace std;

typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;
};

void
add_vec ( const vector_t *  x,
          const vector_t *  y,
          vector_t *        z ) {
    for ( int i = 0; i < x->size; i++ )
        z->coeffs[i] = x->coeffs[i] + y->coeffs[i];
}


int main() {
    int      n = 10;
    vector_t * a = new vector_t,
             * b = new vector_t,
             * c = new vector_t;

    a->size = n;
    b->size = n;
    c->size = n;

    a->coeffs = new real_t[n];
    b->coeffs = new real_t[n];
    c->coeffs = new real_t[n];

    for ( int i = 0; i < n; i++ ) {
        a->coeffs[i] = i;
        b->coeffs[i] = 2*i;
    }

    add_vec( a, b, c );

    cout << "a:" << endl;
    cout << "a->size = " << a->size << endl;
    cout << "a->coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << a->coeffs[i] << endl;
```

```
    cout << "b:" << endl;
    cout << "b->size = " << b->size << endl;
    cout << "b->coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << b->coeffs[i] << endl;

    cout << "c:" << endl;
    cout << "c->size = " << c->size << endl;
    cout << "c->coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << c->coeffs[i] << endl;

    delete[] a->coeffs;
    delete[] b->coeffs;
    delete[] c->coeffs;

    delete a;
    delete b;
    delete c;

    return 0;
}
```

7.5 br_struct_array.cpp

```
/* program to illustrate using struct array
 *
 * Rajeev Singh
 * 2013-04-03
 *
 */

#include <iostream>
using namespace std;

typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;
};

void
add_vec ( const vector_t *  x,
          const vector_t *  y,
          vector_t *        z ) {
    for ( int i = 0; i < x->size; i++ )
        z->coeffs[i] = x->coeffs[i] + y->coeffs[i];
}


int main() {
    int      n = 10;
    vector_t * a = new vector_t[3];

    for ( int i = 0; i < 3; i++ ) {
        a[i].size = n;
        a[i].coeffs = new real_t[n];
    }

    for ( int i = 0; i < n; i++ ) {
        a[0].coeffs[i] = i;
        a[1].coeffs[i] = 2*i;
    }

    add_vec( &a[0], &a[1], &a[2] );

    cout << "a[0]:" << endl;
    cout << "a[0].size = " << a[0].size << endl;
    cout << "a[0].coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << a[0].coeffs[i] << endl;

    cout << "a[1]:" << endl;
    cout << "a[1].size = " << a[1].size << endl;
    cout << "a[1].coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "        " << a[1].coeffs[i] << endl;
```

```
    cout << "a[2]:" << endl;
    cout << "a[2].size = " << a[2].size << endl;
    cout << "a[2].coeffs:" << endl;
    for ( int i = 0; i < n; i++ )
        cout << "         " << a[2].coeffs[i] << endl;


    for ( int i = 0; i < 3; i++ )
        delete[] a[i].coeffs;

    delete[] a;

    return 0;
}
```

GO TO THE TALK TO DISCUSS BLAS AND SPARSE MATRICES

8 Day 9: Modules and Namespaces, Classes

GO TO THE TALK TO DISCUSS MODULES AND NAMESPACES

8.1 bs_struct_with_functions.cpp

```
/* program to illustrate using struct with functions as members
 *
 * Rajeev Singh
 * 2013-04-05
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;

    void init  ( const unsigned n );
    void del   ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print ();
};


int main() {
    vector_t x;

    x.init( 10 );
    x.print();
    x.fill( 1.0 );
    x.print();
    x.scale( 5.0 );
    x.print();
    x.del();

    return 0;
}

void vector_t::init (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

void vector_t::del () {
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
```

```
        coeffs[i] *= f;
}

void vector_t::print () {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

8.2 bt_struct_constructor_destructor.cpp

```
/* program to illustrate using struct with special functions for
 * construction and destruction of objects
 *
 * Rajeev Singh
 * 2013-04-05
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;

    vector_t ( const unsigned n );
    ~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print ();
};


int main() {
    vector_t x(10);

    x.print();
    x.fill( 1.0 );
    x.print();
    x.scale( 5.0 );
    x.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
```

```
}

void vector_t::print () {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "         " << coeffs[i] << endl;
}
```

