# Educational Deep Learning Network

Generated by Doxygen 1.9.2

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# Chapter 1

# Todo List

**Member Net::addLayer (int l, acFunc activation)**
this one probably has to go

**Member Net::calculate_initial_delta (VectorBatch &result, VectorBatch &gTruth)**
stuff to be done?

**Member VectorBatch::add_vector (const std::vector$<$ float $>$ &v)**
use the allocate method

**Member VectorBatch::set_batch_size (int n)**
should be private, maybe eliminated?

**Member VectorBatch::set_col (int j, const std::vector$<$ float $>$ &v)**
rename to set_vector?

**Member VectorBatch::set_item_size (int n)**
should be private, maybe eliminated?

# Chapter 2

# Class Index

## 2.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:


Categorization . . . . . . . . . . 7
dataItem . . . . . . . . . . 10
Dataset . . . . . . . . . . 12
Layer . . . . . . . . . . 21
Matrix . . . . . . . . . . 27
Net . . . . . . . . . . 36
Vector . . . . . . . . . . 52
VectorBatch . . . . . . . . . . 60

# Chapter 3

# File Index

## 3.1 File List

Here is a list of all documented files with brief descriptions:


configure.py . . . ??
dataset.cpp . . . ??
dataset.h . . . ??
funcs.cpp . . . ??
funcs.h . . . ??
layer.cpp . . . ??
layer.h . . . ??
Make.inc . . . ??
matrix.cpp . . . ??
matrix.h . . . ??
matrix_impl_blis.cpp . . . ??
matrix_impl_reference.cpp . . . ??
net.cpp . . . ??
net.h . . . ??
net_mpi.cpp . . . ??
test_linear.cpp . . . ??
test_mnist.cpp . . . ??
test_mpi.cpp . . . ??
test_posneg.cpp . . . ??
trace.cpp . . . ??
trace.h . . . ??
unittest.cpp . . . ??
vector.cpp . . . ??
vector.h . . . ??
vector2.cpp . . . ??
vector2.h . . . ??
vector_impl_blis.cpp . . . ??
vector_impl_reference.cpp . . . ??
vectorbatch_impl_blis.cpp . . . ??
vectorbatch_impl_reference.cpp . . . ??

# Chapter 4

# Class Documentation

## 4.1 Categorization Class Reference

### Public Member Functions

- Categorization (Vector v)
- Categorization (std::vector< float > p)
- Categorization (int n)
- Categorization (int n, int i)
- const std::vector< float > & probabilities () const
- int size () const
- void normalize ()
- bool close_enough (const Categorization &approx) const
- bool close_enough (const std::vector< float > &approx) const

### 4.1.1 Detailed Description

Definition at line 68 of file vector.h.

### 4.1.2 Constructor & Destructor Documentation

#### 4.1.2.1 Categorization() [1/4]

```
Categorization::Categorization (
            Vector v )  [inline]
```

Definition at line 72 of file vector.h.

```
00073     : _probabilities(v.values()) {};
```

#### 4.1.2.2 Categorization() [2/4]

```
Categorization::Categorization (
        std::vector< float > p ) [inline]
```

Definition at line 74 of file vector.h.

```
00075     : _probabilities(p) {};
```

#### 4.1.2.3 Categorization() [3/4]

```
Categorization::Categorization (
        int n ) [inline]
```

Definition at line 76 of file vector.h.

```
00077     : _probabilities( std::vector<float>(n) ) {};
```

#### 4.1.2.4 Categorization() [4/4]

```
Categorization::Categorization (
        int n,
        int i ) [inline]
```

Definition at line 78 of file vector.h.

```
00079     : _probabilities( std::vector<float>(n) ) {
00080     _probabilities.at(i) = 1.;
00081   };
```

### 4.1.3 Member Function Documentation

#### 4.1.3.1 close_enough() [1/2]

```
bool Categorization::close_enough (
        const Categorization & approx ) const [inline]
```

Definition at line 89 of file vector.h.

```
00089                                                        {
00090     return close_enough( approx.probabilities() );
00091   };
```

#### 4.1.3.2 close_enough() [2/2]

```
bool Categorization::close_enough (
            const std::vector< float > & approx ) const [inline]
```

Definition at line 92 of file vector.h.

```
00092                                                      {
00093     assert( size()==approx.size() );
00094     //return _probabilities==approx;
00095     bool close{true};
00096     for ( int i=0; i<size(); i++) {
00097       close = close and
00098     ( ( _probabilities.at(i)==approx.at(i) )
00099       or ( approx.at(i)==0. and ( std::abs(_probabilities.at(i))<1.e-5 ) )
00100       or ( std::abs( (_probabilities.at(i)-approx.at(i))/approx.at(i) )<1.e-5 )
00101       );
00102     }
00103     return close;
00104   };
```

#### 4.1.3.3 normalize()

```
void Categorization::normalize ( ) [inline]
```

Definition at line 84 of file vector.h.

```
00084                      {
00085     auto it = std::max_element(_probabilities.begin(), _probabilities.end());
00086     std::fill(_probabilities.begin(), _probabilities.end(), 0);
00087     *it = 1;
00088   };
```

#### 4.1.3.4 probabilities()

```
const std::vector< float > & Categorization::probabilities ( ) const [inline]
```

Definition at line 82 of file vector.h.

```
00082 { return _probabilities; };
```

#### 4.1.3.5 size()

```
int Categorization::size ( ) const [inline]
```

Definition at line 83 of file vector.h.

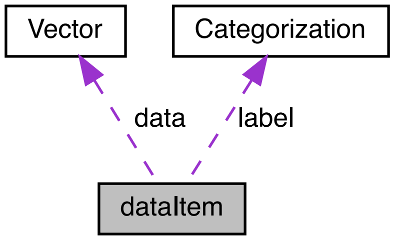
```
00083 { return _probabilities.size(); };
```

The documentation for this class was generated from the following file:

- vector.h

## 4.2 dataItem Class Reference

Collaboration diagram for dataItem:




### Public Member Functions

- dataItem (Vector data, Categorization label)
- dataItem (float data, Categorization label)
- dataItem (std::vector< float > indata, std::vector< float > outdata)
- int data_size () const
- const std::vector< float > & data_values () const
- int label_size () const
- const std::vector< float > & label_values () const

### Public Attributes

- Vector data
- Categorization label

### 4.2.1 Detailed Description

Definition at line 22 of file dataset.h.

### 4.2.2 Constructor & Destructor Documentation

#### 4.2.2.1 dataItem() [1/3]

```
dataItem::dataItem (
            Vector data,
            Categorization label )   [inline]
```

Definition at line 28 of file dataset.h.

```
00029     : data(data),label(label) {};
```

#### 4.2.2.2 dataItem() [2/3]

```
dataItem::dataItem (
            float data,
            Categorization label ) [inline]
```

Definition at line 30 of file dataset.h.

```
00031     : data( std::vector<float>(data) ),label(label) {};
```

#### 4.2.2.3 dataItem() [3/3]

```
dataItem::dataItem (
            std::vector< float > indata,
            std::vector< float > outdata ) [inline]
```

Definition at line 32 of file dataset.h.

```
00033     : data( Vector(indata) ),label( Categorization(outdata) ) {};
```

### 4.2.3 Member Function Documentation

#### 4.2.3.1 data_size()

```
int dataItem::data_size ( ) const [inline]
```

Definition at line 34 of file dataset.h.

```
00034 { return data.size(); };
```

#### 4.2.3.2 data_values()

```
const std::vector< float > & dataItem::data_values ( ) const [inline]
```

Definition at line 35 of file dataset.h.

```
00035 { return data.values(); };
```

#### 4.2.3.3 label_size()

```
int dataItem::label_size ( ) const [inline]
```

Definition at line 36 of file dataset.h.

```
00036 { return label.size(); };
```

#### 4.2.3.4 label_values()

```
const std::vector< float > & dataItem::label_values ( ) const [inline]
```

Definition at line 37 of file dataset.h.

```
00037 { return label.probabilities(); };
```

### 4.2.4 Member Data Documentation

#### 4.2.4.1 data

```
Vector dataItem::data
```

Definition at line 24 of file dataset.h.

#### 4.2.4.2 label

```
Categorization dataItem::label
```

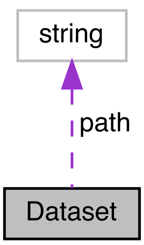
Definition at line 26 of file dataset.h.

The documentation for this class was generated from the following file:

- dataset.h

## 4.3 Dataset Class Reference

Collaboration diagram for Dataset:



## Public Member Functions

- Dataset (int n)
- Dataset (std::vector< dataItem >)
- void set_lowerbound (int b)
- void set_number (int b)
- void push_back (dataItem it)
- int size () const
- int data_size () const
- int label_size () const
- dataItem item (int i) const
- const Vector & data (int i) const
- const std::vector< float > data_vals (int i) const
- const std::vector< float > label_vals (int i) const
- std::vector< float > stacked_data_vals (int i) const

    *Same, of the stacked object.*
- std::vector< float > stacked_label_vals (int i) const

    *Same, of the stacked object.*
- const auto & inputs () const
- const auto & labels () const
- int readTest (std::string dataPath)
- void shuffle ()
- std::vector< Dataset > batch (int n) const
- void stack ()
- std::pair< Dataset, Dataset > split (float trainFraction) const

## Public Attributes

- std::string path

### 4.3.1 Detailed Description

Definition at line 40 of file dataset.h.

