Kaldi's matrix library

Kaldi matrix library

- A C++ library that internally calls widely available C libraries, BLAS and CLAPACK
  - Note: BLAS ("Basic Linear Algebra Subroutines") is an interface for a low-level linear algebra library (goes up to matrix multiplication)
  - CLAPACK uses BLAS and provides higher level functionality (inversion, SVD, etc.)
- Our library is configurable to use either ATLAS, or (BLAS+e.g. Netlib CLAPACK), or Intel's MKL library.
- Note: ATLAS implements BLAS and a subset of LAPACK. We add code to fill the important holes in ATLAS, e.g. SVD.
  - Used public-domain code from the JAMA project.

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Kaldi matrix library: important types

- Types below templated on (float or double).

```
// Matrix class:
template<class Real> class Matrix;
// Vector class:
template<class Real> class Vector;
// Symmetric packed matrix class:
template<class Real> class SpMatrix;
// Triangular packed matrix class:
template<class Real> class TpMatrix;
```

- Note: implementation of many functions requires template specialization (since BLAS not templated).

Kaldi matrix library: example

- Example of using the matrix library;

```
Vector<float> v(10), w(9);
for(int i=0; i < 9; i++) {
   v(i) = i;
   w(i) = i+1;
}
Matrix<float> M(10,9);
M.AddVecVec(1.0, v, w); // M += v w^T
```

- Mathematical operations involve class-member functions (which are not operators)
- No “auto-resizing” takes place.

Kaldi matrix library: next example

```
Matrix<float> M(5, 10), N(5, 10), P(5, 5);
// initialize M and N somehow...
// next line: P := 1.0 * M * N^T + 0.0 * P.
P.AddMatMat(1.0, M, kNoTrans, N, kTrans, 0.0);
// Note: kTrans, kNoTrans are enum values.
// next: compute, tr(M N^T), tr(P)
float f = TraceMatMat(M, N, kTrans),
      g = P.Trace();
KALDI_ASSERT(f == g);  // we use this macro for
// asserts in Kaldi code (prints stack trace
// and throws exception).
```

- AddMatMat corresponds to BLAS's GEMM

Kaldi matrix library: naming scheme

- Because it's based on BLAS, there are a lot of operations of the form:

$$M = \alpha P Q + \beta M$$

- These functions would be class-members of M.
- The naming scheme is: "Add", and then elements for the types of P and Q (etc.), in the order they appear. "Vector" becomes "Vec", etc.
- E.g. AddMatMat, AddMatSp, AddMatMatMat
- Class Vector has similar class-members, e.g. AddMatVec.
- Things that appear twice in the expression get a "2" after their elements… (e.g. AddVec2).

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...another example

```
Matrix<float> feats(1000, 39);
// ... initialize feats somehow ...
SpMatrix<float> scatter(39);
// next line: scatter = 0.001 * feats' * feats.
scatter.AddMat2(1.0/1000, feats, kTrans, 0.0);
TpMatrix<float> cholesky(39);
cholesky.Cholesky(scatter);
cholesky.Invert();
Matrix<float> whitened(1000, 39);
// If scatter = C C^T, next line does:
//  whitened = feats * C^{-T}
whitenedAddMatTp(1.0, feats, kNoTrans,
                 cholesky, kTrans, 0.0);
```

SubMatrix and SubVector classes

- SubMatrix represents part of a matrix
- SubVector represents part of a vector (or a row of a matrix).
- These cannot be resized; destroying them does not free the memory (it's "owned" by underying Matrix or Vector class).
- All operations not involving resizing can be done on SubMatrix and SubVector the same way as Matrix and Vector.

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SubMatrix and SubVector: example

```
Vector<float> v(10), w(10);
Matrix<float> M(10, 10);
SubVector<float> vs(v, 1, 9), ws(w, 1, 9);
SubMatrix<float> Ms(M, 1, 9, 1, 9);
// next line would be:
// v(2:10) += M(2:10,2:10)*w(2:10)
// in some math scripting languages.
vs.AddMatVec(1.0, Ms, kNoTrans, ws);
```

- Limitations of SubMatrix/SubVector
  - not memory safe if underlying Matrix/Vector resized or destroyed while SubVector exists.
  - can be used to “defeat” constness
  - No representation of matrix columns

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Other functionality

- Matrix inversion
- Cholesky decomposition
- Singular Value Decomposition (SVD)
- Eigenvalue decomposition
- Fast Fourier Transform (FFT): various implementations, real and complex
- Extensive testing code included (to ensure accuracy; also provides examples of usage).

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