C++ for Scientific Computation

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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;
}
```

14 Day 17: Boost Continued

OPEN Boost Document

14.1 do_mpi.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <mpi.h>
#include <iostream>

int main(int argc, char* argv[])
{
  MPI_Init(&argc, &argv);

  int rank;
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  if (rank == 0) {
    int value = 17;
    int result = MPI_Send(&value, 1, MPI_INT, 1, 0, MPI_COMM_WORLD);
    if (result == MPI_SUCCESS)
      std::cout << "Rank 0 OK!" << std::endl;
  } else if (rank == 1) {
    int value;
    int result = MPI_Recv(&value, 1, MPI_INT, 0, 0, MPI_COMM_WORLD,
                          MPI_STATUS_IGNORE);
    if (result == MPI_SUCCESS && value == 17)
      std::cout << "Rank 1 OK!" << std::endl;
  }
  MPI_Finalize();
  return 0;
}
```

14.2 dp_boost_mpi_1.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * compile command:
 * mpic++ -I /home/rajeev/software/general/boost_1_53_0
 * dp_boost_mpi_1.cpp -lboost_mpi
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi/environment.hpp>
#include <boost/mpi/communicator.hpp>
#include <iostream>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;
  std::cout << "I am process " << world.rank() << " of " << world.size()
            << "." << std::endl;
  return 0;
}
```

14.3 dq_boost_mpi_point_to_point.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * compile command:
 *  mpic++ dq_boost_mpi_point_to_point.cpp -lboost_mpi
 *  -lboost_serialization
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <string>
#include <boost/serialization/string.hpp>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  if (world.rank() == 0) {
    world.send(1, 0, std::string("Hello"));
    std::string msg;
    world.recv(1, 1, msg);
    std::cout << msg << "!" << std::endl;
  } else {
    std::string msg;
    world.recv(0, 0, msg);
    std::cout << msg << ", ";
    std::cout.flush();
    world.send(0, 1, std::string("world"));
  }

  return 0;
}
```

14.4 dr_boost_mpi_non_blocking.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <string>
#include <boost/serialization/string.hpp>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  if (world.rank() == 0) {
    mpi::request reqs[2];
    std::string msg, out_msg = "Hello";
    reqs[0] = world.isend(1, 0, out_msg);
    reqs[1] = world.irecv(1, 1, msg);
    mpi::wait_all(reqs, reqs + 2);
    std::cout << msg << "!" << std::endl;
  } else {
    mpi::request reqs[2];
    std::string msg, out_msg = "world";
    reqs[0] = world.isend(0, 1, out_msg);
    reqs[1] = world.irecv(0, 0, msg);
    mpi::wait_all(reqs, reqs + 2);
    std::cout << msg << ", ";
  }

  return 0;
}
```

14.5 ds_boost_mpi_broadcast.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <string>
#include <boost/serialization/string.hpp>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  std::string value;
  if (world.rank() == 0) {
    value = "Hello, World!";
  }

  broadcast(world, value, 0);

  std::cout << "Process #" << world.rank() << " says " << value
            << std::endl;
  return 0;
}
```

14.6 dt_boost_mpi_gather.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <vector>
#include <cstdlib>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  std::srand(time(0) + world.rank());
  int my_number = std::rand();
  if (world.rank() == 0) {
    std::vector<int> all_numbers;
    gather(world, my_number, all_numbers, 0);
    for (int proc = 0; proc < world.size(); ++proc)
      std::cout << "Process #" << proc << " thought of "
                << all_numbers[proc] << std::endl;
  } else {
    gather(world, my_number, 0);
  }

  return 0;
}
```

14.7 du_boost_mpi_reduce.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <cstdlib>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  std::srand(time(0) + world.rank());
  int my_number = std::rand();

  if (world.rank() == 0) {
    int minimum;
    reduce(world, my_number, minimum, mpi::minimum<int>(), 0);
    std::cout << "The minimum value is " << minimum << std::endl;
  } else {
    reduce(world, my_number, mpi::minimum<int>(), 0);
  }

  return 0;
}
```

14.8 dv_boost_mpi_reduce_2.cpp

```
/* program to illustrate the use of boost::mpi
 *
 * example taken from boost document
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/mpi.hpp>
#include <iostream>
#include <string>
#include <functional>
#include <boost/serialization/string.hpp>
namespace mpi = boost::mpi;

int main(int argc, char* argv[])
{
  mpi::environment env(argc, argv);
  mpi::communicator world;

  std::string names[10] = { "zero ", "one ", "two ", "three ",
                            "four ", "five ", "six ", "seven ",
                            "eight ", "nine " };

  std::string result;
  reduce(world,
         world.rank() < 10? names[world.rank()]
                          : std::string("many "),
         result, std::plus<std::string>(), 0);

  if (world.rank() == 0)
    std::cout << "The result is " << result << std::endl;

  return 0;
}
```

14.9 dw_boost_python_hello_world.cpp

```
/* program to illustrate the use of boost::python
 *
 * example taken from boost document
 *
 * compile command:
 *  g++ -shared -fPIC -o a.so dw_boost_python_hello_world.cpp -I
 *  /usr/include/python2.7 -lpython2.7 -lboost_python
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <Python.h>
#include <boost/python.hpp>

char const* greet()
{
   return "hello, world";
}

BOOST_PYTHON_MODULE(a)
{
    using namespace boost::python;
    def("greet", greet);
}
```

14.10 dx_boost_python_exposing_classes.cpp

```
/* program to illustrate the use of boost::python
 *
 * example taken from boost document
 *
 * compile command:
 *  g++ -shared -fPIC -o a.so dx_boost_python_exposing_classes.cpp -I
 *  /usr/include/python2.7 -lpython2.7 -lboost_python
 *
 *
 * Rajeev Singh
 * 2013-04-15
 *
 */

#include <boost/python.hpp>
using namespace boost::python;

struct World
{
    void set(std::string msg) { this->msg = msg; }
    std::string greet() { return msg; }
    std::string msg;
};

BOOST_PYTHON_MODULE(a)
{
    class_<World>("World")
        .def("greet", &World::greet)
        .def("set", &World::set)
    ;
}
```

15 Day 18: MTL

Open MTL Document

15.1 dy_mtl_vector1.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: vector1.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    // Define dense vector of doubles with 10 elements all set to 0.0.
    dense_vector<double>   v(20, 0.0);

    // Set element 7 to 3.0.
    v[7]= 3.0;

    std::cout << "v is " << v << "\n";
    return 0;
}
```

15.2 dz_mtl_vector2.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: vector2.cpp

#include <complex>
#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    // Define dense vector of complex with 7 elements.
    dense_vector<std::complex<float>, mtl::vector::parameters<tag::row_major> >
v(7);

    // Set all elements to 3+2i
    v= std::complex<float>(3.0, 2.0);
    std::cout << "v is " << v << "\n";

    // Set all elements to 5+0i
    v= 5.0;
    std::cout << "v is " << v << "\n";

    v= 6;
    std::cout << "v is " << v << "\n";

    return 0;
}
```