### 4.3.2 Constructor & Destructor Documentation

#### 4.3.2.1 Dataset() [1/3]

```
Dataset::Dataset ( )  [inline]
```

Definition at line 49 of file dataset.h.

```
00049 {};
```

#### 4.3.2.2 Dataset() [2/3]

```
Dataset::Dataset (
                int n )
```

Definition at line 33 of file dataset.cpp.

```
00033                         : nclasses(n) {
00034   assert(n>=0);
00035 };
```

#### 4.3.2.3 Dataset() [3/3]

```
Dataset::Dataset (
                std::vector< dataItem > dv )
```

Definition at line 37 of file dataset.cpp.

```
00037                                      {
00038   for ( const auto& v : dv )
00039     push_back(v);
00040 };
```

### 4.3.3 Member Function Documentation

#### 4.3.3.1 batch()

```
std::vector< Dataset > Dataset::batch (
                int n ) const
```

Definition at line 178 of file dataset.cpp.

```
00178                                                   {
00179
00180   std::vector<Dataset> batches;
00181   int nitems = size(), itemsize = data_size();
00182   int nbatches = nitems/batch_size + ( nitems%batch_size>0 ? 1 : 0 );
00183   for (int b=0; b<nbatches; b++) {
00184     int first = b*batch_size, last= std::min( (b+1)*batch_size,nitems );
00185     Dataset batch; //(itemsize,last-first);
00186     batch.set_lowerbound(first); batch.set_number(b);
00187     for (int i=first; i<last; i++) {
00188       batch.push_back( item(i) );
00189     }
00190     batches.push_back(batch);
00191   }
00192
00193   return batches;
00194 }
```

#### 4.3.3.2 data()

```
const Vector & Dataset::data (
                int i ) const
```

Get the i-th data object

Definition at line 92 of file dataset.cpp.

```
00092                                     {
00093   throw( string("Do not use Dataset::data") );
00094   //  return _items.at(i).data;
00095 };
```

#### 4.3.3.3 data_size()

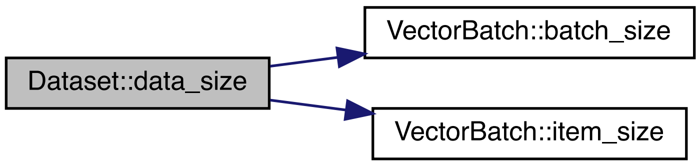
```
int Dataset::data_size ( ) const
```

What is the size of the feature vector in this dataset?

Definition at line 74 of file dataset.cpp.

```
00074                                      {
00075   if (dataBatch.batch_size()==0)
00076     throw( string("Can not get data size for empty dataset") );
00077   return dataBatch.item_size();
00078 };
```

Here is the call graph for this function:




#### 4.3.3.4 data_vals()

```
const vector< float > Dataset::data_vals (
                int i ) const
```

Get the features of i-th data object

Definition at line 99 of file dataset.cpp.

```
00099                                                        {
00100   return dataBatch.extract_vector(i);
00101 };
```

#### 4.3.3.5 inputs()

```
const auto & Dataset::inputs ( ) const  [inline]
```

Definition at line 75 of file dataset.h.

```
00075 { return dataBatch; };
```

#### 4.3.3.6 item()

```
dataItem Dataset::item (
            int i ) const
```

Definition at line 61 of file dataset.cpp.

```
00061                             {
00062   return dataItem( data_vals(i),label_vals(i) );
00063 };
```

#### 4.3.3.7 label_size()

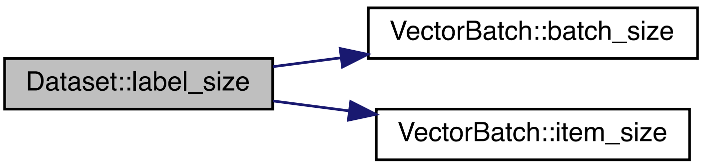
```
int Dataset::label_size ( ) const
```

What is the number of categories in the labels of this dataset?

Definition at line 83 of file dataset.cpp.

```
00083                           {
00084   if (labelBatch.batch_size()==0)
00085     throw( string("Can not get label size for empty dataset") );
00086   return labelBatch.item_size();
00087 }
```

Here is the call graph for this function:




#### 4.3.3.8 label_vals()

```
const vector< float > Dataset::label_vals (
            int i ) const
```

Get the categorization of i-th data object

Definition at line 105 of file dataset.cpp.

```
00105                                           {
00106   return labelBatch.extract_vector(i);
00107 };
```

#### 4.3.3.9 labels()

```
const auto & Dataset::labels ( ) const [inline]
```

Definition at line 76 of file dataset.h.

```
00076 { return labelBatch; };
```

#### 4.3.3.10 push_back()

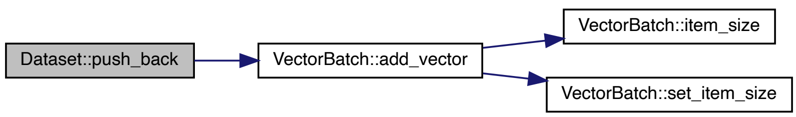
```
void Dataset::push_back (
            dataItem it )
```

Add a new data item, and check its consistency with previous items

Definition at line 48 of file dataset.cpp.

```
00048                                     {
00049   if (nclasses>0 and it.label_size()!=nclasses) {
00050     cout « "Set dimensionality " « nclasses
00051          « " does not match item size " « it.label_size() « endl;
00052     throw( string("Fail to add item to dataset") );
00053   }
00054   if (nclasses==0)
00055     nclasses = it.label_size();
00056   dataBatch.add_vector( it.data_values() );
00057   labelBatch.add_vector( it.label_values() );
00058   //_items.push_back(it);
00059 };
```

Here is the call graph for this function:




#### 4.3.3.11 readTest()

```
int Dataset::readTest (
            std::string dataPath )
```

Definition at line 120 of file dataset.cpp.

```
00120                                         {
00121     /*
00122      * This reader is specifically for a modified MNIST dataset which
00123      * does not include the file header, metadata, etc.
00124      * Link to the dataset: http://cis.jhu.edu/~sachin/digit/digit.html
00125      * I chose this dataset for now to make it easy to read the data;
00126      * in later iterations I will generalize the read function, maybe OpenCV support
00127      */
00128
00129     FILE *file;
00130     std::string fileName;
00131     uint8_t temp[IMSIZE * IMSIZE]; // Image buffer to read data into
```

```
00132     for (int dataid = 0; dataid < 10; dataid++) {
00133         fileName = dataPath + "/data" + std::to_string(dataid); // Put together the path
00134         file = fopen(fileName.c_str(), "r");
00135 
00136 
00137         if (!file) { // File checking
00138             cout « "Error opening file" « endl;
00139             return -2; // Arbitrary error code
00140         }
00141         for (int k = 0; k < 1000; k++) {
00142             Vector imageVec(IMSIZE * IMSIZE, 0); // initialize matrix to be read into
00143             fread(temp, 1, IMSIZE * IMSIZE, file); // Read 28*28 into buffer
00144 
00145             for (int i = 0; i < IMSIZE; i++) {
00146                 for (int j = 0; j < IMSIZE; j++) {
00147                     // Transfer from buffer into matrix
00148           float *i_data = imageVec.data();
00149           *( i_data + i * IMSIZE + j ) // imageVec.vals[i * IMSIZE + j]
00150             = static_cast<float>( temp[i * IMSIZE + j] );
00151                 }
00152             }
00153             fseek(file, k * IMSIZE * IMSIZE, SEEK_SET); // Seek to the kth image bytes
00154 
00155         Categorization label(10,dataid);
00156 
00157             dataItem x = {imageVec, label}; // Initialize an item with the data and the label in it
00158             push_back(x); // Store in the vector
00159 
00160         }
00161         fclose(file);
00162     }
00163     return 0;
00164 }
```

#### 4.3.3.12 set_lowerbound()

```
void Dataset::set_lowerbound (
               int b )
```

Definition at line 42 of file dataset.cpp.

```
00042 { lowerbound = b; };
```

#### 4.3.3.13 set_number()

```
void Dataset::set_number (
               int b )
```

Definition at line 43 of file dataset.cpp.

```
00043 { number = b; };
```

#### 4.3.3.14 shuffle()

```
void Dataset::shuffle ( )
```

Definition at line 167 of file dataset.cpp.

```
00167                         {
00168     std::random_device r;
00169     std::seed_seq seed{r(), r(), r(), r(), r(), r(), r(), r()}; // Seed
00170     std::mt19937 eng1(seed); // Randomizer engine
00171 
00172     throw( string("shuffling doesn't work") );
00173     //    std::shuffle(begin(_items), end(_items), eng1); // Shuffle the dataset
00174     return; // todo add return codes instead of printing
00175 }
```

#### 4.3.3.15 size()

```
int Dataset::size ( ) const
```

Definition at line 65 of file dataset.cpp.

```
00065                                {
00066     int ds = dataBatch.batch_size(), ls = labelBatch.batch_size();
00067     assert( ds==ls );
00068     return ds;
00069 }
```

