EMatrix Documentation

Version 0.1.3

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Contents

Abstract

EMatrix is a lightweight matrix library developed in C++. EMatrix is designed to aid in solving engineering problems requiring linear algebra and matrix math. EMatrix is operating system independent, and is as portable as can be made.

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1 Introduction

1.1 Authors

EMatrix, formerly CMatrix and DMatrix, was originally written by Jack Riddle. Andy Douglas next took over the maintenance with help from Jeremy Hatcher, Neal Conrardy, Dan Benzing, Jeff Blanchard, Ernie Fasse, Bryan Walsh, Justin Keesling, and many others.

1.2 Overview

EMatrix is a lightweight matrix library developed in C++. EMatrix is designed to aid in solving engineering problems requiring linear algebra and matrix math. EMatrix is operating system independent, and is as portable as can be made.

EMatrix overloads the addition, subtraction and multiplication operators after the standard mathematical definitions, including scalar multiplication and the unary sign operators. Additional operator overloading extends the library compatibility to that of the Octave syntax as well as other matrix laboratories. The goal of the library is for the user to translate an equation like the following Kalman filter covariance update equation: $P_1 = aP_0a^T - aP_0c^Ts^{-1}cP_0a^T + S_w$ into C++ of a similar form; e.g.,

```
P1 = a*P0*trans(a) - a*P0*trans(c)*inv(s)*c*P0*trans(a) + Sw;
```

EMatrix supports all C++ primitive types as well as the `<complex>` type from the C++ standard library. The library supports both C++ and FORTRAN indexing of matrices; i.e. `A(1,2) == A[0][1]`. However, the memory storage of elements is row-wise as in C++. Calls to the Lapack library are transparent to the user and account for the differences in storage between C++ and FORTRAN either explicitly by transposing matrices when necessary or implicitly by solving a different algebraic problem that yields the desired solution.

1.3 Scope

After a quick introduction to the syntax in Section 1.5, Section 2 will cover the public library functionality in detail; e.g., constructors, overload operators, and friend functions. Section 3 will cover details regarding compilation and portability of EMatrix in the Unix and Windows environments. Examples are always helpful when attempting to show the usage of software library, Sections 4 and 5 will illustrate the solution several standard engineering problems with EMatrix . The private functionality will be described in Appendix A.

1.4 Document Conventions

General text is written in the roman font. Source code, shell commands, EMatrix attributes and EMatrix methods will be denoted by the `typewriter font`.

1.5 A Quick Look

1.5.1 Example Code

```
#include <cstdlib>
#include <iostream>
#include "EMatrix.h"

using namespace std;
using namespace ematrix;

// For g++, compile with: -ansi -pedantic -Wall -D_HAVE_LAPACK
// For Linux, link with: -llapack -lg2c
// N.B., If you don't have Lapack installed, don't worry about the link
//       options and don't include the -D_HAVE_LAPACK compile flag.

int main(void) {
  // Declare and set to random values where the template declaration
  // follows Matrix< type, rows, cols >
  Matrix<double,3,3> A; A.rand();
  Matrix<double,3,1> B; B.rand();
  Matrix<double,3,1> C; C.rand();
  Matrix<double,3,3> D; D.rand();

  if(A(2,3) != A[1][2]) {
    cerr << "There is foul play asunder!!" << endl;
    abort();
  }

  // copy constructor and binary addition operator
  Matrix<double,3,3> E = A+D;

  // stream operator, scalar and matrix multiplication, matrix transpose
  cout << trans(B+B)*E*C*5.0;

  // stream operator, scalar multiplication, matrix inverse
  // The inverse routine is provide through and interface to Lapack.
#ifdef _HAVE_LAPACK
  cout << 0.5*inv(A) << endl;
#endif

  return(0);
}
```

1.5.2 Compilation

Under a Unix style system compilation is straight forward. Put the file, `EMatrix.h`, in the same directory as you source code and issue the following command:

```
$ g++ -ansi -pedantic -Wall -D_HAVE_LAPACK example0.cpp -llapack -lg2c
```

```
$ ./a.out
  31.4536
   0.191504   0.928666  -1.200350
  -0.293600  -0.054978   0.866813
   0.580886  -0.968679   0.851310
```

The following assumptions are made:

- g++, the GNU C++ compiler, is installed and in the path.
- Lapack is installed, otherwise remove the `-D_HAVE_LAPACK` compile flag.
- liblapack.so is the name of your Lapack library and it is in the library search path.
- Under Linux and g++ one must link with libg2c because Lapack is FORTRAN based and requires this library.