9 Day 10: Classes Continued

9.1 bu_struct_this_pointer.cpp

```
/* program to illustrate the use of this pointer
 * members
 *
 * Rajeev Singh
 * 2013-04-07
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    ~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void add   ( const real_t   alpha, const vector_t & a );
    void print () const;
};


int main() {
    vector_t x(10), y(10);

    x.fill( 1.0 );
    y.fill( 2.0 );
    cout << "x:" << endl;
    x.print();
    cout << "y:" << endl;
    y.print();
    x.add( 10.0, y );
    cout << "x:" << endl;
    x.print();
    cout << "y:" << endl;
    y.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
```

```
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::add ( const real_t alpha, const vector_t & a ) {
    for (int i = 0; i < this->size; i++ )
        this->coeffs[i] += alpha * a.coeffs[i];
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

9.2 bv_copy_constructor.cpp

```
/* program to illustrate the use of copy constructor
 * members
 *
 * Rajeev Singh
 * 2013-04-07
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    vector_t ( const vector_t & a );
    ~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void add   ( const real_t   alpha, const vector_t & a );
    void print () const;
};


int main() {
    vector_t x(10);

    x.fill( 1.0 );
    cout << "x:" << endl;
    x.print();

    vector_t y(x);
    cout << "y:" << endl;
    y.print();

    x.scale( 5.0 );
    cout << "x:" << endl;
    x.print();
    cout << "y:" << endl;
    y.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}
```

```
vector_t::vector_t (const vector_t & a ) {
    this->size = a.size;
    this->coeffs = new real_t[a.size];
    for (int i = 0; i < a.size; i++ )
        this->coeffs[i] = a.coeffs[i];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::add ( const real_t alpha, const vector_t & a ) {
    for (int i = 0; i < this->size; i++ )
        this->coeffs[i] += alpha * a.coeffs[i];
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

9.3 bw_default_copy_constructor.cpp

```
/* program to illustrate the problem with the default copy constructor
 * members
 *
 * Rajeev Singh
 * 2013-04-07
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    //~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void add   ( const real_t   alpha, const vector_t & a );
    void print () const;
};


int main() {
    vector_t x(10);

    x.fill( 1.0 );
    cout << "x:" << endl;
    x.print();

    vector_t y(x);
    cout << "y:" << endl;
    y.print();

    x.scale( 5.0 );
    cout << "x:" << endl;
    x.print();
    cout << "y:" << endl;
    y.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

/*
```

```
vector_t::~vector_t () {
    delete[] coeffs;
}
*/

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::add ( const real_t alpha, const vector_t & a ) {
    for (int i = 0; i < this->size; i++ )
        this->coeffs[i] += alpha * a.coeffs[i];
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

9.4 bx_struct_with_const_functions.cpp

```
/* program to illustrate using struct with const functions
 *
 * Rajeev Singh
 * 2013-04-05
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
    size_t size;
    real_t * coeffs;

    vector_t ( const unsigned n );
    ~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print () const;
};


int main() {
    const vector_t x(10);

    x.print();
    //x.fill( 1.0 );     // error
    //x.print();
    //x.scale( 5.0 );    // error
    //x.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}
```

```
void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "         " << coeffs[i] << endl;
}
```

9.5 by_struct_visibility.cpp

```
/* program to illustrate using struct with different visibility for
 * members
 *
 * Rajeev Singh
 * 2013-04-05
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    ~vector_t ();
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print () const;
};


int main() {
    vector_t x(10);

    x.print();
    x.fill( 1.0 );
    x.print();
    x.scale( 5.0 );
    x.print();

    //cout << x.size << endl; // error

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}
```

```
void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

9.6 bz_safely_changing_size_of_array.cpp

```
/* program to illustrate using visibility to change the size of array
 * safely
 *
 * Rajeev Singh
 * 2013-04-07
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    ~vector_t ();
    int  get_size ();
    void set_size ( const unsigned n );
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print () const;
};


int main() {
    vector_t x(10);

    x.print();
    x.fill( 1.0 );
    x.print();
    x.scale( 5.0 );
    x.print();
    cout << "Size of x = " << x.get_size() << endl;
    x.set_size( 4 );
    x.print();

    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

int  vector_t::get_size () {
```

```
    return size;
}

void vector_t::set_size ( const unsigned n ) {
    if (size != n) {
        size = n;
        delete coeffs;  // delete the old data
        coeffs = new real_t[n];
    }
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

10 Day 11: Classes Continued, Templates

10.1 ca_operator_overloading.cpp