#### 4.3.3.16 split()

```
std::pair< Dataset, Dataset > Dataset::split (
             float trainFraction ) const
```

Definition at line 220 of file dataset.cpp.

```
00220                                                                             {
00221       int dataset_size = size(); // _items.size();
00222       int testSize{0},trainSize;
00223       while ( true ) {
00224         trainSize= ceil( static_cast<float>( dataset_size ) * trainFraction);
00225         testSize = dataset_size - trainSize;
00226         if ( testSize>0 ) break;
00227         trainFraction *= .9;
00228       }
00229 
00230       auto random_index = permutation(dataset_size);
00231       Dataset trainSplit;
00232       if (trace_progress())
00233         cout « "split into " « trainSize « "+" « testSize « endl;
00234       for (int i=0; i<trainSize; i++) {
00235         const auto& di = item( random_index[i] );
00236         trainSplit.push_back(di);
00237       }
00238       Dataset testSplit;
00239       for (int i=trainSize; i<trainSize+testSize; i++) {
00240         const auto& di = item( random_index[i] );
00241         testSplit.push_back(di);
00242       }
00243 
00244       return std::make_pair(trainSplit,testSplit);
00245 }
```

#### 4.3.3.17 stack()

```
void Dataset::stack ( )
```

Definition at line 196 of file dataset.cpp.

```
00196                       { // Stacks vectors horizontally (column-wise) in a Matrix object
00197     throw( string("Stacking no longer needed") );
00198       //dataBatch  = VectorBatch( data_size(),  size(), 0);
00199       //labelBatch = VectorBatch( label_size(), size(), 0);
00200 
00201       dataBatch  = VectorBatch( size(),  data_size(), 0);
00202       labelBatch = VectorBatch( size(), label_size(), 0);
00203 
00204       for (int j = 0; j < size(); j++) {
00205           //dataBatch.set_col( j,data_vals(j) );
00206           dataBatch.set_row( j, data_vals(j) );
00207       }
00208 
00209       for (int j = 0; j < size(); j++) {
00210           //labelBatch.set_col( j,label_vals(j) );
00211           labelBatch.set_row( j, label_vals(j) );
00212       }
00213 }
```

#### 4.3.3.18 stacked_data_vals()

```
vector< float > Dataset::stacked_data_vals (
              int i ) const
```

Same, of the stacked object.

Definition at line 109 of file dataset.cpp.

```
00109                                                       {
00110   throw( string("Do not use Dataset::stacked_data_vals") );
00111   return dataBatch.get_row(i);
00112 };
```

#### 4.3.3.19 stacked_label_vals()

```
vector< float > Dataset::stacked_label_vals (
              int i ) const
```

Same, of the stacked object.

Definition at line 115 of file dataset.cpp.

```
00115                                                        {
00116   throw( string("Do not use Dataset::stacked_label_vals") );
00117   return labelBatch.get_row(i);
00118 };
```

### 4.3.4 Member Data Documentation

#### 4.3.4.1 path

```
std::string Dataset::path
```

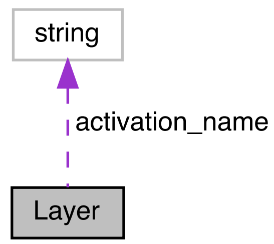
Definition at line 73 of file dataset.h.

The documentation for this class was generated from the following files:

- dataset.h
- dataset.cpp

## 4.4 Layer Class Reference

Collaboration diagram for Layer:




### Public Member Functions

- Layer (int insize, int outsize)
- Layer & set_uniform_weights (float)
- Layer & set_uniform_biases (float)
- auto & input ()
- const auto & input () const
- Layer & set_number (int n)
- int input_size () const
- int output_size () const
- void **set_recursive_deltas** (Vector &, const Layer &, const Layer &)
- void set_topdelta (const VectorBatch &, const VectorBatch &)
- void allocate_batch_specific_temporaries (int batchsize)
- void forward (const VectorBatch &, VectorBatch &)
- const VectorBatch & intermediate () const
- void backward (const VectorBatch &delta, const Matrix &W, const VectorBatch &prev)
- void **backward_update** (const VectorBatch &, const VectorBatch &, bool=false)
- void update_dw (const VectorBatch &delta, const VectorBatch &prevValues)
- void set_activation (acFunc f)
- Layer & set_activation (std::function< void(const VectorBatch &, VectorBatch &) > apply, std::function< void(const VectorBatch &, VectorBatch &) > activate, std::string name=std::string("custom"))
- Layer & set_activation (std::function< float(const float &) > activate_pt, std::function< float(const float &) > gradient_pt, std::string name=std::string("custom"))

### Public Attributes

- std::string activation_name {"custom"}

### Friends

- class Net

### 4.4.1 Detailed Description

Definition at line 25 of file layer.h.

### 4.4.2 Constructor & Destructor Documentation

#### 4.4.2.1 Layer() [1/2]

```
Layer::Layer ( )
```

Definition at line 21 of file layer.cpp.

```
00021 {};
```

#### 4.4.2.2 Layer() [2/2]

```
Layer::Layer (
            int insize,
            int outsize )
```

Definition at line 22 of file layer.cpp.

```
00023   : weights( Matrix(outsize,insize,1) ),
00024     dw     ( Matrix(outsize,insize, 0) ),
00025     //dW( Matrix(outsize,insize, 0) ),
00026     dw_velocity( Matrix(outsize,insize, 0) ),
00027     biases( Vector(outsize, 1 ) ),
00028     // biased_product( Vector(outsize, 0) ),
00029     activated( Vector(outsize, 0) ),
00030     d_activated( Vector(outsize, 0) ),
00031     delta( VectorBatch(outsize,1) ),
00032     // biased_productm( VectorBatch(outsize,insize,0) ),
00033     //    activated_batch( VectorBatch(outsize,1, 0) ),
00034     //    d_activated_batch ( VectorBatch(outsize,insize, 0) ),
00035     db( Vector(insize, 0) ),
00036     // delta_mean( Vector(insize, 0) ),
00037     dl( VectorBatch(insize, 1) ),
00038     db_velocity( Vector(insize, 0) ) {};
```

### 4.4.3 Member Function Documentation

#### 4.4.3.1 allocate_batch_specific_temporaries()

```
void Layer::allocate_batch_specific_temporaries (
            int batchsize )
```

Definition at line 43 of file layer.cpp.

```
00043                                                             {
00044   const int insize = weights.colsize(), outsize = weights.rowsize();
00045
00046   biased_batch.allocate( batchsize,outsize );
00047   input_batch.allocate( batchsize,insize );
00048   //  activated_batch.allocate( batchsize,outsize );
00049   d_activated_batch.allocate( batchsize,outsize );
00050   dl.allocate( batchsize, outsize );
00051   delta.allocate( batchsize,outsize );
00052 };
```

#### 4.4.3.2 backward()

```
void Layer::backward (
            const VectorBatch & delta,
            const Matrix & W,
            const VectorBatch & prev )
```

Definition at line 133 of file layer.cpp.

```
00134                                                                                          {
00135
00136   // compute delta ell
00137   activate_gradient_batch(prev_output, d_activated_batch);
00138   prev_delta.v2mtp( W, dl );
00139
00140    // delta  = Dl . sigma
00141   if (trace_progress())
00142     cout « "L-" « layer_number « " delta\n";
00143   delta.hadamard( d_activated_batch,dl ); // Derivative of the current layer
00144
00145   // prev_output.outer2( delta, dw );
00146   // if (trace_scalars())
00147   //   cout « "L-" « layer_number « " dw: "
00148   //     « delta.normf() « "x" « prev_output.normf() « " => " « dw.normf() « "\n";
00149
00150   update_dw(delta, prev_output);
00151   // weights.axpy( 1.,dw );
00152   // db = delta.meanh();
00153   // biases.add( db );
00154 }
```

#### 4.4.3.3 forward()

```
void Layer::forward (
            const VectorBatch & input,
            VectorBatch & output )
```

Definition at line 99 of file layer.cpp.

```
00099                                                                     {
00100   assert( input.batch_size()==output.batch_size() );
00101   if (trace_progress()) {
00102     cout « "Forward layer " « layer_number
00103      « ": " « input_size() « "->" « output_size() « endl;
00104   }
00105
00106   allocate_batch_specific_temporaries(input.batch_size());
00107   input_batch.copy_from(input);
00108   if (trace_progress()) {
00109     assert( input_batch.notnan() ); assert( input_batch.notinf() );
00110     assert( weights.notnan() ); assert( weights.notinf() );
00111   }
00112   input_batch.v2mp( weights, biased_batch );
00113   if (trace_progress()) {
00114     assert( biased_batch.notnan() ); assert( biased_batch.notinf() );
00115   }
00116
00117   biased_batch.addh(biases); // Add the bias
00118   if (trace_progress()) {
00119     assert( biased_batch.notnan() ); assert( biased_batch.notinf() );
00120   }
00121
00122   apply_activation_batch(biased_batch, output);
00123   //cout « "layer output: " « output.data()[0] « "\n";
00124   if (trace_progress()) {
00125     assert( output.notnan() ); assert( output.notinf() );
00126   }
00127   //return activated_batch;
00128 }
```