15.3 ea_mtl_dense2D.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: dense2D.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    // A is a row-major matrix
    dense2D<double>               A(10, 10);

    // Matrices are not initialized by default
    A= -5.0;

    // Assign a value to a matrix element
    A(2, 3)= 7.0;

    // You can also use a more C-like notation
    A[2][4]= 3.0;

    std::cout << "A is \n" << A << "\n";

    // B is a column-major matrix
    dense2D<float, matrix::parameters<tag::col_major> > B(10, 10);

    // Assign the identity matrix times 3 to B
    B= 3;
    std::cout << "B is \n" << B << "\n";

    return 0;
}
```

15.4 eb_mtl_morton_dense.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: morton_dense.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    // Z-order matrix
    morton_dense<double, recursion::morton_z_mask>  A(10, 10);

    A= 0;
    A(2, 3)= 7.0;
    A[2][4]= 3.0;
    std::cout << "A is \n" << A << "\n";

    // B is an N-order matrix with column-major 4x4 blocks, see paper
    morton_dense<float, recursion::doppled_4_col_mask> B(10, 10);

    // Assign the identity matrix times 3 to B
    B= 3;
    std::cout << "B is \n" << B << "\n";

    return 0;
}
```

15.5 ec_mtl_compressed2D.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: compressed2D.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    // CRS matrix
    compressed2D<double>   A(12, 12);

    // Laplace operator discretized on a 3x4 grid
    matrix::laplacian_setup(A, 3, 4);
    std::cout << "A is \n" << A;

    // Element access is allowed for reading
    std::cout << "A[3][2] is " << A[3][2] << "\n\n";
    std::cout << "A[3][1] is " << A[3][1] << "\n\n";

    // CCS matrix
    compressed2D<float, matrix::parameters<tag::col_major> > B(10, 10);

    // Assign the identity matrix times 3 to B
    B= 3;
    std::cout << "B is \n" << B << "\n";

    return 0;
}
```

15.6 ed_mtl_element_structure.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace std;
int main(int, char**)
{
    typedef double value_type;
    typedef int    size_type;
    const int nb_elements= 6, nb_nodes= 12;

    value_type array[][4]= {{2, 3,   4,   5},
                            {4, 10, 13,  16},
                            {6, 25, 38,  46},
                            {8, 32, 77, 100}};
    mtl::dense2D<value_type>   E_mat(array);

    std::cout<<"E_mat=\n"<< E_mat <<"\n";

    mtl::matrix::element_structure<value_type> A;

    typedef mtl::matrix::element<value_type>    element_type;
    element_type* elements = new element_type[nb_elements];

    mtl::dense_vector<size_type>  index_a(4, 0),
                                  index_b(4, 0),
                                  index_c(4, 0),
                                  index_d(4, 0),
                                  index_e(4, 0),
                                  index_f(4, 0);

    // construct nodes for every element
    index_a[0]= 0; index_a[1]= 1; index_a[2]= 4; index_a[3]= 5;
    index_b= index_a + 1;
    index_c= index_a + 2;
    index_d= index_a + 4;
    index_e= index_a + 5;
    index_f= index_a + 6;

    //construct the 6 elements from the example grid
    element_type a(0, index_a, E_mat);
    element_type b(1, index_b, E_mat);
    element_type c(2, index_c, E_mat);
    element_type d(3, index_d, E_mat);
    element_type e(4, index_e, E_mat);
```

```
    element_type f(5, index_f, E_mat);

    //construct neighborhood information for each element
    a.add_neighbors(&b, &d, &e);
    b.add_neighbors(&a, &c, &d, &e, &f);
    c.add_neighbors(&a, &b, &e);
    d.add_neighbors(&a, &b, &e);
    e.add_neighbors(&a, &b, &c, &d, &f);
    f.add_neighbors(&b, &c, &e);

    std::cout<< "a=" << a << "\n";

    //construct array of elements
    elements[0]=a;
    elements[1]=b;
    elements[2]=c;
    elements[3]=d;
    elements[4]=e;
    elements[5]=f;

    //construct element_structure from the 6 single elements
    A.consume(nb_elements, nb_nodes, elements);
    mtl::dense_vector<value_type> x(nb_nodes, 1.0), test(A * x);

    std::cout<< "test="<< test << "\n";

    return 0;
}
```

15.7 ee_mtl_multi_vector.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: multi_vector.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef dense_vector<double>   Vector;

    Vector                        v(2, 3.4), w(3, 2.5);
    mtl::multi_vector<Vector>     A(2, 3);
    dense2D<double>               B(2,2), C(3,2), D(3,3);

    // Initialize matrices
    A= 3.0; B= 4.0; C= 5.0; D= 6.0;

    std::cout << "A = " << A << std::endl;
    // vector= multi_vector * vector
    v= A * w;
    std::cout << "v = " << v << std::endl;

    // vector= transposed multi_vector * vector
    w= trans(A) * v;
    std::cout << "w = " << w << std::endl;

    // vector= matrix * vector
    v= B * A.vector(1);
    std::cout << "v = " << v << std::endl;

    // vector= matrix * vector
    A.vector(0)= B * A.vector(1);
    std::cout << "A.vector(0) = " << A.vector(0) << std::endl;

    // Orthogonalize multi_vectorq
    A(0,0) = 1;
    orth(A);
    std::cout << "A = " << A << std::endl;

    return 0;
}
```

15.8 ef_mtl_insert.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: insert.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace mtl;

template <typename Matrix>
void fill(Matrix& m)
{
    // Matrices are not initialized by default
    m= 0.0;

    // Create inserter for matrix m
    matrix::inserter<Matrix> ins(m);

    // Insert value in m[0][0]
    ins[0][0] << 2.0;
    ins[1][2] << 0.5;
    ins[2][1] << 3.0;

    // Destructor of ins sets final state of m
}

template <typename Matrix>
void modify(Matrix& m)
{
    // Type of m's elements
    typedef typename Collection<Matrix>::value_type value_type;

    // Create inserter for matrix m
    // Existing values are not overwritten but inserted
    matrix::inserter<Matrix, update_plus<value_type> > ins(m, 3);

    // Increment value in m[0][0]
    ins[0][0] << 1.0;

    // Elements that doesn't exist (in sparse matrices) are inserted
    ins[1][1] << 2.5;
    ins[2][1] << 1.0;
    ins[2][2] << 4.0;

    // Destructor of ins sets final state of m
}
```

```
int main(int, char**)
{
    // Matrices of different types
    compressed2D<double>              A(3, 3);
    dense2D<double>                   B(3, 3);
    morton_dense<float, morton_mask>  C(3, 3);

    // Fill the matrices generically
    fill(A); fill(B); fill(C);
    std::cout << "A is \n" << A << "\nB is \n" << B << "\nC is \n" << C;

    // Modify the matrices generically
    modify(A); modify(B); modify(C);
    std::cout << "\n\nAfter modification:\nA is \n" << A
              << "\nB is \n" << B << "\nC is \n" << C;

    return 0;
}
```