```
/* program to illustrate operator overloading
 * safely
 *
 * Rajeev Singh
 * 2013-04-08
 *
 */

#include <iostream>
using namespace std;
typedef double real_t;

struct vector_t {
private:
    size_t size;
    real_t * coeffs;

public:
    vector_t ( const unsigned n );
    ~vector_t ();
    int  get_size ();
    void set_size ( const unsigned n );
    void fill  ( const real_t   f );
    void scale ( const real_t   f );
    void print () const;

    vector_t & operator += (const vector_t & a) {
        for (size_t i = 0; i < size; i++ )
            coeffs[i] += a.coeffs[i];
        return *this;
    }

    vector_t & operator -= (const vector_t & a) {
        for (size_t i = 0; i < size; i++ )
            coeffs[i] -= a.coeffs[i];
        return *this;
    }
};


int main() {
    vector_t x(4), y(4);

    x.fill( 3.0 );
    y.fill( 1.0 );
    x.print();
    y.print();

    x += y;
    x.print();
    y.print();
```

```
    return 0;
}

vector_t::vector_t (const unsigned n ) {
    size = n;
    coeffs = new real_t[n];
}

vector_t::~vector_t () {
    delete[] coeffs;
}

int  vector_t::get_size () {
    return size;
}

void vector_t::set_size ( const unsigned n ) {
    if (size != n) {
        size = n;
        delete coeffs;  // delete the old data
        coeffs = new real_t[n];
    }
}

void vector_t::fill ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] = f;
}

void vector_t::scale ( const real_t f ) {
    for (int i = 0; i < size; i++ )
        coeffs[i] *= f;
}

void vector_t::print () const {
    cout << "size = " << size << endl;
    cout << "coeffs:" << endl;
    for (int i = 0; i < size; i++ )
        cout << "        " << coeffs[i] << endl;
}
```

10.2 cb_templates.cpp

```
/* program to illustrate generic programming using templates
 * safely
 *
 * Rajeev Singh
 * 2013-04-08
 *
 */

#include <iostream>
using namespace std;

template <typename T>
T square(const T f) {
    return f*f;
}

int main() {
    double x = square( 2.1 );
    int    m = square( 2 );

    cout << "x = : " << x << endl;
    cout << "m = : " << m << endl;

    return 0;
}
```

GO TO THE TALK TO DISCUSS BLAS AND TEMPLATES

11 Day 14: STL

OPEN http://www.cplusplus.com/reference/

11.1 cc_list.cpp

```
/* program to illustrate lists from STL
 *
 * Rajeev Singh
 * 2013-04-11
 *
 */

#include <iostream>
#include <list>

using namespace std;

int main() {
    list< int > ilist;

    ilist.push_front( 1 );
    ilist.push_front( 2 );
    ilist.push_back(  3 );
    ilist.push_back(  4 );

    for ( list<int>::iterator it = ilist.begin(); it != ilist.end(); it++)
        cout << *it << endl;

    int sum = 0;

    while ( ! ilist.empty() ) {
        sum += ilist.front();
        ilist.pop_front();
    }

    cout << "Sum of the list = " << sum << endl;
    return 0;
}
```

11.2 cd_vector.cpp

```
/* program to illustrate vector from STL
 *
 * Rajeev Singh
 * 2013-04-11
 *
 */

#include <iostream>
#include <vector>

using namespace std;

int main() {
    vector< int > ivector;

    ivector.push_back( 1 );
    ivector.push_back( 2 );
    ivector.push_back( 3 );
    ivector.push_back( 4 );

    for ( vector<int>::iterator it = ivector.begin(); it != ivector.end(); it++)
        cout << *it << endl;

    cout << endl;
    for ( int i = 0; i < ivector.size(); i++ )
        cout << ivector[i] << endl;

    int sum = 0;

    while ( ! ivector.empty() ) {
        sum += ivector.back();
        ivector.pop_back();
    }

    cout << "Sum of the vector = " << sum << endl;
    return 0;
}
```

11.3 ce_valarray.cpp