2 Public Functionality

2.1 Types

EMatrix is a template library in two respects, that of type and size. The library has been been tested around the C++ primitives as well as the `<complex>` type in the standard C++ library. Memory is statically allocated and the validity with respect to the dimensions of matrix algebraic operations is verified at compile time.
Template Definition:

```
template < typename tData, int tRows, int tCols >
class Matrix { ... }
```

Examples:

```
Matrix < unsigned char, 64, 64 > Image;
Matrix < int, 6, 1 > Permutation;
Matrix < float, 1, 3 > ColVector;
Matrix < double, 3, 1 > RowVector;
Matrix < complex < double >, 3, 3 > Z;
```

2.2 Constructors

2.2.1 Default Constructor

The default constructor takes no arguments. However, the protected method, `matalloc`, is called to set up row indices and zero the storage area. Note that `matalloc` does not perform any dynamic memory allocation; the name is as such due to legacy implementations that did support dynamic memory allocation.
Definition:

```
template < typename tData, int tRows, int tCols >
Matrix< tData, tRows, tCols > (void);
```

Examples:

```
Matrix < unsigned char, 64, 64 > Bitmap;
Matrix < double, 3, 1 > R;
Matrix < complex < double >, 3, 3 > Z;
```

2.2.2 Copy Constructor

The copy constructor, not to be confused with the assignment operator, takes one argument, another matrix of the same type. Since the basic EMatrix type, `Matrix<>`, is a template, for the two matrices to be of the same type, both the matrix type and the dimensions must be the same. The protected method, `matalloc`, is called before the data is `memcpy'd` to the new area. There is an error check to ensure that the matrix is of greater than zero size, which may not be necessary.
Definition:

```
template < typename tData, int tRows, int tCols >
Matrix< tData, tRows, tCols > (const Matrix< tData, tRows, tCols > & R);
```

Examples:

```
Matrix < double, 3, 1 > R;
R.rand();
Matrix < double, 3, 1 > S(R);
Matrix < double, 3, 1 > T = S;  // This is still the copy constructor
```

2.2.3 Array Initialize Constructor

The array initialize constructor takes one argument, the address of the beginning of a contiguous block of data to be loaded row-wise, as is the C++ convention, into the element storage area. No offsets are necessary and the address must be of type `tData*` relative to the definition below:
Definition:

```
template < typename tData, int tRows, int tCols >
Matrix< tData, tRows, tCols > (tData* tArray);
```

Examples:

```
double r[3] = {0.0,1.0,2.0};
Matrix < double, 3, 1 > R(r);

double s[2][2] = {{0.0, 1.0}, {2.0, 3.0}};
Matrix < double, 4, 1 > S((double*)s);
Matrix < double, 4, 1 > T(&s[0][0]);
```

There are many different possible and valid pointer and address combinations; be careful. Two point are important. If the size of the input array or block is larger than the matrix only the fist $(tRows * tCols)$ elements will be loaded.If the size of the input array or block is smaller than $(tRows * tCols)$, the values of the remaining elements are not deterministic.