15.9 eg_mtl_insert_scope.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// Filename: insert_scope.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace mtl;

int main(int, char**)
{
    compressed2D<double>              A(3, 3);
    //{
        matrix::inserter<compressed2D<double> > ins(A);
        ins[0][0] << 2.0;
        ins[1][2] << 0.5;
        ins[2][1] << 3.0;
    //} // ins is destroyed here

    std::cout << "A is \n" << A;  // we can access A now

    return 0;
}
```

15.10 eh_mtl_element_matrix.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: element_matrix.cpp

#include <iostream>
#include <vector>
#include <boost/numeric/mtl/mtl.hpp>

using namespace mtl;

template <typename Matrix>
void fill(Matrix& m)
{
    // Matrices are not initialized by default
    m= 0.0;

    // Type of m's elements
    typedef typename Collection<Matrix>::value_type value_type;

    // Create inserter for matrix m
    // Existing values are not overwritten but inserted
    matrix::inserter<Matrix, update_plus<value_type> > ins(m, 3);

    // Define element matrix (array)
    double m1[2][2]= {{1.0, -.4}, {-0.5, 2.0}};

    // Corresponding indices of the elements
    std::vector<int> v1(2);
    v1[0]= 1; v1[1]= 3;

    // Insert element matrix
    ins << element_array(m1, v1);

    // Insert same array with different indices
    v1[0]= 0; v1[1]= 2;
    ins << element_array(m1, v1);

    // Use element matrix type with dynamic size
    dense2D<double> m2(2, 3);
    m2[0][0]= 1; m2[0][1]= 0.2; m2[0][2]= 0.1;
    m2[1][0]= 2; m2[1][1]= 1.2; m2[1][2]= 1.1;

    // Vector for column indices
    dense_vector<int> v2(3);
    // Indices can be out of order
    v2[0]= 4; v2[1]= 1; v2[2]= 3;
```

```
    // Use element_matrix and separate vectors for row and column indices
    ins << element_matrix(m2, v1, v2);
}

int main(int, char**)
{
    // Matrices of different types
    compressed2D<double>              A(5, 5);
    dense2D<double>                   B(5, 5);
    morton_dense<float, morton_mask>  C(5, 5);

    // Fill the matrices generically
    fill(A); fill(B); fill(C);
    std::cout << "A is \n" << with_format(A, 4, 3)
              << "\nB is \n" << with_format(B, 4, 3)
              << "\nC is \n" << with_format(C, 4, 3);

    return 0;
}
```

15.11 ei_mtl_insert_class_expensive.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// Filename: insert_class_expensive.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace mtl;

class world_matrix
{
  public:
    world_matrix(unsigned nrows, unsigned ncols) : A(nrows, ncols) {}

    void add_entry(unsigned row, unsigned col, double value)
    {
        // Extremely expensive -> must not be done
        matrix::inserter<compressed2D<double>, update_plus<double> > ins(A);
        ins[row][col] << value;
    }

    friend inline std::ostream& operator<<(std::ostream& os, const world_matrix& w)
    { return os << w.A; }

  private:
    compressed2D<double>              A;
};


int main(int, char**)
{
    world_matrix              A(3, 3);

    A.add_entry(0, 0, 2.0);
    A.add_entry(1, 2, 0.5);
    A.add_entry(2, 1, 3.0);

    std::cout << "A is \n" << A;  // we can access A now

    return 0;
}
```

16 Day 19: MTL Continued

Open MTL Document

16.1 ej_mtl_insert_scope.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// Filename: insert_scope.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace mtl;

class world_matrix
{
    typedef matrix::inserter<compressed2D<double>, update_plus<double> > inserter_ty
  public:
    world_matrix(unsigned nrows, unsigned ncols) : A(nrows, ncols), ins(0) {}

    void add_entry(unsigned row, unsigned col, double value)
    {  (*ins)[row][col] << value;    }

    void start_insertion() // must be called before first insertion
    { if (!ins) ins= new inserter_type(A); }

    void finish_insertion() // must be called before first usage
    {
        if (ins) {
            delete ins;
            ins= 0;
        }
    }

    friend inline std::ostream& operator<<(std::ostream& os, const world_matrix& w)
    { return os << w.A; }

  private:
    compressed2D<double>      A;
    inserter_type*            ins;
};
```

```
int main(int, char**)
{
    world_matrix               A(3, 3);

    A.start_insertion();
    A.add_entry(0, 0, 2.0);
    A.add_entry(1, 2, 0.5);
    A.add_entry(2, 1, 3.0);
    A.finish_insertion();

    std::cout << "A is \n" << A;  // we can access A now

    return 0;
}
```

16.2 ek_mtl_array_initialization.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: array_initialization.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double array[][4]= {{3, 7.2,   0, 6},
                        {2, 4.444, 5, 3},
                        {1, 7,     9, 2}};

    dense2D<double> A(array);

    std::cout << "A = \n" << A << "\n";

    return 0;
}
```

16.3 el_mtl_vector_expr.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: vector_expr.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         u(10), v(10);
    dense_vector<double>          w(10), x(10, 4.0);

    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, 10-i), w[i]= 2 * i + 2;

    u= v + w + x;
    std::cout << "u is " << u << "\n";

    u-= 3 * w;
    std::cout << "u is " << u << "\n";

    u*= 6 ;
    std::cout << "u is " << u << "\n";

    u/= 2;
    std::cout << "u is " << u << "\n";

    u+= dot(v, w) * w + 4.0 * v + 2 * w;
    std::cout << "u is " << u << "\n";

    std::cout << "i * w is " << cdouble(0,1) * w << "\n";

    return 0;
}
```

16.4 em_mtl_rich_vector_expr.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

// File: rich_vector_expr.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         u(10), v(10);
    dense_vector<double>          w(10), x(10, 4.0);

    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, 10-i), w[i]= 2 * i + 2;

    // Increment w by x
    // and assign the sum of--the incremented--w and v to u
    u= v + (w+= x);
    std::cout << "u is " << u << "\n";

    // w= w * 3; x= 2; v= v + w + x; u= u + v;
    u+= v+= (w*= 3) + (x= 2);
    std::cout << "u is " << u << "w is " << w << "\n";

    return 0;
}
```

16.5 en_mtl_matrix_expressions1.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    const unsigned n= 10;
    compressed2D<double>                          A(n, n);
    dense2D<int, matrix::parameters<col_major> > B(n, n);
    morton_dense<double, 0x555555f0>              C(n, n), D(n, n);

    matrix::laplacian_setup(A, 2, 5);
    matrix::hessian_setup(B, 1);
    matrix::hessian_setup(C, 2.0);
    matrix::hessian_setup(D, 3.0);

    D+= A - 2 * B + C;

    std::cout << "The matrices are: A=\n" << A << "B=\n" << B << "C=\n" << C << "D=\

    return 0;
}
```