```
/* program to illustrate valarray from STL
 *
 * Example taken from:
 * http://www.cplusplus.com/reference/valarray/valarray/operators/
 *
 * Rajeev Singh
 * 2013-04-11
 *
 */

// valarray operators example
#include <iostream>
#include <valarray>
using namespace std;

void print_all( valarray<int> & foo, valarray<int> & bar ) {
  cout << endl << "foo:   " << "bar:" << endl;
  for (int i = 0; i < foo.size(); i++ )
      cout << foo[i] << "     " << bar[i] << endl;
}

int main () {
  int init[]= {10,20,30,40};
                                  //     foo:           bar:

  valarray<int> foo (init, 4);    //  10 20 30 40
  valarray<int> bar (25,4);       //  10 20 30 40    25 25 25 25
  print_all(foo, bar);

  bar += foo;                     //  10 20 30 40    35 45 55 65
  print_all(foo, bar);

  foo = bar + 10;                 //  45 55 65 75    35 45 55 65
  print_all(foo, bar);

  foo -= 10;                      //  35 45 55 65    35 45 55 65
  print_all(foo, bar);

  valarray<bool> comp = (foo==bar);

  if ( comp.min() == true )
          cout << "They are equal.\n";
  else
          cout << "They are not equal.\n";

  return 0;
}
```

11.4 cf_complex_numbers.cpp

```
/* program to illustrate complex numbers from STL
 *
 * Rajeev Singh
 * 2013-04-11
 *
 */

#include <iostream>
#include <complex>
using namespace std;

int main () {
    complex< float > c1;
    c1.real() = 1.0;
    c1.imag() = -2.0;
    cout << "c1 = " << c1 << endl << endl;

    complex< double > I ( 0.0, 1.0 );
    complex< double > r ( 5.0 );
    complex< double > z;
    complex< double > i = I;

    cout << "I = " << I << endl;
    cout << "r = " << r << endl;
    cout << "z = " << z << endl;
    cout << "i = " << i << endl;
    cout << endl;
    cout << " sqrt( r + i ) = " << sqrt( r + i ) << endl;
    cout << "  sin( r + i ) = " <<  sin( r + i ) << endl;

  return 0;
}
```

11.5 cg_auto_pointer.cpp

GO TO THE TALK TO DISCUSS THE NEED FOR AUTO POINTER

```
/* program to illustrate the use of auto-pointers from STL
 *
 * Rajeev Singh
 * 2013-04-11
 *
 */

#include <iostream>
#include <memory>
using namespace std;

int main () {
    {
        double   x[100];
        double * y = new double[100];
    } // "x" is deallocated, but not "y"

    {
        double   x[100];
        auto_ptr< double > y( new double[100] );
    } // both "x" and "y" are deallocated

    cout << "done" << endl;

  return 0;
}
```

12 Day 15: Boost

OPEN Boost Document

12.1 ch_boost_array.cpp

```
/* program to illustrate the use of boost::array
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <iostream>
#include <boost/array.hpp>
using namespace std;
using namespace boost;

void print_all( array<int,4> & foo, array<int,4> & bar ) {
  cout << endl << "foo:   " << "bar:" << endl;
  for (int i = 0; i < foo.size(); i++ )
      cout << foo[i] << "     " << bar[i] << endl;
}

int main () {
                                  //     foo:           bar:

  array<int,4> foo = {10,20,30,40};       //  10 20 30 40
  array<int,4> bar = {25} ;       //  10 20 30 40    25 25 25 25
  print_all(foo, bar);

  //foo += bar; // doesn't work as '+' is not overloaded
                // not really sure what is the use of it
  return 0;
}
```

12.2 ci_boost_multi_array.cpp

```
/* program to illustrate the use of boost::multi_array
 *
 * example taken from the documentation of Boost.MultiArray
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <iostream>
#include "boost/multi_array.hpp"
#include <cassert>

using namespace std;

int
main () {
  // Create a 3D array that is 3 x 4 x 2
  typedef boost::multi_array<double, 3> array_type;
  typedef array_type::index index;
  array_type A(boost::extents[3][4][2]);