#### 4.4.3.4 input() [1/2]

```
auto & Layer::input ( ) [inline]
```

Definition at line 47 of file layer.h.

```
00047 { return input_batch; };
```

#### 4.4.3.5 input() [2/2]

```
const auto & Layer::input ( ) const [inline]
```

Definition at line 48 of file layer.h.

```
00048 { return input_batch; };
```

#### 4.4.3.6 input_size()

```
int Layer::input_size ( ) const [inline]
```

Definition at line 75 of file layer.h.

```
00075 { return weights.colsize(); };
```

#### 4.4.3.7 intermediate()

```
const VectorBatch & Layer::intermediate ( ) const
```

Definition at line 131 of file layer.cpp.

```
00131 { return biased_batch; };
```

#### 4.4.3.8 output_size()

```
int Layer::output_size ( ) const [inline]
```

Definition at line 76 of file layer.h.

```
00076 { return weights.rowsize(); };
```

#### 4.4.3.9 set_activation() [1/3]

```
void Layer::set_activation (
            acFunc f )
```

Definition at line 54 of file layer.cpp.

```
00054                                   {
00055   activation = f;
00056   apply_activation_batch  = apply_activation<VectorBatch>.at(f);
00057   activate_gradient_batch = activate_gradient<VectorBatch>.at(f);
00058 };
```

#### 4.4.3.10 set_activation() [2/3]

```
Layer & Layer::set_activation (
            std::function< float(const float &) > activate_pt,
            std::function< float(const float &) > gradient_pt,
            std::string name = std::string("custom") )
```

Definition at line 60 of file layer.cpp.

```
00065       {
00066     set_activation
00067     (
00068      [activate_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
00069         batch_activation( activate_pt,i,o ); },
00070      [gradient_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
00071         batch_activation( gradient_pt,i,o ); },
00072      name );
00073   return *this;
00074 };
```

#### 4.4.3.11 set_activation() [3/3]

```
Layer & Layer::set_activation (
            std::function< void(const VectorBatch &, VectorBatch &) > apply,
            std::function< void(const VectorBatch &, VectorBatch &) > activate,
            std::string name = std::string("custom") )
```

Definition at line 76 of file layer.cpp.

```
00079                         {
00080   activation = acFunc::RELU;
00081   apply_activation_batch  = apply;
00082   activate_gradient_batch = activate;
00083   return *this;
00084 };
```

#### 4.4.3.12 set_number()

```
Layer & Layer::set_number (
            int n )  [inline]
```

Definition at line 72 of file layer.h.

```
00072 { layer_number = n; return *this; };
```

#### 4.4.3.13 set_topdelta()

```
void Layer::set_topdelta (
            const VectorBatch & gTruth,
            const VectorBatch & output )
```

Definition at line 168 of file layer.cpp.

```
00168                                                                               {
00169
00170    // top delta ell is different
00171   activate_gradient_batch(output, d_activated_batch);
00172   dl = output - gTruth;
00173   dl.scaleby( 1.f / gTruth.batch_size() );
00174   // delta  = Dl . sigma
00175   delta.hadamard( d_activated_batch,dl );
00176   if (trace_scalars())
00177     cout « "L-" « layer_number « " top delta: "
00178      « d_activated_batch.normf() « "x" « dl.normf() « " => " « delta.normf() « "\n";
00179
00180   //  update_dw(delta, prev_output);
00181 };
```

#### 4.4.3.14 set_uniform_biases()

```
Layer & Layer::set_uniform_biases (
            float v )
```

Definition at line 92 of file layer.cpp.

```
00092                                        {
00093   for ( auto& e : biases.values() )
00094     e = v;
00095   return *this;
00096 };
```

#### 4.4.3.15 set_uniform_weights()

```
Layer & Layer::set_uniform_weights (
            float v )
```

Definition at line 86 of file layer.cpp.

```
00086                                         {
00087   for ( auto& e : weights.values() )
00088     e = v;
00089   return *this;
00090 };
```

#### 4.4.3.16 update_dw()

```
void Layer::update_dw (
            const VectorBatch & delta,
            const VectorBatch & prevValues )
```

Definition at line 156 of file layer.cpp.

```
00156                                                                             {
00157    prev_output.outer2( delta, dw );
00158    if (trace_scalars())
00159      cout « "L-" « layer_number « " dw: "
00160       « delta.normf() « "x" « prev_output.normf() « " => " « dw.normf() « "\n";
00161
00162   // Delta W = delta here X activated prevous
00163   weights.axpy( 1.,dw );
00164   db = delta.meanh();
00165   biases.add( db );
00166 }
```

### 4.4.4 Friends And Related Function Documentation

#### 4.4.4.1 Net

```
friend class Net  [friend]
```

Definition at line 26 of file layer.h.

### 4.4.5 Member Data Documentation

#### 4.4.5.1 activation_name

```
std::string Layer::activation_name {"custom"}
```

Definition at line 101 of file layer.h.

The documentation for this class was generated from the following files:

- layer.h
- layer.cpp

## 4.5 Matrix Class Reference

### Public Member Functions

- Matrix (int nRows, int nCols, int rand)
- std::vector< float > & values ()
- const std::vector< float > & values () const
- float * data ()
- const float * data () const
- int nelements () const
- int rowsize () const
- int colsize () const
- Matrix transpose () const
- void show () const
- void mvpt (const Vector &x, Vector &y) const
- void mvp (const Vector &x, Vector &y) const
- void addvh (const Vector &y)
- void mmp (const Matrix &x, Matrix &y) const
- void outerProduct (const Vector &x, const Vector &y)
- Vector meanv ()
- void zeros ()
- void square ()
- float normf () const
- bool notnan () const
- bool notinf () const
- Matrix operator- ()
- Matrix & operator= (const Matrix &m2)
- Matrix operator+ (const Matrix &m2) const
- Matrix operator* (const Matrix &m2)
- Matrix operator/ (const Matrix &m2)
- Matrix operator- (const Matrix &m2)
- void axpy (float a, const Matrix &x)

## Friends

- Matrix operator* (const float &c, const Matrix &m)
- Matrix operator/ (const Matrix &m, const float &c)

## 4.5.1 Detailed Description

Definition at line 22 of file matrix.h.

## 4.5.2 Constructor & Destructor Documentation

### 4.5.2.1 Matrix() [1/2]

```
Matrix::Matrix ( )
```

Definition at line 22 of file matrix.cpp.

```
00022                 { // Default constructor
00023     r = 0;
00024     c = 0;
00025     mat.clear();
00026 }
```

### 4.5.2.2 Matrix() [2/2]

```
Matrix::Matrix (
               int nRows,
               int nCols,
               int rand = 0 )
```

Definition at line 26 of file matrix_impl_blis.cpp.

```
00027         : r(nRows), c(nCols) {
00028
00029     mat = vector<float>(nRows * nCols);
00030     float scal_fac = 0.05; // randomize between (-1;1)
00031     if (random==0){
00032         float zero = 0.0;
00033         bli_ssetm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
00034                 r, c, &zero, &mat[0], c, 1);
00035     } else if (random==1){
00036         bli_srandm(0, BLIS_DENSE, r, c, &mat[0], c, 1);
00037         bli_sscalm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
00038                 r, c, &scal_fac, &mat[0], c, 1);
00039     }
00040 }
```

## 4.5.3 Member Function Documentation

#### 4.5.3.1 addvh()

```
void Matrix::addvh (
            const Vector & y )
```

Definition at line 108 of file matrix.cpp.

```
00108                                    {
00109     for (int j = 0; j < c; j++) {
00110         for (int i = 0; i < y.size(); i++) {
00111             mat[j + c * i] += y.vals[i];
00112         }
00113     }
00114 }
```

#### 4.5.3.2 axpy()

```
void Matrix::axpy (
            float a,
            const Matrix & x )
```

Definition at line 121 of file matrix_impl_blis.cpp.

```
00121                                             {
00122   assert( r==x.r );
00123   assert( c==x.c );
00124   const int n = nelements();
00125   assert( n==x.nelements() );
00126
00127   bli_saxpyv( BLIS_NO_CONJUGATE,
00128           n, &a, const_cast<float*>( x.data() ),1,
00129           data(),1 );
00130 };
```

#### 4.5.3.3 colsize()

```
int Matrix::colsize ( ) const  [inline]
```

Definition at line 39 of file matrix.h.

```
00039 { return c; };
```

#### 4.5.3.4 data() [1/2]

```
float * Matrix::data ( )
```

Definition at line 34 of file matrix.cpp.

```
00034 { return mat.data(); };
```

#### 4.5.3.5 data() [2/2]

```
const float * Matrix::data ( ) const
```

Definition at line 35 of file matrix.cpp.

```
00035 { return mat.data(); };
```

#### 4.5.3.6 meanv()

```
Vector Matrix::meanv ( )
```

Definition at line 116 of file matrix.cpp.

```
00116                           { // Returns a vector of column-wise means
00117     Vector mean(r, 0);
00118     float avg;
00119     for (int i = 0; i < r; i++) {
00120         avg = 0.0;
00121         for (int j = 0; j < c; j++) {
00122             avg += mat[i * c + j];
00123         }
00124         mean.vals[i] = avg;
00125     }
00126     return mean;
00127 }
```