16.6 eo_mtl_matrix_expressions2.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl; using namespace mtl::matrix;

    const unsigned n= 20;
    dense2D<double>                              A(n, n), B(n, n);
    morton_dense<double, doppled_64_row_mask>  C(n, n);

    hessian_setup(A, 3.0); hessian_setup(B, 1.0);
    hessian_setup(C, 2.0);

    // Corresponds to A= B * B;
    mult(B, B, A);

    A= B * B;    // use BLAS
    A= B * C;    // use recursion + tiling from MTL4

    A+= B * C;  // Increment A by the product of B and C
    A-= B * C;  // Likewise with decrement

    std::cout << "The matrices are: A=\n" << A << "B=\n" << B << "C=\n" << C;

    return 0;
}
```

16.7 ep_mtl_matrix_expressions3.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl; using namespace mtl::matrix;

    const unsigned n= 40;
    dense2D<double>                              A(n, n), B(n, n);
    morton_dense<double, doppled_64_row_mask>  C(n, n), D(n, n);

    hessian_setup(A, 3.0); hessian_setup(B, 1.0);
    hessian_setup(C, 2.0); hessian_setup(D, 11.0);

    A+= B * B + C * B - B * B * C * D;

    std::cout << "The matrices are: A=\n" << A << "B=\n" << B << "C=\n" << C << "D=\

    return 0;
}
```

16.8 eq_mtl_matrix_vector1.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl; using namespace mtl::matrix;

    const unsigned                  xd= 2, yd= 5, n= xd * yd;
    dense2D<double>                 A(n, n);
    compressed2D<double>            B(n, n);
    hessian_setup(A, 3.0); laplacian_setup(B, xd, yd);

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         v(n), w(n);
    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, n-i), w[i]= cdouble(i+n);

    v+= A * w;
    w= B * v;

    std::cout << "v is " << v << "\n";
    std::cout << "w is " << w << "\n";

    return 0;
}
```

16.9 er_mtl_matrix_vector2.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-16
 *
 */

#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl; using namespace mtl::matrix;

    const unsigned                  xd= 2, yd= 5, n= xd * yd;
    dense2D<double>                 A(n, n);
    laplacian_setup(A, xd, yd);
    dense_vector<double>            v(n), w(n, 7.0);

    // Scale A with 4 and multiply the scaled view with w
    v= 4 * A * w;
    std::cout << "v is " << v << "\n";

    // Scale w with 4 and multiply the scaled view with A
    v= A * (4 * w);
    std::cout << "v is " << v << "\n";

    // Scale both with 2 before multiplying
    v= 2 * A * (2 * w);
    std::cout << "v is " << v << "\n";

    // Scale v after the MVP
    v= A * w;
    v*= 4;
    std::cout << "v is " << v << "\n";

    return 0;
}
```

16.10 es_mtl_vector_norm.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// File: vector_norm.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         v(10000);

    // Initialize vector
    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, 10000-i);

    std::cout << "one_norm(v) is " << one_norm(v)<< "\n";

    std::cout << "two_norm(v) is " << two_norm(v)<< "\n";

    std::cout << "infinity_norm(v) is " << infinity_norm(v)<< "\n";

    // Unroll computation of two-norm to 6 independent statements
    std::cout << "two_norm<6>(v) is " << two_norm<6>(v)<< "\n";

    return 0;
}
```

16.11 et_mtl_matrix_norm.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    const unsigned n= 10;
    dense2D<float, matrix::parameters<col_major> > B(n, n);

    matrix::hessian_setup(B, 1.0);

    std::cout << "one_norm(B) is " << one_norm(B)<< "\n";
    std::cout << "infinity_norm(B) is " << infinity_norm(B)<< "\n";
    std::cout << "frobenius_norm(B) is " << frobenius_norm(B)<< "\n";

    return 0;
}
```

16.12 eu_mtl_vector_reduction.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// File: vector_reduction.cpp

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         v(100);

    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, 100-i);

    std::cout << "sum(v) is " << sum(v)<< "\n";

    std::cout << "product(v) is " <<  product(v)<< "\n";

    std::cout << "sum<6>(v) is " <<  sum<6>(v)<< "\n";

    return 0;
}
```

16.13 ev_mtl_vector_min_max.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// File: vector_min_max.cpp

#include <iostream>
#include <cmath>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using mtl::max; using std::pow; // to avoid possible ambiguity with ARPREC

    mtl::dense_vector<double>          v(100);

    for (unsigned i= 0; i < size(v); i++)
        v[i]= double(i+1) * pow(-1.0, int(i)); // Amb. in MSVC

    std::cout << "max(v) is " << max(v)<< "\n";

    std::cout << "min(v) is " <<  min(v)<< "\n";

    std::cout << "max<6>(v) is " <<  max<6>(v)<< "\n";

    return 0;
}
```

16.14 ew_mtl_dot_example.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// Filename: dot_example.cpp (part of MTL4)

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>  cdouble;
    dense_vector<cdouble>         v(10000), x(10, cdouble(3, 2));
    dense_vector<double>          w(10000);

    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, 10000-i), w[i]= 2 * i + 2;

    std::cout << "dot(v, w) is " << dot(v, w)<< "\n";

    std::cout << "dot<6>(v, w) is " <<  dot<6>(v, w)<< "\n";

    std::cout << "dot_real<6>(v, w) is " <<  dot_real<6>(v, w)<< "\n";

    std::cout << "conj(x) is " <<  conj(x)<< "\n";

    return 0;
}
```

16.15 ex_mtl_conj_trans_hermitian.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    typedef std::complex<double>      cdouble;
    const unsigned                    xd= 2, yd= 3, n= xd * yd;
    compressed2D<cdouble>             A(n, n);
    matrix::laplacian_setup(A, xd, yd);

    // Fill imaginary part of the matrix
    A*= cdouble(1, -1);
    std::cout << "A is\n" << A << "\n";
    std::cout << "A is\n" << with_format(A, 7, 1) << "\n";

    std::cout << "trace(A) is " << trace(A) << "\n\n";
    std::cout << "conj(A) is\n" << with_format(conj(A), 7, 2) << "\n";
    std::cout << "trans(A) is\n" << with_format(trans(A), 7, 1) << "\n";
    std::cout << "hermitian(A) is\n" << with_format(hermitian(A), 7, 1) << "\n";

    return 0;
}
```

17 Day 20: MTL Continued

Open MTL Document

17.1 ey_mtl_sub_matrices.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl; using mtl::iall;

    typedef std::complex<double>      cdouble;
    const unsigned                    xd= 2, yd= 5, n= xd * yd;
    dense2D<cdouble>                  A(n, n);
    matrix::laplacian_setup(A, xd, yd);

    // Fill imaginary part of the matrix
    A*= cdouble(1, -1);
    std::cout << "A is\n" << with_format(A, 7, 1) << "\n";

    std::cout << "sub_matrix(A, 2, 4, 1, 7) is\n"
              << with_format(sub_matrix(A, 2, 4, 1, 7), 7, 1) << "\n";