  // Assign values to the elements
  int values = 0;
  for(index i = 0; i != 3; ++i)
    for(index j = 0; j != 4; ++j)
      for(index k = 0; k != 2; ++k)
        A[i][j][k] = values++;

  // Verify values
  int verify = 0;
  for(index i = 0; i != 3; ++i) {
    for(index j = 0; j != 4; ++j) {
      for(index k = 0; k != 2; ++k) {
        assert(A[i][j][k] == verify++);
        cout << A[i][j][k] << " ";
      } // k
      cout << endl;
    } // j
    cout << endl;
  } // i

  return 0;
}
```

12.3 cj_boost_mulitprecision_cpp_int.cpp

```
/* program to illustrate the use of boost::multiprecision
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/multiprecision/cpp_int.hpp>

using namespace boost::multiprecision;

int main () {
    int128_t v = 1;

    // Do some fixed precision arithmetic:
    for(unsigned i = 1; i <= 20; ++i)
       v *= i;

    std::cout << v << std::endl; // prints 20!

    // Repeat at arbitrary precision:
    cpp_int u = 1;
    for(unsigned i = 1; i <= 100; ++i)
       u *= i;

    std::cout << u << std::endl; // prints 100!

    return 0;
}
```

12.4 ck_boost_mulitprecision_gmp.cpp

```
/* program to illustrate the use of boost::multiprecision
 *
 * example taken from boost document
 *
 * compile command:
 *   g++ -I /home/rajeev/software/general/boost_1_53_0/
 *   ck_boost_mulitprecision_gmp.cpp -lgmp
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/multiprecision/gmp.hpp>

using namespace boost::multiprecision;

int main () {
    mpz_int v = 1;

    // Do some arithmetic:
    for(unsigned i = 1; i <= 1000; ++i)
       v *= i;

    std::cout << v << std::endl; // prints 1000!

    // Access the underlying representation:
    mpz_t z;
    mpz_init(z);
    mpz_set(z, v.backend().data());

    return 0;
}
```

12.5 cl_boost_mulitprecision_cpp_int_2.cpp

```
/* program to illustrate the use of boost::multiprecision
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/multiprecision/cpp_int.hpp>
#include <iostream>
#include <iomanip>
#include <vector>


void print_factorials()
{
   using boost::multiprecision::cpp_int;
   //
   // Print all the factorials that will fit inside a 128-bit integer.
   //
   // Begin by building a big table of factorials, once we know just how
   // large the largest is, we'll be able to "pretty format" the results.
   //
   // Calculate the largest number that will fit inside 128 bits, we could
   // also have used numeric_limits<int128_t>::max() for this value:
   cpp_int limit = (cpp_int(1) << 128) - 1;
   //
   // Our table of values:
   std::vector<cpp_int> results;
   //
   // Initial values:
   unsigned i = 1;
   cpp_int factorial = 1;
   //
   // Cycle through the factorials till we reach the limit:
   while(factorial < limit)
   {
      results.push_back(factorial);
      ++i;
      factorial *= i;
   }
   //
   // Lets see how many digits the largest factorial was:
   unsigned digits = results.back().str().size();
   //
   // Now print them out, using right justification, while we're at it
   // we'll indicate the limit of each integer type, so begin by defining
   // the limits for 16, 32, 64 etc bit integers:
   cpp_int limits[] = {
      (cpp_int(1) << 16) - 1,
      (cpp_int(1) << 32) - 1,
      (cpp_int(1) << 64) - 1,
```

```
      (cpp_int(1) << 128) - 1,
   };
   std::string bit_counts[] = { "16", "32", "64", "128" };
   unsigned current_limit = 0;
   for(unsigned j = 0; j < results.size(); ++j)
   {
      if(limits[current_limit] < results[j])
      {
         std::string message = "Limit of " + bit_counts[current_limit] + " bit integ
         std::cout << std::setfill('.') << std::setw(digits+1) << std::right << mess
         ++current_limit;
      }
      std::cout << std::setw(digits + 1) << std::right << results[j] << std::endl;
   }
}


int main() {
    print_factorials();
    return 0;
}
```

12.6 cm_boost_random_uniform.cpp