#### 4.5.3.7 mmp()

```
void Matrix::mmp (
        const Matrix & x,
        Matrix & y ) const
```

Definition at line 105 of file matrix_impl_blis.cpp.

```
00105                                                    { // In place matrix matrix multiplication
00106     assert( c==x.r );
00107     assert( r==y.r );
00108     assert( x.c==y.c );
00109 
00110     float alpha = 1.0;
00111     float beta = 0.0;
00112     // m = r, n = x.c, k = c
00113     //printf("BLIS gemm %dx%dx%d\n",r,x.c,c);
00114     bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_NO_TRANSPOSE,
00115            r, x.c, c, &alpha, const_cast<float*>(&mat[0]),
00116            //c, 1, &t.mat[0],
00117            c, 1, const_cast<float*>( x.data() ),
00118            x.c, 1, &beta, &y.mat[0], x.c, 1);
00119 }
```

#### 4.5.3.8 mvp()

```
void Matrix::mvp (
            const Vector & x,
            Vector & y ) const
```

Definition at line 61 of file matrix_impl_blis.cpp.

```
00061                                                {
00062     assert( c==x.size() );
00063     assert( r==y.size() );
00064 
00065     float alpha = 1.0;
00066     float beta = 0.0;
00067     //printf("BLIS gemv %dx%d\n",c,r);
00068     bli_sgemv( BLIS_NO_TRANSPOSE, BLIS_NO_CONJUGATE,
00069            r, c, &alpha, const_cast<float*>(&mat[0]),
00070            c, 1, const_cast<float*>( x.data() ) /* &t.vals[0] */,
00071            // c, 1, &t.vals[0] ,
00072            1, &beta, &y.vals[0], 1 );
00073 
00074 }
```

#### 4.5.3.9 mvpt()

```
void Matrix::mvpt (
            const Vector & x,
            Vector & y ) const
```

Definition at line 76 of file matrix_impl_blis.cpp.

```
00076                                                 {
00077     assert( r==x.size() );
00078     assert( c==y.size() );
00079 
00080     float alpha = 1.0;
00081     float beta = 0.0;
00082     //printf("BLIS gemv %dx%d\n",c,r);
00083     bli_sgemv( BLIS_TRANSPOSE, BLIS_NO_CONJUGATE,
00084            r, c, &alpha, const_cast<float*>(&mat[0]), // test if r and c need to be flipped
00085            //c, 1, &t.vals[0],
00086            c, 1, const_cast<float*>( x.data() ),
00087            1, &beta, &y.vals[0], 1 );
00088 }
```

#### 4.5.3.10 nelements()

```
int Matrix::nelements ( ) const  [inline]
```

Definition at line 35 of file matrix.h.

```
00035                                  {
00036       return mat.size();
00037     };
```

#### 4.5.3.11 normf()

```
float Matrix::normf ( ) const
```

Definition at line 132 of file matrix_impl_blis.cpp.

```
00132                             {
00133   float norm;
00134   auto r = rowsize(), c = colsize();
00135   const auto mval = values().data();
00136   bli_snormfv( r*c, const_cast<float*>(mval), 1, &norm );
00137   return norm;
00138 };
```

#### 4.5.3.12 notinf()

```
bool Matrix::notinf ( ) const  [inline]
```

Definition at line 60 of file matrix.h.

```
00060                             {
00061       return all_of
00062     ( mat.begin(),mat.end(),
00063       [] (float e) { return not isinf(e); }
00064     );
00065     }
```

#### 4.5.3.13 notnan()

```
bool Matrix::notnan ( ) const  [inline]
```

Definition at line 54 of file matrix.h.

```
00054                             {
00055       return all_of
00056     ( mat.begin(),mat.end(),
00057       [] (float e) { return not isnan(e); }
00058     );
00059     }
```

#### 4.5.3.14 operator*()

```
Matrix Matrix::operator* (
             const Matrix & m2 )
```

Definition at line 82 of file matrix.cpp.

```
00082                                           { // Hadamard product
00083     Matrix out(m2.r, m2.c, 0);
00084     assert(out.mat.size()==m2.r * m2.c);
00085     for (int i = 0; i < m2.r * m2.c; i++) {
00086         out.mat[i] = this->mat[i] * m2.mat[i];
00087     }
00088     return out;
00089 }
```

#### 4.5.3.15 operator+()

```
Matrix Matrix::operator+ (
            const Matrix & m2 ) const
```

Definition at line 46 of file matrix.cpp.

```
00046                                               {
00047     Matrix out(m2.r, m2.c, 0);
00048     for (int i = 0; i < m2.r * m2.c; i++) {
00049         out.mat[i] = this->mat[i] + m2.mat[i];
00050     }
00051     return out;
00052 }
```

#### 4.5.3.16 operator-() [1/2]

```
Matrix Matrix::operator- ( )
```

Definition at line 99 of file matrix.cpp.

```
00099                           {
00100     Matrix result = *this;
00101     for (int i = 0; i < r * c; i++) {
00102         result.mat[i] = -mat[i];
00103     }
00104 
00105     return result;
00106 };
```

#### 4.5.3.17 operator-() [2/2]

```
Matrix Matrix::operator- (
            const Matrix & m2 )
```

Definition at line 54 of file matrix.cpp.

```
00054                                         {
00055     Matrix out(m2.r, m2.c, 0);
00056     for (int i = 0; i < m2.r * m2.c; i++) {
00057         out.mat[i] = this->mat[i] - m2.mat[i];
00058     }
00059     return out;
00060 }
```

#### 4.5.3.18 operator/()

```
Matrix Matrix::operator/ (
            const Matrix & m2 )
```

Definition at line 91 of file matrix.cpp.

```
00091                                         { // Hadamard product
00092     Matrix out(m2.r, m2.c, 0);
00093     for (int i = 0; i < m2.r * m2.c; i++) {
00094         out.mat[i] = this->mat[i] / m2.mat[i];
00095     }
00096     return out;
00097 }
```

#### 4.5.3.19 operator=()

```
Matrix & Matrix::operator= (
            const Matrix & m2 )
```

Definition at line 37 of file matrix.cpp.

```
00037                                         { // Overloading the = operator
00038     r = m2.r;
00039     c = m2.c;
00040
00041     this->mat = m2.mat; // IM Since we're using vectors we can just use the assignment from that
00042
00043     return *this;
00044 }
```

#### 4.5.3.20 outerProduct()

```
void Matrix::outerProduct (
            const Vector & x,
            const Vector & y )
```

Definition at line 91 of file matrix_impl_blis.cpp.

```
00091                                                               {
00092     assert( x.size() == r );
00093     assert( y.size() == c );
00094     float val = 1.0;
00095
00096     //printf("BLIS gemm (outer) %dx%d\n",r,c);
00097     bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_TRANSPOSE,
00098             r, c, 1, &val,
00099             const_cast<float*>(x.data()), 1, 1,
00100             const_cast<float*>(y.data()), c, 1, &val, &mat[0], c, 1);
00101
00102 }
```

#### 4.5.3.21 rowsize()

```
int Matrix::rowsize ( ) const  [inline]
```

Definition at line 38 of file matrix.h.

```
00038 { return r; };
```

#### 4.5.3.22 show()

```
void Matrix::show ( ) const
```

Definition at line 53 of file matrix_impl_blis.cpp.

```
00053                            {
00054
00055     char e[5] = "";
00056     char format[8] = "%4.4f";
00057     bli_sprintm( e, r, c, const_cast<float*>(&mat[0]), c, 1, format, e );
00058 }
```

#### 4.5.3.23 square()

void Matrix::square ( )

Definition at line 134 of file matrix.cpp.

```
00134                         {
00135     std::for_each(mat.begin(), mat.end(), [](auto &n) { n *= n;});
00136 }
```

#### 4.5.3.24 transpose()

Matrix Matrix::transpose ( ) const

Definition at line 42 of file matrix_impl_blis.cpp.

```
00042                                {
00043     Matrix result(c, r, 0); // Initialize a new matrix with inverted dimension values
00044 
00045     // m = r, n = c
00046     // rs = 1, cs = m, rsf = 1, csf = n
00047     //printf("BLIS copy %dx%d\n",c,r);
00048     bli_scopym( 0, BLIS_NONUNIT_DIAG, BLIS_DENSE, BLIS_TRANSPOSE,
00049         c, r, const_cast<float*>(&mat[0]), c, 1, &result.mat[0], r, 1);
00050     return result;
00051 }
```

#### 4.5.3.25 values() [1/2]

std::vector< float > & Matrix::values ( ) [inline]

Definition at line 31 of file matrix.h.

```
00031 { return mat; };
```

#### 4.5.3.26 values() [2/2]

const std::vector< float > & Matrix::values ( ) const [inline]

Definition at line 32 of file matrix.h.

```
00032 { return mat; };
```

#### 4.5.3.27 zeros()

void Matrix::zeros ( )

Definition at line 130 of file matrix.cpp.

```
00130                        {
00131     std::fill(mat.begin(), mat.end(), 0);
00132 }
```

### 4.5.4 Friends And Related Function Documentation

#### 4.5.4.1 operator*

```
Matrix operator* (
        const float & c,
        const Matrix & m ) [friend]
```

Definition at line 64 of file matrix.cpp.

```
00064                                                    {
00065     Matrix o = m;
00066     assert(o.mat.size()==o.r*o.c);
00067     for (int i = 0; i < o.r * o.c; i++) {
00068         o.mat[i] = c * o.mat[i];
00069     }
00070     return o;
00071 }
```