    //col-vector from matrix
    dense_vector<cdouble>   v_c(A[iall][0]);

    std::cout << "col-vector v_c is\n" << v_c << "\n";
    v_c[0] = 1;
    std::cout << "sub_matrix(A, 0, 2, 0, 7) is\n"
              << with_format(sub_matrix(A, 0, 2, 0, 7), 7, 1) << "\n";


    //row-vector from matrix
    dense_vector<cdouble, mtl::vector::parameters<tag::row_major> > v_r(A[0][iall]);

    std::cout << "row-vector v_r is\n" << v_r << "\n";

    //row-vector in matrix
    RowInMatrix<dense2D<cdouble> >::type v_r2(A[0][iall]);
```

```
    std::cout << "row-vector v_r2 is\n" << v_r2 << "\n";
    v_r2[0] = 1;
    std::cout << "sub_matrix(A, 0, 2, 0, 7) is\n"
              << with_format(sub_matrix(A, 0, 2, 0, 7), 7, 1) << "\n";

    //submatrix from matrix per begin and end of row and column
    dense2D<cdouble> B= sub_matrix(A, 2, 4, 1, 7);
    std::cout << "B is\n" << B << "\n";
    B[1][2]= 88;

    std::cout << "B is\n" << B << "\n";

    //submatrix from matrix per irange
    using mtl::irange;
    irange row(2, 4), col(1, 7);
    dense2D<cdouble> B1= A[row][col];

    std::cout << "B1 is\n" << B1 << "\n";

    //scalar from matrix
    cdouble C= A[1][1];

    std::cout << "C is\n" << C << "\n";

    return 0;
}
```

17.2 ez_mtl_permutation.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double           array[][3]= {{1., 2., 3.}, {4., 5., 6.}, {7., 8., 9.}};
    dense2D<double>  A(array), A2, A3;

    // Creating a permutation matrix from a vector (or an array respectively)
    int indices[]= {1, 2, 0};
    matrix::traits::permutation<>::type P= matrix::permutation(indices);
    std::cout << "\nP =\n" << P;

    // Permutating rows
    A2= P * A;
    std::cout << "\nP * A =\n" << A2;

    // Permutating columns
    A3= A2 * trans(P);
    std::cout << "\nA2 * trans(P) =\n" << A3;

    dense_vector<double> v(array[2]), w(P * v);
    std::cout << "\nP * v =\n" << w << "\n";

    return 0;
}
```

17.3 fa_mtl_reordering.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double           array[][3]= {{1., 2., 3.}, {4., 5., 6.}, {7., 8., 9.}};
    dense2D<double>  A(array), B2, B3;

    // Creating a reordering matrix from a vector (or an array respectively)
    int indices[]= {1, 0};
    matrix::traits::reorder<>::type R= matrix::reorder(indices);
    std::cout << "\nR =\n" << R;

    // Reorder rows
    B2= R * A;
    std::cout << "\nR * A =\n" << B2;

    // Reorder columns
    B3= B2 * trans(R);
    std::cout << "\nB2 * trans(R) =\n" << B3;

    dense_vector<double> v(array[2]), w(R * v);
    std::cout << "\nR * v =\n" << w << "\n";

    return 0;
}
```

17.4 fb_mtl_reordering2.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double           array[][3]= {{1., 2., 3.}, {4., 5., 6.}, {7., 8., 9.}};
    dense2D<double>  A(array), B2, B3;

    // Creating a reordering matrix from a vector (or an array respectively)
    int indices[]= {2, 1, 1, 2};
    matrix::traits::reorder<>::type R= matrix::reorder(indices);
    std::cout << "\nR =\n" << R;

    // Reorder rows
    B2= R * A;
    std::cout << "\nR * A =\n" << B2;

    // Reorder columns
    B3= B2 * trans(R);
    std::cout << "\nB2 * trans(R) =\n" << B3;

    dense_vector<double> v(array[2]), w(R * v);
    std::cout << "\nR * v =\n" << w << "\n";

    return 0;
}
```

17.5 fc_mtl_reordering3.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double            array[][3]= {{1., 0., 3.},
                                   {4., 0., 6.},
                                   {7., 0., 9.},
                                   {0., 0., 0.}};
    dense2D<double>  A(array), B2, B3;

    // Creating a compression (reordering) matrix from a vector
    // (or an array respectively)
    int non_zero_rows[]= {0, 1, 2}, non_zero_columns[]= {0, 2};
    // To be sure, we give the number of columns for a consistent size!
    matrix::traits::reorder<>::type RR= matrix::reorder(non_zero_rows, 4),
                                    RC= matrix::reorder(non_zero_columns);
    std::cout << "A =\n" << A << "\nRR =\n" << RR << "\nRC =\n" << RC;

    // Compress rows
    B2= RR * A;
    std::cout << "\nRR * A, i.e. compress row of A =\n" << B2;

    // Compress columns
    B3= B2 * trans(RC);
    std::cout << "\nB2 * trans(RC), i.e. compress columns of B2 =\n" << B3;

    // Decompress rows
    dense2D<double>  C1(trans(RR) * B3);
    std::cout << "\ntrans(RR) * B3, i.e. row decompression of B3 =\n" << C1;

    // Decompress columns
    dense2D<double>  C2(C1 * RC);
    std::cout << "\nC1 * RC, i.e. column decompression of C1 (should be A) =\n"
              << C2;

    return 0;
}
```

17.6 fd_mtl_indirection.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// Filename: matrix_indirect.cpp (part of MTL4) #include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace std;

int main(int, char**)
{
    typedef mtl::dense2D<double> matrix;
    matrix A(5, 3);
    hessian_setup(A, 1.0);

    mtl::iset rows, cols;
    rows= 2, 0, 3; cols= 2, 1;

    cout << "rows = " << rows << ", cols = " << cols << "\n"
         << "The sub-matrix A[{2, 0, 3}][{2, 1}] is\n" << A[rows][cols];

    mtl::matrix::indirect<matrix> B(A[rows][cols]);
    //B[0][0] = 10;
    cout << "B is\n" << B;
    cout << "A is\n" << A;

    return 0;
}
```

17.7 fe_mtl_upper.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double            array[][3]= {{1., 2., 3.}, {4., 5., 6.}, {7., 8., 9.}};
    dense2D<double>   A(array);

    std::cout << "\nupper(A) = \n" << upper(A);

    std::cout << "\nstrict_upper(A) = \n" << strict_upper(A);

    return 0;
}
```

17.8 ff_mtl_lower.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double           array[][3]= {{1., 2., 3.}, {4., 5., 6.}, {7., 8., 9.}};
    dense2D<double>  A(array), L, SL;

    L= lower(A);
    std::cout << "\nlower(A) = \n" << L;

    SL= strict_lower(A);
    std::cout << "\nstrict_lower(A) = \n" << SL;

    return 0;
}
```

17.9 fg_mtl_bands.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    double                 array[][5]= {{1., 2., 3., 4., 5.}, {4., 5., 6., 7., 8.},
                                        {7., 8., 9., 8., 7.}, {6., 5., 4., 3., 2.}};
    dense2D<double>        A(array), B;
    compressed2D<double>   T;