```
/* program to illustrate the use of boost::random
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <iostream>
#include <boost/random/mersenne_twister.hpp>
#include <boost/random/uniform_real.hpp>

using namespace std;

int main (void) {
    boost::random::mt19937 generator;
    boost::uniform_real<> uni_dist(0,1);

    int i, j;

    for (i = 0; i < 100; i++)
        cout << uni_dist(generator) << endl;

    return 0;
}
```

12.7 cn_boost_ublas_vector.cpp

```
/* program to illustrate the use of boost::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v (3);
    for (unsigned i = 0; i < v.size (); ++ i)
        v (i) = i;
    std::cout << v << std::endl;
}
```

12.8 co_boost_ublas_unit_vector.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    for (int i = 0; i < 3; ++ i) {
        unit_vector<double> v (3, i);
        std::cout << v << std::endl;
    }
}
```

12.9 cp_boost_ublas_zero_vector.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    zero_vector<double> v (3);
    std::cout << v << std::endl;
}
```

12.10 cq_boost_ublas_scalar_vector.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    scalar_vector<double> v (3);
    std::cout << v << std::endl;
}
```

12.11 cr_boost_ublas_sparse_vector_mapped.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector_sparse.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    mapped_vector<double> v (6, 3);
    for (unsigned i = 0; i < v.size ()/2; ++ i)
        v (2*i) = i+10;
    std::cout << v << std::endl;
}
```

12.12 cs_boost_ublas_sparse_vector_compressed.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector_sparse.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    compressed_vector<double> v (6, 3);
    for (unsigned i = 0; i < v.size ()/2; ++ i)
        v (2*i) = i+10;
    std::cout << v << std::endl;
}
```

12.13 ct_boost_ublas_sparse_vector_coordinate.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-12
 *
 */

#include <boost/numeric/ublas/vector_sparse.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    coordinate_vector<double> v (6, 3);
    for (unsigned i = 0; i < v.size ()/2; ++ i)
        v (2*i) = i+10;
    std::cout << v << std::endl;
}
```

13 Day 16: Boost Continued

OPEN Boost Document

13.1 cu_boost_ublas_vector_expressions_conj_etc.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<std::complex<double> > v (3);
    for (unsigned i = 0; i < v.size (); ++ i)
        v (i) = std::complex<double> (i, i);

    std::cout << - v << std::endl;
    std::cout << conj (v) << std::endl;
    std::cout << real (v) << std::endl;
    std::cout << imag (v) << std::endl;
    std::cout << trans (v) << std::endl;
    std::cout << herm (v) << std::endl;
}
```

13.2 cv_boost_ublas_vector_expressions_binary.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v1 (3), v2 (3);
    for (unsigned i = 0; i < std::min (v1.size (), v2.size ()); ++ i)
        v1 (i) = v2 (i) = i;

    std::cout << v1 + v2 << std::endl;
    std::cout << v1 - v2 << std::endl;
}
```

13.3 cw_boost_ublas_vector_expressions_outer_prod.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v1 (3), v2 (3);
    for (unsigned i = 0; i < std::min (v1.size (), v2.size ()); ++ i)
        v1 (i) = v2 (i) = i;

    std::cout << outer_prod (v1, v2) << std::endl;
}
```

13.4 cx_boost_ublas_vector_expressions_scalar_multi.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/vector.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v (3);
    for (unsigned i = 0; i < v.size (); ++ i)
        v (i) = i;

    std::cout << 2.0 * v << std::endl;
    std::cout << v * 2.0 << std::endl;
}
```

13.5 cy_boost_ublas_vector_expressions_reductions.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/vector.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v (3);
    for (unsigned i = 0; i < v.size (); ++ i)
        v (i) = i;

    std::cout << sum (v) << std::endl;
    std::cout << norm_1 (v) << std::endl;
    std::cout << norm_2 (v) << std::endl;
    std::cout << norm_inf (v) << std::endl;
    std::cout << index_norm_inf (v) << std::endl;
}
```