#### 4.5.4.2 operator/

```
Matrix operator/ (
        const Matrix & m,
        const float & c ) [friend]
```

Definition at line 73 of file matrix.cpp.

```
00073                                                    {
00074     Matrix o = m;
00075     for (int i = 0; i < o.r * o.c; i++) {
00076         o.mat[i] = o.mat[i] / c;
00077     }
00078     return o;
00079 }
```

The documentation for this class was generated from the following files:

- matrix.h
- matrix.cpp
- matrix_impl_blis.cpp
- matrix_impl_reference.cpp

## 4.6 Net Class Reference

### Public Member Functions

- Net (int s)
- Net (const Dataset &d)
- void addLayer (int l, acFunc activation)
- void **addLayer** (int l, std::function< float(const float &) > activate_pt, std::function< float(const float &) > gradient_pt, std::string name=std::string("custom"))
- void **addLayer** (int l, std::function< void(const VectorBatch &, VectorBatch &) > apply_activation_batch, std::function< void(const VectorBatch &, VectorBatch &) > activate_gradient_batch, std::string name=std::↩ ::string("custom"))

- void push_layer (const Layer &layer)
- int outputsize () const
- int inputsize (int layer) const
- VectorBatch create_output_batch (int batchsize)
- Layer & backlayer ()
- const Layer & backlayer () const
- const Layer & layer (int i) const
- const Layer & at (int i) const
- Layer & at (int i)
- void show ()
- Categorization **output_vector** () const
- const VectorBatch & **outputs** () const
- void set_lossfunction (lossfn lossFuncName)
- void set_uniform_weights (float)
- void set_uniform_biases (float)
- void feedForward (const Vector &, Vector &)
- void feedForward (const VectorBatch &, VectorBatch &)
- void allocate_batch_specific_temporaries (int batchsize)
- void **calcGrad** (Dataset data)
- void **calcGrad** (VectorBatch data, VectorBatch labels)
- void **backPropagate** (const Vector &input, const Vector &gTruth, const Vector &output)
- void backPropagate (const VectorBatch &input, const VectorBatch &gTruth, const VectorBatch &output)
- void calculate_initial_delta (VectorBatch &result, VectorBatch &gTruth)
- void SGD (float lr, float momentum)
- void RMSprop (float lr, float momentum)
- void set_learning_rate (float lr)
- float learning_rate () const
- void set_decay (float d)
- float decay () const
- void set_momentum (float m)
- float momentum () const
- void set_optimizer (int m)
- int optimizer () const
- void train (const Dataset &train, const Dataset &test, int epochs, int batchSize)
- float calculateLoss (const Dataset &testSplit)
- float accuracy (const Dataset &valSet)
- void saveModel (std::string path)
- void loadModel (std::string path)
- void info ()

## Public Attributes

- std::vector< std::function< void(float lr, float momentum) > > optimize

### 4.6.1 Detailed Description

Definition at line 26 of file net.h.

### 4.6.2 Constructor & Destructor Documentation

#### 4.6.2.1 Net() [1/2]

```
Net::Net (
            int s )
```

Definition at line 29 of file net.cpp.

```
00029                {  // Input vector size
00030     this->inR = s;
00031     this->inC = 1;
00032     samples = 0;
00033 }
```

#### 4.6.2.2 Net() [2/2]

```
Net::Net (
            const Dataset & d )
```

Definition at line 35 of file net.cpp.

```
00035                              {
00036   this->inR = data.data_size(); //data.items.at(0).data.size();
00037   this->inC = 1;
00038   samples = 0;
00039 }
```

### 4.6.3 Member Function Documentation

#### 4.6.3.1 accuracy()

```
float Net::accuracy (
            const Dataset & valSet )
```

Definition at line 407 of file net.cpp.

```
00407                                                   {
00408   if (trace_progress())
00409     cout « "Accuracy calculation\n";
00410
00411   int correct = 0;
00412   int incorrect = 0;
00413
00414   assert( test_set.size()>0 );
00415   const auto& test_inputs = test_set.inputs();
00416   const auto& test_labels = test_set.labels();
00417   assert( test_inputs.batch_size()==test_labels.batch_size() );
00418   assert( test_inputs.batch_size()>0 );
00419
00420   //      allocate_batch_specific_temporaries(test_inputs.batch_size());
00421   if (trace_arrays()) {
00422       cout « "inputs:\n"; test_inputs.show();
00423   }
00424   assert( test_inputs.normf()!=0.f );
00425   auto output_batch = this->create_output_batch(test_labels.batch_size());
00426   feedForward(test_inputs,output_batch);
00427   if (trace_arrays()) {
00428       cout « "outputs:\n"; output_batch.show();
00429   }
00430   assert( output_batch.notnan() );
00431
00432   for(int idx=0; idx < output_batch.batch_size(); idx++ ) {
00433       Vector oneItem = output_batch.get_vectorObj(idx);
00434       Categorization result( oneItem );
00435       result.normalize();
00436       if ( result.close_enough( test_labels.extract_vector(idx) ) ) {
```

```
      correct++;
      } else {
      incorrect++;
      }
  }
  assert( correct+incorrect==test_set.size() );

  float acc = static_cast<float>( correct ) / static_cast<float>( test_set.size() );
  return acc;
}
```

#### 4.6.3.2 addLayer()

```
void Net::addLayer (
            int l,
            acFunc f )
```

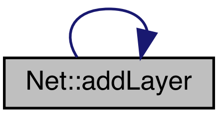
Add a layer from indexed activation function

**Todo** this one probably has to go

Definition at line 89 of file net.cpp.

```
00089                                  {
00090   addLayer( l,
00091         apply_activation<VectorBatch>.at(f),
00092         activate_gradient<VectorBatch>.at(f),
00093         activation_names.at(f)
00094         );
00095 }
```

Here is the call graph for this function:




#### 4.6.3.3 allocate_batch_specific_temporaries()

```
void Net::allocate_batch_specific_temporaries (
            int batchsize )
```

Resize temporaries to reflect current batch size

Definition at line 346 of file net.cpp.

```
00346                                                          {
00347 #ifdef DEBUG
00348   cout « "allocating temporaries for batch size " « batchsize « endl;
00349 #endif
00350   for ( auto& layer : layers )
00351     layer.allocate_batch_specific_temporaries(batchsize);
00352 }
```

#### 4.6.3.4 at() [1/2]

```
Layer & Net::at (
            int i )  [inline]
```

Definition at line 79 of file net.h.

```
00079 { return layers.at(i); };
```

#### 4.6.3.5 at() [2/2]

```
const Layer & Net::at (
            int i ) const  [inline]
```

Definition at line 78 of file net.h.

```
00078 { return layers.at(i); };
```

#### 4.6.3.6 backlayer() [1/2]

```
Layer & Net::backlayer ( )  [inline]
```

Definition at line 73 of file net.h.

```
00073                         {
00074     assert(layers.size()>0); return layers.back(); };
```

#### 4.6.3.7 backlayer() [2/2]

```
const Layer & Net::backlayer ( ) const  [inline]
```

Definition at line 75 of file net.h.

```
00075                                   {
00076     assert(layers.size()>0); return layers.back(); };
```

#### 4.6.3.8 backPropagate()

```
void Net::backPropagate (
            const VectorBatch & input,
            const VectorBatch & output,
            const VectorBatch & gTruth )
```

Full back propagation sweep

Definition at line 199 of file net.cpp.

```
{

  if (layers.size()==1) {
    throw(string("single layer case does not work"));
      // const VectorBatch& prev = input;
      // layers.back().update_dw(delta, prev);
      // return;
  } else {

    if (trace_progress()) cout « "Layer-" « layers.back().layer_number « "\n";
    layers.back().set_topdelta( gTruth,output );
    const VectorBatch& prev = layers.back().input();
    layers.back().update_dw(layers.back().delta, prev);


    for (unsigned i = layers.size() - 2; i > 0; i--) {
      if (trace_progress()) cout « "Layer-" « layers.at(i).layer_number « "\n";
      layers.at(i).backward
      ( layers.at(i+1).delta, layers.at(i+1).weights, layers.at(i).input());
    }

    if (trace_progress()) cout « "Layer-" « layers.at(0).layer_number « "\n";
    layers.at(0).backward(layers.at(1).delta, layers.at(1).weights, input);

  }
}
```

#### 4.6.3.9 calculate_initial_delta()

```
void Net::calculate_initial_delta (
            VectorBatch & input,
            VectorBatch & gTruth )
```

Set up delta values for back propagation

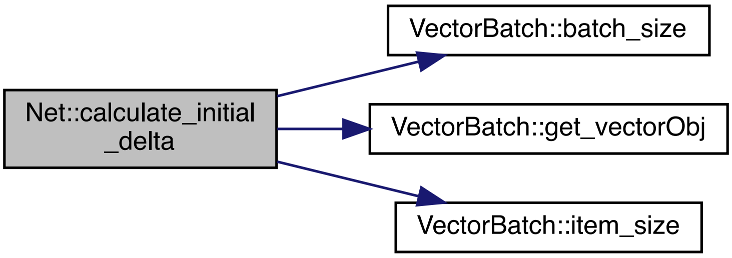
**Todo** stuff to be done?