    B= bands(A, 1, 3);
    std::cout << "\nbands(A, 1, 3) = \n" << B;

    T= bands(A, -1, 2);
    std::cout << "\ntri_diagonal(A):= bands(A, -1, 2) = \n" << T;

    return 0;
}
```

17.10 fh_mtl_rank_one_and_two_update.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;
    typedef std::complex<double>  cdouble;

    const unsigned n= 8;
    dense2D<cdouble>              A(n, n);

    A= 3.0;

    dense_vector<cdouble>         v(n), w(n);
    for (unsigned i= 0; i < size(v); i++)
        v[i]= cdouble(i+1, n-i), w[i]= cdouble(i+n);

    rank_one_update(A, v, w);
    std::cout << "A after rank-one update is \n"
              << with_format(A, 9, 3) << "\n";

    A= 3.0;
    rank_two_update(A, v, w);
    std::cout << "A after rank-two update is \n"
              << with_format(A, 9, 3) << "\n";

    return 0;
}
```

17.11 fi_mtl_other.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    const unsigned n= 10;
    compressed2D<double>                              A(n, n);
    dense2D<float, matrix::parameters<col_major> > B(n, n);
    morton_dense<double, 0x55555555>                  C(n, n);
    morton_dense<double, 0x555555f0>                  D(n, n);

    matrix::hessian_setup(B, 1.0);
    matrix::hessian_setup(C, 2.0);
    matrix::hessian_setup(D, 3.0);

    std::cout << "one_norm(B) is " << one_norm(B)<< "\n";
    std::cout << "infinity_norm(B) is " << infinity_norm(B)<< "\n";
    std::cout << "frobenius_norm(B) is " << frobenius_norm(B)<< "\n";

    return 0;
}
```

17.12 fj_mtl_eigenvalue_example.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// Filename: eigenvalue_example.cpp (part of MTL4)

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int, char**)
{
    using namespace mtl;

    dense_vector<double>                    eig;

    double array[][4]= {{1,  1,   1,  0},
                        {1, -1,  -2,  0},
                        {1, -2,   1,  0},
                        {0,  0,   0, 10}};
    dense2D<double> A(array);
    std::cout << "A=\n" << A << "\n";

    eig= eigenvalue_symmetric(A,22);
    std::cout<<"eigenvalues  ="<< eig <<"\n";

    eig= 0;
    eig= qr_sym_imp(A);
    std::cout<<"eigenvalues  ="<< eig <<"\n";

    eig= 0;
    eig= qr_algo(A, 5);  // only 5 qr iterations (Q-R-changes)
    std::cout<<"eigenvalues  ="<< eig <<"\n";

    return 0;
}
```

18 Day 21: MTL Continued

Open MTL Document

18.1 fk_mtl_eigenvalue_example2.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// Filename: eigenvalue_example.cpp (part of MTL4)

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace std;
typedef mtl::matrix::dense2D<double> dMatrix;

int main() {
    dMatrix M1(3,3), M2(3,3), M3(3,3), M4(3,3);

    M1 = 2,0,0,
         1,1,0,
         0,1,3; //EWs: 1,2,3

    mtl::matrix::eigenvalue_solver<dMatrix> E1(M1);
    E1.setMaxIteration(10);
    E1.calc();
    cout << "M1(setting the number of iteraions): "
         << E1.get_eigenvalues() << "\n";

    M2 = 1,0,0,
         0,1,5,
         0,-2,3; //EWs: 1,2+3i,2-3i

    mtl::matrix::eigenvalue_solver<dMatrix> E2(M2);
    E2.setTolerance(1.0e-10);
    E2.calc();
    cout << "M2(providing tolerance): "
         << E2.get_eigenvalues() << "\n";

    M3 = -261, 209,  -49,
         -530, 422,  -98,
         -800, 631, -144; //EWs: 3,4,10
```

```
    mtl::matrix::eigenvalue_solver<dMatrix> E3(M3);
    E3.setMaxIteration(1);
    E3.setTolerance(1.0e-10);
    E3.calc();
    cout << "M3(providing both): "
         << E3.get_eigenvalues() << "\n";

    M4 = 1,-3,3,
         3,-5,3,
         6,-6,4; //EWs: -2,-2,4

    mtl::matrix::eigenvalue_solver<dMatrix> E4(M4);
    E4.calc();
    cout << "M4(with defaults): "
         << E4.get_eigenvalues() << "\n";

    // Creating the solver implicitly
    cout << "M4(with defaults): " << eigenvalues(M4) << "\n";

    return 0;
}
```

18.2 fl_mtl_qr_givens_example.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-17
 *
 */

// Filename: qr_givens_example.cpp (part of MTL4)

#include <boost/tuple/tuple.hpp>
#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace std;
typedef mtl::matrix::dense2D<double> dMatrix;

int main() {
    dMatrix M1(3,3), M2(3,3);


    M1 = 2,0,0,
         1,1,0,
         0,1,3; //EWs: 1,2,3

    mtl::matrix::qr_givens_solver<dMatrix> QR1(M1);
    QR1.setTolerance(1.0e-5);
    QR1.calc();
    cout << "M1(providing tolerance):\n Q: \n"  << QR1.getQ()
         << "\n R: \n" << QR1.getR() << "\n";
    M2 = -261, 209,  -49,
         -530, 422,  -98,
         -800, 631, -144; //EWs: 3,4,10

    mtl::matrix::qr_givens_solver<dMatrix> QR2(M2);
    QR2.calc();
    cout << "M2(with defaults):\n Q: \n"  << QR2.getQ()
         << "\n R: \n" << QR2.getR() << "\n";

    dMatrix Q2, R2;
    boost::tie(Q2, R2)= qr_givens(M2);
    cout << "M2(with defaults):\n Q: \n"  << Q2
         << "\n R: \n" << R2 << "\n";

    return 0;
}
```

18.3 fm_mtl_predefined_linear_solvers.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-18
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>
#include <boost/numeric/itl/itl.hpp>

using namespace mtl;
using namespace itl;

int main(int, char**)
{
    const int size = 40, N = size * size;
    typedef compressed2D<double>  matrix_type;

    // Set up a matrix 1,600 x 1,600 with 5-point-stencil
    matrix_type                   A(N, N);
    matrix::laplacian_setup(A, size, size);

    // Create an ILU(0) preconditioner
    pc::ilu_0<matrix_type>        P(A);

    // Set b such that x == 1 is solution; start with x == 0
    dense_vector<double>          x(N, 1.0), b(N);
    b= A * x; x= 0;

    // Termination criterion: r < 1e-6 * b or N iterations
    noisy_iteration<double>       iter(b, 500, 1.e-8);