13.6 cz_boost_ublas_vector_expressions_inner_prod.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/vector.hpp>

int main () {
    using namespace boost::numeric::ublas;
    vector<double> v1 (3), v2 (3);
    for (unsigned i = 0; i < std::min (v1.size (), v2.size ()); ++ i)
        v1 (i) = v2 (i) = i;

    std::cout << inner_prod (v1, v2) << std::endl;
}
```

13.7 da_boost_ublas_matrix_basic.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m (3, 3);
    for (unsigned i = 0; i < m.size1 (); ++ i)
        for (unsigned j = 0; j < m.size2 (); ++ j)
            m (i, j) = 3 * i + j;
    std::cout << m << std::endl;
}
```

13.8 db_boost_ublas_matrix_special.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    {
    identity_matrix<double> m (3);
    std::cout << "Identity:" << std::endl;
    std::cout << m << std::endl;
    }

    {
    zero_matrix<double> m (3, 3);
    std::cout << "Zero:" << std::endl;
    std::cout << m << std::endl;
    }

    {
    scalar_matrix<double> m (3, 3);
    std::cout << "Scalar:" << std::endl;
    std::cout << m << std::endl;
    }
}
```

13.9 dc_boost_ublas_triangular_matrix.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/triangular.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    triangular_matrix<double, lower> ml (3, 3);
    for (unsigned i = 0; i < ml.size1 (); ++ i)
        for (unsigned j = 0; j <= i; ++ j)
            ml (i, j) = 3 * i + j;
    std::cout << ml << std::endl;
    triangular_matrix<double, upper> mu (3, 3);
    for (unsigned i = 0; i < mu.size1 (); ++ i)
        for (unsigned j = i; j < mu.size2 (); ++ j)
            mu (i, j) = 3 * i + j;
    std::cout << mu << std::endl;
}
```

13.10 dd_boost_ublas_symmetric_matrix.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/symmetric.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    symmetric_matrix<double, lower> ml (3, 3);
    for (unsigned i = 0; i < ml.size1 (); ++ i)
        for (unsigned j = 0; j <= i; ++ j)
            ml (i, j) = 3 * i + j;
    std::cout << ml << std::endl;
    symmetric_matrix<double, upper> mu (3, 3);
    for (unsigned i = 0; i < mu.size1 (); ++ i)
        for (unsigned j = i; j < mu.size2 (); ++ j)
            mu (i, j) = 3 * i + j;
    std::cout << mu << std::endl;
}
```

13.11 de_boost_ublas_hermitian_matrix.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/hermitian.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    hermitian_matrix<std::complex<double>, lower> ml (3, 3);
    for (unsigned i = 0; i < ml.size1 (); ++ i) {
        for (unsigned j = 0; j < i; ++ j)
            ml (i, j) = std::complex<double> (3 * i + j, 3 * i + j);
        ml (i, i) = std::complex<double> (4 * i, 0);
    }
    std::cout << ml << std::endl;
    hermitian_matrix<std::complex<double>, upper> mu (3, 3);
    for (unsigned i = 0; i < mu.size1 (); ++ i) {
        mu (i, i) = std::complex<double> (4 * i, 0);
        for (unsigned j = i + 1; j < mu.size2 (); ++ j)
            mu (i, j) = std::complex<double> (3 * i + j, 3 * i + j);
    }
    std::cout << mu << std::endl;
}
```

13.12 df_boost_ublas_banded_matrix.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/banded.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    banded_matrix<double> m (3, 3, 1, 1);
    for (signed i = 0; i < signed (m.size1 ()); ++ i)
        for (signed j = std::max (i - 1, 0); j < std::min (i + 2, signed (m.size2 ()
            m (i, j) = 3 * i + j;
    std::cout << m << std::endl;
}
```

13.13 dg_boost_ublas_sparse_matrix.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix_sparse.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    {
        mapped_matrix<double> m (3, 3, 3 * 3);
        for (unsigned i = 0; i < m.size1 (); ++ i)
            for (unsigned j = 0; j < m.size2 (); ++ j)
                m (i, j) = 3 * i + j;
        std::cout << m << std::endl;
    }
    {
        compressed_matrix<double> m (3, 3, 3 * 3);
        for (unsigned i = 0; i < m.size1 (); ++ i)
            for (unsigned j = 0; j < m.size2 (); ++ j)
                m (i, j) = 3 * i + j;
        std::cout << m << std::endl;
    }
    {
        coordinate_matrix<double> m (3, 3, 3 * 3);
        for (unsigned i = 0; i < m.size1 (); ++ i)
            for (unsigned j = 0; j < m.size2 (); ++ j)
                m (i, j) = 3 * i + j;
        std::cout << m << std::endl;
    }
}
```