Definition at line 178 of file net.cpp.

```
{
    VectorBatch d_loss = d_lossFunction( gTruth, input);

    if (layers.back().activation_name == "SoftMax" ) { // Softmax derivative function
        Matrix jacobian( input.item_size(), input.item_size(), 0 );
        for(int i = 0; i < input.batch_size(); i++ ) {
          auto one_column = input.get_vector(i);
          jacobian = smaxGrad_vec( one_column );
          Vector one_vector( jacobian.rowsize(), 0 );
          Vector one_grad = d_loss.get_vectorObj(i);
          jacobian.mvp( one_grad, one_vector );
          layers.back().d_activated_batch.set_vector(one_vector,i);
        }
    }
    /* Will add the rest of the code here, not done yet
    */
}
```

Here is the call graph for this function:




#### 4.6.3.10 calculateLoss()

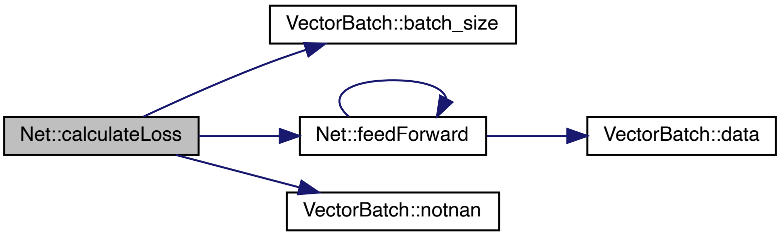
```
float Net::calculateLoss (
              const Dataset & testSplit )
```

Calculate the los function as sum of losses of the individual data point.

Definition at line 359 of file net.cpp.

```
00359                                                     {
00360
00361 #ifdef DEBUG
00362   cout « "Loss calculation\n";
00363 #endif
00364   //  allocate_batch_specific_temporaries(testSplit.inputs().batch_size());
00365   VectorBatch result = this->create_output_batch( testSplit.inputs().batch_size() );
00366   feedForward( testSplit.inputs(),result );
00367   assert( result.notnan() );
00368
00369     float loss = 0.0;
00370     auto tmp_labels =  testSplit.labels();
00371     if (trace_arrays()) {
00372       cout « "Compare results\n"; result.show();
00373       cout « " to label\n"; tmp_labels.show();
00374     }
00375     for (int vec=0; vec<result.batch_size(); vec++) { // iterate over all items
00376       const auto& one_result = result.extract_vector(vec); // VLE figure out const span !!!
00377       auto one_label  = tmp_labels.get_vector(vec);
00378       assert( one_result.size()==one_label.size() );
00379       for (int i=0; i<one_result.size(); i++) { // Calculate loss of result
00380     auto this_label = one_label[i], this_result = one_result[i];
00381     assert( not std::isnan(this_label) );
00382     assert( not std::isnan(this_result) );
00383     auto oneloss = lossFunction( this_label, this_result );
00384     assert( not std::isnan(oneloss) );
00385     loss += oneloss;
00386       }
00387     }
00388     const int bs = result.batch_size();
00389     assert( bs>0 );
00390     auto scale = 1.f / static_cast<float>(bs);
00391     loss = loss * scale;
00392
00393     return loss;
00394 }
```

Here is the call graph for this function:




#### 4.6.3.11 create_output_batch()

```
VectorBatch Net::create_output_batch (
              int batchsize )  [inline]
```

Definition at line 67 of file net.h.

```
00067                                                     {
00068     return VectorBatch( outputsize(),batchsize );
00069     };
```

#### 4.6.3.12 decay()

```
float Net::decay ( ) const  [inline]
```

Definition at line 117 of file net.h.

```
00117 { return _decay; };
```

#### 4.6.3.13 feedForward() [1/2]

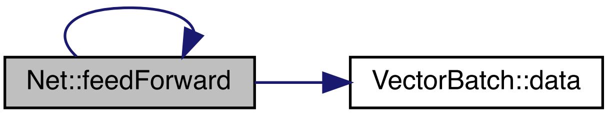
```
void Net::feedForward (
              const Vector & input,
              Vector & output )
```

Feed a single vector input forward through the network This first converts the vector to a batch, so it is not efficient.

Definition at line 155 of file net.cpp.

```
00155                                                           {
00156     VectorBatch input_batch(input), output_batch(input_batch);
00157     feedForward(input_batch,output_batch);
00158     const auto& in_data = input_batch.data();
00159     const auto& out_data = output_batch.data();
00160     //    cout « "net forward: " « in_data[0] « " -> " « out_data[0] « "\n";
00161     output.copy_from( output_batch );
00162 };
```

Here is the call graph for this function:




#### 4.6.3.14 feedForward() [2/2]

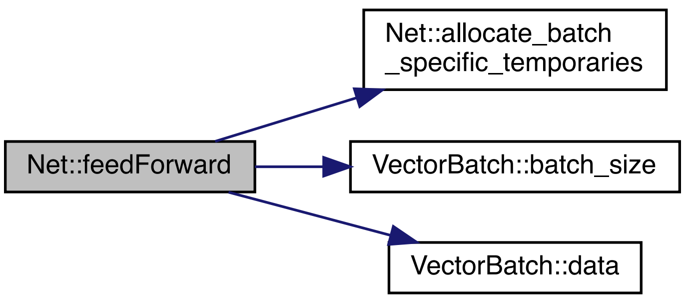
```
void Net::feedForward (
            const VectorBatch & input,
            VectorBatch & output )
```

Feed an input forward through the network The input here is a batch of vectors

Definition at line 126 of file net.cpp.

```
00126                                                                             {
00127   if (trace_progress())
00128     cout « "Feed forward batch of size " « input.batch_size() « endl;
00129   allocate_batch_specific_temporaries(input.batch_size());
00130
00131   if (layers.size()==1) {
00132     layers.front().forward(input,output);
00133     //cout « "single layer output: " « output.data()[0] « "\n";
00134   } else {
00135     layers.front().forward( input, layers.at(1).input() );
00136     cout « " first layer : "
00137      « input.data()[0] « " -> " « layers.at(1).input().data()[0] « "\n";
00138     for (unsigned i = 1; i<layers.size()-1; i++) {
00139       layers.at(i).forward
00140     (layers.at(i).input(),
00141      layers.at(i+1).input()
00142      );
00143     }
00144     layers.back().forward(layers.back().input(),output);
00145     cout « "last layer : "
00146      « layers.back().input().data()[0] « " -> " « output.data()[0] « "\n";
00147   }
00148 };
```

Here is the call graph for this function:



#### 4.6.3.15 info()

```
void Net::info ( )
```

Definition at line 515 of file net.cpp.

```
00515                     {
00516     cout « "Model info\n---------------\n";
00517 
00518     for ( auto l : layers ) {
00519         cout « "Weights: " « l.output_size() « " x " « l.input_size() « "\n";
00520         cout « "Biases: " « l.biases.size() « "\n";
00521         cout « "Activation: " « l.activation_name « "\n";
00522 
00523         // switch (l.activation) {
00524         //  case RELU: cout « "RELU\n"; break;
00525         //  case SIG: cout « "Sigmoid\n"; break;
00526         //  case SMAX: cout « "Softmax\n"; break;
00527         //  case NONE: break;
00528         // }
00529         cout « "---------------\n";
00530     }
00531 
00532 }
```

#### 4.6.3.16 inputsize()

```
int Net::inputsize (
              int layer ) const  [inline]
```

Definition at line 60 of file net.h.

```
00060                                     {
00061     assert(layer>=0); assert(layer<=layers.size());
00062     if (layers.empty())
00063         return inR; // Input's row size for the first layer
00064     else
00065         return layers.at(layer-1).output_size(); // Previous layer's row size
00066     };
```

#### 4.6.3.17 layer()

```
const Layer & Net::layer (
              int i ) const  [inline]
```

Definition at line 77 of file net.h.

```
00077 { return layers.at(i); };
```

#### 4.6.3.18 learning_rate()

```
float Net::learning_rate ( ) const  [inline]
```

Definition at line 112 of file net.h.

```
00112 { return _lr; };
```

#### 4.6.3.19 loadModel()

```
void Net::loadModel (
        std::string path )
```

Definition at line 486 of file net.cpp.

```
00486                                  {
00487     std::ifstream file(path);
00488     std::string buffer;
00489 
00490     int no_layers;
00491     file.read( reinterpret_cast<char *>(&no_layers), sizeof(no_layers) );
00492 
00493     float temp;
00494     layers.resize(no_layers);
00495     for ( int i=0; i < layers.size(); i++ ) {
00496         int insize,outsize;
00497         file.read( reinterpret_cast<char *>(&outsize), sizeof(int) );
00498         file.read( reinterpret_cast<char *>(&insize), sizeof(int) );
00499 
00500         file.read( reinterpret_cast<char *>(&layers[i].activation), sizeof(int) );
00501 
00502         layers[i].weights = Matrix( outsize, insize, 0 );
00503         float *w_data = layers[i].weights.data();
00504         file.read(reinterpret_cast<char *>( w_data ), //(&layers[i].weights.mat[0]),
00505               sizeof(temp) * insize*outsize);
00506 
00507         layers[i].biases = Vector( outsize, 0 );
00508         float *b_data = layers[i].biases.data();
00509         file.read(reinterpret_cast<char *>( b_data ), //(&layers[i].biases.vals[0]),
00510               sizeof(temp) * layers[i].biases.size());
00511     }
00512 }
```