    // Solve Ax == b with left preconditioner P
    bicgstab(A, x, b, P, iter);

    std::cout << x << std::endl;

    return 0;
}
```

18.4 fn_mtl_umfpack_solve_example.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * compile command:
 *  g++ -I /home/rajeev/software/linear_algebra/MTL-all-4.0.9140-Linux/usr/include
 *  fn_mtl_umfpack_solve_example.cpp
 *  -DMTL_HAS_UMFPACK -I /home/rajeev/software/general/julia/deps/SuiteSparse-4.1.0/
 *  -I /home/rajeev/software/general/julia/deps/SuiteSparse-4.1.0/UMFPACK/Include
 *  -I /home/rajeev/software/general/julia/deps/SuiteSparse-4.1.0/AMD/Include
 *  -L /home/rajeev/software/general/julia/usr/lib
 *  -lumfpack -lcholmod -lcolamd -lcamd -lccolamd -lamd -lopenblas -lrt
 *
 * run command:
 *  LD_LIBRARY_PATH=/home/rajeev/software/general/julia/usr/lib ./a.out
 *
 * Rajeev Singh
 * 2013-04-18
 *
 */

// Filename: umfpack_solve_example.cpp (part of MTL4)

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

using namespace std;

int main(int, char**)
{
#ifdef MTL_HAS_UMFPACK
    typedef mtl::compressed2D<double> matrix_type;

    matrix_type A(5, 5);
    A= 2.,  3.,  0.,  0.,  0.,
       3.,  0.,  4.,  0.,  6.,
       0., -1., -3.,  2.,  0.,
       0.,  0.,  1.,  0.,  0.,
       0.,  4.,  2.,  0.,  1.;
    crop(A);

    mtl::dense_vector<double>   x(5), b(5);
    b= 8., 45., -3., 3., 19.;
    mtl::dense_vector<double>   b2(2 * b);
    cout << "A = \n" << A << "b = " << b << "\n";

    // Factorize and solve
    umfpack_solve(A, x, b);
    cout << "\nA \\ b using umfpack_solve = " << x << "\n";

    // Define a solver object by internally factorizing A
    mtl::matrix::umfpack::solver<matrix_type> solver(A);
```

```
    // Solve A * x == b and b2 with the solver object
    solver(x, b);
    solver(x, b2);

    // Change one or more matrix entries while keeping the sparsity pattern
    A.lvalue(1, 2)= 5.0;

    // Compute a new factorization (relying on unchanged sparsity)
    solver.update_numeric();

    // If we change b accordingly we will get the same result
    b[1]= 48;
    solver(x, b);
    cout << "\nA \\ b after numeric update = " << x << "\n";

    // Change matrix's values and sparsity
    {
        mtl::matrix::inserter<matrix_type> ins(A);
        ins[3][4] << 2.;
    }
    cout << "\nA is now = \n" << A << "\n";

    // Perform a completely new factorization
    solver.update();

    b[3]= 13.;
    int status= solver(x, b);
    cout << "A \\ b after (complete) update = " << x << ", status is " << status <<

#endif
    return 0;
}
```

18.5 fo_mtl_mixed_complex.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-18
 *
 */

// Filename: mixed_complex.cpp (part of MTL4)

#include <complex>
#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>
//#include <boost/numeric/mtl/operation/extended_complex.hpp>

int main()
{
    std::complex<double>  z(2.0, 3.0);
    std::cout << "2 * z = " << 2 * z << '\n';
    std::cout << "2 + z = " << 2 + z << '\n';
    std::cout << "z / 2 = " << z / 2 << '\n';
    std::cout << "2 / z = " << 2 / z << '\n';
    std::cout << "2 - z = " << 2 - z << '\n';

    return 0;
}
```

18.6 fp_mtl_performance_tuning.cpp

```
/* program to illustrate the use of mtl
 *
 * example taken from mtl document
 *
 * Rajeev Singh
 * 2013-04-18
 *
 */

#include <iostream>
#include <boost/numeric/mtl/mtl.hpp>

int main(int , char**)
{
    using namespace mtl;
    typedef mtl::vector::parameters<tag::col_major,
            mtl::vector::fixed::dimension<2> > fvec_para;
    typedef matrix::parameters<tag::row_major,
            mtl::index::c_index, mtl::fixed::dimensions<2, 2> > fmat_para;

    dense2D<float, fmat_para>        A, B; // dimension not needed here
    dense_vector<float, fvec_para>   v, w; // here neither

    A= 2., 3.,
       4., 5.;
    v= 3., 4.;

    w= A * v; // Same syntax as dynamic size
    B= A * A;

    std::cout << "A * v is " << w << "\n\n";
    std::cout << "A * A is\n" << B;

    return 0;
}
```

19 Day 22: Eigen

Open Eigen Document

19.1 fq_eigen_first_program.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using Eigen::MatrixXd;

int main()
{
  MatrixXd m(2,2);
  m(0,0) = 3;
  m(1,0) = 2.5;
  m(0,1) = -1;
  m(1,1) = m(1,0) + m(0,1);
  std::cout << m << std::endl;
}
```

19.2 fr_eigen_matrix_vector.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;
using namespace std;

int main()
{
  MatrixXd m = MatrixXd::Random(3,3);
  m = (m + MatrixXd::Constant(3,3,1.2)) * 50;
  cout << "m =" << endl << m << endl;
  VectorXd v(3);
  v << 1, 2, 3;
  cout << "m * v =" << endl << m * v << endl;
}
```

19.3 fs_eigen_coefficient_accessors.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;

int main()
{
  MatrixXd m(2,2);
  m(0,0) = 3;
  m(1,0) = 2.5;
  m(0,1) = -1;
  m(1,1) = m(1,0) + m(0,1);
  std::cout << "Here is the matrix m:\n" << m << std::endl;
  VectorXd v(2);
  v(0) = 4;
  v(1) = v(0) - 1;
  std::cout << "Here is the vector v:\n" << v << std::endl;
}
```

19.4 ft_eigen_resizing.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;

int main()
{
  MatrixXd m(2,5);
  m.resize(4,3);
  std::cout << "The matrix m is of size "
            << m.rows() << "x" << m.cols() << std::endl;
  std::cout << "It has " << m.size() << " coefficients" << std::endl;
  VectorXd v(2);
  v.resize(5);
  std::cout << "The vector v is of size " << v.size() << std::endl;
  std::cout << "As a matrix, v is of size "
            << v.rows() << "x" << v.cols() << std::endl;
}
```

19.5 fu_eigen_addition_and_subtraction.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;

int main()
{
  Matrix2d a;
  a << 1, 2,
       3, 4;
  MatrixXd b(2,2);
  b << 2, 3,
       1, 4;
  std::cout << "a + b =\n" << a + b << std::endl;
  std::cout << "a - b =\n" << a - b << std::endl;
  std::cout << "Doing a += b;" << std::endl;
  a += b;
  std::cout << "Now a =\n" << a << std::endl;
  Vector3d v(1,2,3);
  Vector3d w(1,0,0);
  std::cout << "-v + w - v =\n" << -v + w - v << std::endl;
}
```