2.2.4 Standard Args Initialize Constructor

The standard args initialize constructor takes a minimum of two arguments. The first argument is the number of elements that the user would like to load; the remaining arguments correspond the the elements themselves. The elements are loaded row-wise into the matrix, as with the array initialize constructor described above.
Definition:

```
template < class tData, int tRows, int tCols >
Matrix< tData, tRows, tCols >::Matrix (int count, tData first, ...);
```

Examples:

```
Matrix <  float, 3, 1 > R1(3,5.0f,6.0f,7.0f);
Matrix < double, 3, 1 > R2(3,5.0,6.0,7.0);
Matrix <    int, 3, 1 > S1(2,10,12);
Matrix <   long, 3, 1 > S2(2,10l,12l);
```

N.B., using standard args is very brittle and not type safe. Make sure to count well and ensure the element you are loading are of the same type as the matrix define. The user must cast appropriately or use other means to identify the type. See the first and the forth examples above.

2.3 Accessor Methods

These methods included provide the capability read from and write to the matrix elements on an individual basis or as a whole.

2.3.1 Array Initializer: `load`

The `load` method takes one argument, the address of the beginning of a contiguous block of data to be loaded row-wise, as is the C++ convention, into the element storage area. No offsets are necessary and the address must be of type `tData*` relative to the definition below:
Definition:

```
template < typename tData, int tRows, int tCols >
void load(tData* tArray);
```

Examples:

```
float r[2][3] = {{1.0,2.0,3.0},{4.0,5.0,6.0}};
Matrix < double, 3, 3 > R;

R.load(&r[0][0]);
```

There are many different possible and valid pointer and address combinations; be careful. Two point are important. If the size of the input array or block is larger than the matrix only the fist ($tRows * tCols$) elements will be loaded.If the size of the input array or block is smaller than ($tRows * tCols$), the values of the remaining elements are not deterministic. For more examples, see Section 2.2.3.

2.3.2 List(Comma) Initializer

Allows the user to load a matrix in a natural way using commas. See the example below. This is implemented in two stages. The first stage is the class, `ListInit`, that has overloaded the comma operator. Secondly, the `Matrix` class overloads the assignment operator for single elements of type `tData`. For a complete reference on this technique and many other for that matter, see

> Veldhuizen, Todd; "Techniques for Scientific C++," Indiana University Technical Report #542, Version 0.4, August 2000, pp 43-45,
>
> http://www.osl.iu.edu/ tveldhui/papers
> http://ematrix.sourceforge.net/techniques.ps

Definition:

```
template < typename tData, int tRows, int tCols >
inline ListInit<tData, tData* > operator = (tData x);
```

Examples:

```
Matrix < double, 3, 3 > R;
R = 0.1,0.2,0.3;
```

3 Compilation

3.1 g++

4 Kalman Filters

Under construction!!

4.1 Brief Theoretical Discussion

Kalman Filter theory typically begins with a set of coupled linear equations expressed in state space form. Consider rectilinear motion covered most undergraduate physic courses:

Let's start with $F = ma$ and assume that acceleration is constant.

$$a = \frac{dv}{dt} = \frac{F}{m} \tag{1}$$

Therefor we can write the above relationship in a different form:

$$\begin{aligned} dv &= \tfrac{F}{m}dt \\ \int_{v_0}^{v} dv &= \int_0^t \tfrac{F}{m}dt \\ v - v_0 &= \tfrac{F}{m}t \\ v &= v_0 + \tfrac{F}{m}t \end{aligned} \tag{2}$$

Finally we arrive at:

$$v = v_0 + \frac{F}{m}t \tag{3}$$

Note that

$$v = \frac{dx}{dt} = v_0 + \frac{F}{m}t \tag{4}$$

so we can write:

$$dx = \left(v_0 + \frac{F}{m}t\right) \tag{5}$$

$$x(t_1) = x(t_0) + v(t_0)t + \frac{1}{2}at^2 \tag{6}$$

If we let x_1 be velocity and x_2 be position we can write the following set of coupled differential equations:

$$\frac{d}{dt}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 1 & t \\ 0 & 1 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} t^2/2 \\ t \end{bmatrix} \tag{7}$$

State Equation:

$$x_{k+1} = Hx_k + Bu_k + w_k \tag{8}$$

Observation Equation:

$$y_k = Cx_k + z_k \tag{9}$$

5 Linear Regression

Under construction!!

A Private Functionality

B License

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