13.14 dh_boost_ublas_matrix_expressions_conj_etc.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<std::complex<double> > m (3, 3);
    for (unsigned i = 0; i < m.size1 (); ++ i)
        for (unsigned j = 0; j < m.size2 (); ++ j)
            m (i, j) = std::complex<double> (3 * i + j, 3 * i + j);

    std::cout << - m << std::endl;
    std::cout << conj (m) << std::endl;
    std::cout << real (m) << std::endl;
    std::cout << imag (m) << std::endl;
    std::cout << trans (m) << std::endl;
    std::cout << herm (m) << std::endl;
}
```

13.15 di_boost_ublas_matrix_expressions_binary.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m1 (3, 3), m2 (3, 3);
    for (unsigned i = 0; i < std::min (m1.size1 (), m2.size1 ()); ++ i)
        for (unsigned j = 0; j < std::min (m1.size2 (), m2.size2 ()); ++ j)
            m1 (i, j) = m2 (i, j) = 3 * i + j;

    std::cout << m1 + m2 << std::endl;
    std::cout << m1 - m2 << std::endl;
}
```

13.16 dj_boost_ublas_matrix_expressions_scalar_multi.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m (3, 3);
    for (unsigned i = 0; i < m.size1 (); ++ i)
        for (unsigned j = 0; j < m.size2 (); ++ j)
            m (i, j) = 3 * i + j;

    std::cout << 2.0 * m << std::endl;
    std::cout << m * 2.0 << std::endl;
}
```

13.17 dk_boost_ublas_matrix_expressions_matrix_vector_multi.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m (3, 3);
    vector<double> v (3);
    for (unsigned i = 0; i < std::min (m.size1 (), v.size ()); ++ i) {
        for (unsigned j = 0; j < m.size2 (); ++ j)
            m (i, j) = 3 * i + j;
        v (i) = i;
    }

    std::cout << prod (m, v) << std::endl;
    std::cout << prod (v, m) << std::endl;
}
```

13.18 dl_boost_ublas_matrix_expressions_matrix_vector_triangular_solver.c

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/triangular.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m (3, 3);
    vector<double> v (3);
    for (unsigned i = 0; i < std::min (m.size1 (), v.size ()); ++ i) {
        for (unsigned j = 0; j <= i; ++ j)
            m (i, j) = 3 * i + j + 1;
        v (i) = i;
    }

    std::cout << solve (m, v, lower_tag ()) << std::endl;
    std::cout << solve (v, m, lower_tag ()) << std::endl;
}
```

13.19 dm_boost_ublas_matrix_expressions_matrix_matrix_multi.cpp

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/matrix.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m1 (3, 3), m2 (3, 3);
    for (unsigned i = 0; i < std::min (m1.size1 (), m2.size1 ()); ++ i)
        for (unsigned j = 0; j < std::min (m1.size2 (), m2.size2 ()); ++ j)
            m1 (i, j) = m2 (i, j) = 3 * i + j;

    std::cout << prod (m1, m2) << std::endl;
}
```

13.20 dn_boost_ublas_matrix_expressions_matrix_matrix_triangular_solver

```
/* program to illustrate the use of boost::numeric::ublas
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-14
 *
 */

#include <boost/numeric/ublas/triangular.hpp>
#include <boost/numeric/ublas/io.hpp>

int main () {
    using namespace boost::numeric::ublas;
    matrix<double> m1 (3, 3), m2 (3, 3);
    for (unsigned i = 0; i < std::min (m1.size1 (), m2.size1 ()); ++ i)
        for (unsigned j = 0; j <= i; ++ j)
            m1 (i, j) = m2 (i, j) = 3 * i + j + 1;

    std::cout << solve (m1, m2, lower_tag ()) << std::endl;
}
```