19.6 fv_eigen_scalar_multi_and_div.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;

int main()
{
  Matrix2d a;
  a << 1, 2,
       3, 4;
  Vector3d v(1,2,3);
  std::cout << "a * 2.5 =\n" << a * 2.5 << std::endl;
  std::cout << "0.1 * v =\n" << 0.1 * v << std::endl;
  std::cout << "Doing v *= 2;" << std::endl;
  v *= 2;
  std::cout << "Now v =\n" << v << std::endl;
}
```

19.7 fw_eigen_trans_and_conj.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace std;
using namespace Eigen;

int main() {
    {
    MatrixXcf a = MatrixXcf::Random(2,2);
    cout << "Here is the matrix a\n" << a << endl;

    cout << "Here is the matrix a^T\n" << a.transpose() << endl;

    cout << "Here is the conjugate of a\n" << a.conjugate() << endl;

    cout << "Here is the matrix a^*\n" << a.adjoint() << endl;
    }

    {
    Matrix2i a; a << 1, 2, 3, 4;
    cout << "Here is the matrix a:\n" << a << endl;

    //a = a.transpose(); // !!! do NOT do this !!!
    //cout << "and the result of the aliasing effect:\n" << a << endl;
    }

    {
    MatrixXf a(2,3); a << 1, 2, 3, 4, 5, 6;
    cout << "Here is the initial matrix a:\n" << a << endl;

    a.transposeInPlace();
    cout << "and after being transposed:\n" << a << endl;
    }

    return 0;
}
```

19.8 fx_eigen_mat_mat_and_mat_vec_multi.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;
int main()
{
  Matrix2d mat;
  mat << 1, 2,
         3, 4;
  Vector2d u(-1,1), v(2,0);
  std::cout << "Here is mat*mat:\n" << mat*mat << std::endl;
  std::cout << "Here is mat*u:\n" << mat*u << std::endl;
  std::cout << "Here is u^T*mat:\n" << u.transpose()*mat << std::endl;
  std::cout << "Here is u^T*v:\n" << u.transpose()*v << std::endl;
  std::cout << "Here is u*v^T:\n" << u*v.transpose() << std::endl;
  std::cout << "Let's multiply mat by itself" << std::endl;
  mat = mat*mat;
  std::cout << "Now mat is mat:\n" << mat << std::endl;
}
```

19.9 fy_eigen_dot_and_cross_prod.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace Eigen;
using namespace std;
int main()
{
  Vector3d v(1,2,3);
  Vector3d w(0,1,2);

  cout << "Dot product: " << v.dot(w) << endl;
  double dp = v.adjoint()*w; // automatic conversion of the inner product to a scal
  cout << "Dot product via a matrix product: " << dp << endl;
  cout << "Cross product:\n" << v.cross(w) << endl;
}
```

19.10 fz_eigen_basic_arithmetic_reduction.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace std;
int main()
{
  Eigen::Matrix2d mat;
  mat << 1, 2,
         3, 4;
  cout << "Here is mat.sum():        " << mat.sum()        << endl;
  cout << "Here is mat.prod():       " << mat.prod()       << endl;
  cout << "Here is mat.mean():       " << mat.mean()       << endl;
  cout << "Here is mat.minCoeff():   " << mat.minCoeff()   << endl;
  cout << "Here is mat.maxCoeff():   " << mat.maxCoeff()   << endl;
  cout << "Here is mat.trace():      " << mat.trace()      << endl;
}
```

19.11 ga_eigen_min_max_location.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-19
 *
 */

#include <iostream>
#include <Eigen/Dense>

using namespace std;
using namespace Eigen;

int main() {
    Matrix3f m = Matrix3f::Random();
    std::ptrdiff_t i, j;
    float minOfM = m.minCoeff(&i,&j);
    cout << "Here is the matrix m:\n" << m << endl;
    cout << "Its minimum coefficient (" << minOfM
         << ") is at position (" << i << "," << j << ")\n\n";

    RowVector4i v = RowVector4i::Random();
    int maxOfV = v.maxCoeff(&i);
    cout << "Here is the vector v: " << v << endl;
    cout << "Its maximum coefficient (" << maxOfV
         << ") is at position " << i << endl;

    return 0;
}
```

19.12 gb_eigen_element_access.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  ArrayXXf  m(2,2);

  // assign some values coefficient by coefficient
  m(0,0) = 1.0; m(0,1) = 2.0;
  m(1,0) = 3.0; m(1,1) = m(0,1) + m(1,0);

  // print values to standard output
  cout << m << endl << endl;

  // using the comma-initializer is also allowed
  m << 1.0,2.0,
       3.0,4.0;

  // print values to standard output
  cout << m << endl;
}
```

19.13 gc_eigen_add_sub.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  ArrayXXf a(3,3);
  ArrayXXf b(3,3);
  a << 1,2,3,
       4,5,6,
       7,8,9;
  b << 1,2,3,
       1,2,3,
       1,2,3;

  // Adding two arrays
  cout << "a + b = " << endl << a + b << endl << endl;

  // Subtracting a scalar from an array
  cout << "a - 2 = " << endl << a - 2 << endl;
}
```

19.14 gd_eigen_array_multi.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  ArrayXXf a(2,2);
  ArrayXXf b(2,2);
  a << 1,2,
       3,4;
  b << 5,6,
       7,8;
  cout << "a * b = " << endl << a * b << endl;
}
```

19.15 ge_eigen_array_others.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  ArrayXf a = ArrayXf::Random(5);
  a *= 2;
  cout << "a =" << endl
       << a << endl;
  cout << "a.abs() =" << endl
       << a.abs() << endl;
  cout << "a.abs().sqrt() =" << endl
       << a.abs().sqrt() << endl;
  cout << "a.min(a.abs().sqrt()) =" << endl
       << a.min(a.abs().sqrt()) << endl;
}
```

19.16 gf_eigen_converting_between_matrix_and_array.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  MatrixXf m(2,2);
  MatrixXf n(2,2);
  MatrixXf result(2,2);

  m << 1,2,
       3,4;
  n << 5,6,
       7,8;

  result = m * n;
  cout << "-- Matrix m*n: --" << endl << result << endl << endl;
  result = m.array() * n.array();
  cout << "-- Array m*n: --" << endl << result << endl << endl;
  result = m.cwiseProduct(n);
  cout << "-- With cwiseProduct: --" << endl << result << endl << endl;
  result = m.array() + 4;
  cout << "-- Array m + 4: --" << endl << result << endl << endl;
}
```

19.17 gg_eigen_converting_between_matrix_and_array2.cpp

```
/* program to illustrate the use of the eigen library
 *
 * example taken from eigen document
 *
 * Rajeev Singh
 * 2013-04-23
 *
 */

#include <Eigen/Dense>
#include <iostream>

using namespace Eigen;
using namespace std;

int main()
{
  MatrixXf m(2,2);
  MatrixXf n(2,2);
  MatrixXf result(2,2);

  m << 1,2,
       3,4;
  n << 5,6,
       7,8;

  result = (m.array() + 4).matrix() * m;
  cout << "-- Combination 1: --" << endl << result << endl << endl;
  result = (m.array() * n.array()).matrix() * m;
  cout << "-- Combination 2: --" << endl << result << endl << endl;
}
```