#### 4.6.3.20 momentum()

```
float Net::momentum ( ) const  [inline]
```

Definition at line 122 of file net.h.

```
00122 { return _momentum; };
```

#### 4.6.3.21 optimizer()

```
int Net::optimizer ( ) const  [inline]
```

Definition at line 127 of file net.h.

```
00127 { return _optimizer; };
```

#### 4.6.3.22 outputsize()

```
int Net::outputsize ( ) const  [inline]
```

Definition at line 56 of file net.h.

```
00056                        {
00057     assert( layers.size()>0 );
00058     return layers.back().output_size();
00059     };
```

#### 4.6.3.23 push_layer()

```
void Net::push_layer (
            const Layer & layer )
```

Push a layer as last layer of a network

Definition at line 76 of file net.cpp.

```
00076                                         {
00077     if (trace_progress())
00078     cout « "Creating layer " « layers.size()
00079         « " of size " « layer.output_size() « "x" « layer.input_size()
00080        //       « " with " « name « " activation"
00081         « endl;
00082     layers.push_back(layer);
00083 };
```

#### 4.6.3.24 RMSprop()

```
void Net::RMSprop (
            float lr,
            float momentum )
```

Definition at line 256 of file net.cpp.

```
00256                                          {
00257     for (int i = 0; i < layers.size(); i++) {
00258         // Get average over all the gradients
00259         Matrix deltaWsq = layers.at(i).dw;
00260         Vector deltaBsq = layers.at(i).db;
00261 
00262     // Gradient step
00263         deltaWsq.square(); // dW^2
00264         deltaBsq.square(); // db^2
00265         // Sdw := m*Sdw + (1-m) * dW^2
00266 
00267     layers.at(i).dw_velocity = momentum * layers.at(i).dw_velocity + (1 - momentum) * deltaWsq;
00268         layers.at(i).db_velocity = momentum * layers.at(i).db_velocity + (1 - momentum) * deltaBsq;
00269 
00270     Matrix sqrtSdw = layers.at(i).dw_velocity;
00271         std::for_each(sqrtSdw.values().begin(), sqrtSdw.values().end(),
00272             [](auto &n) {
00273             n = sqrt(n);
00274             if(n==0) n= 1-1e-7;
00275             });
00276     Vector sqrtSdb = layers.at(i).db_velocity;
00277         std::for_each(sqrtSdb.values().begin(), sqrtSdb.values().end(),
00278             [](auto &n) {
00279             n = sqrt(n);
00280             if(n==0) n= 1-1e-7;
00281             });
00282 
00283         // W := W - lr * dW / sqrt(Sdw)
00284         layers.at(i).weights = layers.at(i).weights - lr * layers.at(i).dw / sqrtSdw;
00285         layers.at(i).biases = layers.at(i).biases - lr * layers.at(i).db / sqrtSdb;
00286 
00287         // Reset the values of delta sums
00288         layers.at(i).dw.zeros();
00289         layers.at(i).db.zeros();
00290     }
00291 }
```

### 4.6.3.25 saveModel()

```
void Net::saveModel (
            std::string path )
```

Write the model to file

Definition at line 453 of file net.cpp.

```
00453                                 {
00454     /*
00455     1. Size of matrix m x n, activation function
00456     2. Values of weight matrix
00457     3. Values of bias vector
00458     4. Repeat for all layers
00459     */
00460     std::ofstream file;
00461     file.open( path, std::ios::binary );
00462 
00463     float temp;
00464     int no_layers = layers.size();
00465     file.write( reinterpret_cast<char *>(&no_layers), sizeof(no_layers) );
00466     for ( auto l : layers ) {
00467         int insize = l.input_size(), outsize = l.output_size();
00468         file.write( reinterpret_cast<char *>(&outsize), sizeof(int) );
00469         file.write( reinterpret_cast<char *>(&insize), sizeof(int) );
00470         file.write( reinterpret_cast<char *>(&l.activation), sizeof(int) );
00471 
00472         const auto& weights = l.weights;
00473         file.write(reinterpret_cast<const char *>(weights.data()), sizeof(float)*weights.nelements());
00474         // const float* weights_data = l.weights.data();
00475         // file.write(reinterpret_cast<char *>(&weights_data), sizeof(temp)*insize*outsize);
00476 
00477         const auto& biases = l.biases;
00478         file.write(reinterpret_cast<const char*>(biases.data()), sizeof(float) * biases.size());
00479         //file.write(reinterpret_cast<char *>(&l.biases.vals[0]), sizeof(temp) * l.biases.size());
00480     }
00481     cout « endl;
00482 
00483     file.close();
00484 }
```

### 4.6.3.26 set_decay()

```
void Net::set_decay (
            float d )  [inline]
```

Definition at line 116 of file net.h.

```
00116 { _decay = d; };
```

### 4.6.3.27 set_learning_rate()

```
void Net::set_learning_rate (
            float lr )  [inline]
```

Definition at line 111 of file net.h.

```
00111 { _lr=lr; };
```

#### 4.6.3.28 set_lossfunction()

```
void Net::set_lossfunction (
            lossfn lossFuncName )
```

Set an indexed loss function

Definition at line 100 of file net.cpp.

```
00100                                                     {
00101   lossFunction = lossFunctions.at(lossFuncName);
00102   d_lossFunction = d_lossFunctions.at(lossFuncName);
00103 };
```

#### 4.6.3.29 set_momentum()

```
void Net::set_momentum (
            float m )  [inline]
```

Definition at line 121 of file net.h.

```
00121 { _momentum = m; };
```

#### 4.6.3.30 set_optimizer()

```
void Net::set_optimizer (
            int m )  [inline]
```

Definition at line 126 of file net.h.

```
00126 { _optimizer = m; };
```

#### 4.6.3.31 set_uniform_biases()

```
void Net::set_uniform_biases (
            float v )
```

Initialize biases of all layers to a uniform value

Definition at line 116 of file net.cpp.

```
00116                                         {
00117   for ( auto& l : layers )
00118     l.set_uniform_biases(v);
00119 };
```

#### 4.6.3.32 set_uniform_weights()

```
void Net::set_uniform_weights (
                float v )
```

Initialize weights of all layers to a uniform value

Definition at line 108 of file net.cpp.

```
00108                                       {
00109   for ( auto& l : layers )
00110     l.set_uniform_weights(v);
00111 };
```

#### 4.6.3.33 SGD()

```
void Net::SGD (
                float lr,
                float momentum )
```

Stochastic Gradient Descent algorithm

Definition at line 230 of file net.cpp.

```
00230                                        {
00231     assert( layers.size()>0 );
00232     int samplesize = layers.front().input().batch_size();
00233     for (int i = 0; i < layers.size(); i++) {
00234         // Normalize gradients to avoid exploding gradients
00235     Matrix deltaW = layers.at(i).dw / static_cast<float>(samplesize);
00236         Vector deltaB = layers.at(i).db / static_cast<float>(samplesize);
00237
00238         // Gradient descent
00239         if (momentum > 0.0) {
00240             layers.at(i).dw_velocity = momentum * layers.at(i).dw_velocity - lr * deltaW;
00241             //layers.at(i).weights = layers.at(i).weights + layers.at(i).dw_velocity;
00242         layers.at(i).weights.axpy( 1.f,layers.at(i).dw_velocity );
00243         } else {
00244       //layers.at(i).weights = layers.at(i).weights - lr * deltaW;
00245       layers.at(i).weights.axpy( -lr,deltaW );
00246         }
00247
00248         layers.at(i).biases = layers.at(i).biases - lr * deltaB;
00249
00250         // Reset the values of delta sums
00251         layers.at(i).dw.zeros();
00252         layers.at(i).db.zeros();
00253     }
00254 }
```

#### 4.6.3.34 show()

```
void Net::show ( )
```

Show the weights of all layers

Definition at line 167 of file net.cpp.

```
00167                     {
00168     for (unsigned i = 0; i < layers.size(); i++) {
00169         cout << "Layer " << i << " weights" << endl;
00170         layers.at(i).weights.show();
00171     }
00172 }
```

#### 4.6.3.35 train()

```
void Net::train (
        const Dataset & train,
        const Dataset & test,
        int epochs,
        int batchSize )
```

Definition at line 300 of file net.cpp.

```
                                    {

    const int Optimizer = optimizer();
    cout « "Optimizing with ";
    switch (Optimizer) {
    case sgd:  cout « "Stochastic Gradient Descent\n";  break;
    case rms:  cout « "RMSprop\n"; break;
    }

    std::vector<Dataset> batches = train_data.batch(batchSize);
    float lrInit = learning_rate();
    const float momentum_value = momentum();

    for (int i_epoch = 0; i_epoch < epochs; i_epoch++) {
      // Iterate through the entire dataset for each epoch
      cout « endl « "Epoch " « i_epoch+1 « "/" « epochs « endl;
      float current_learning_rate = lrInit; // Reset the learning rate to undo decay

      for (int j = 0; j < batches.size(); j++) {
    // Iterate through all batches within dataset
    auto& batch = batches.at(j);
#ifdef DEBUG
    cout « ".. batch " « j « "/" « batches.size() « " of size " « batch.size() « "\n";
#endif
    //  allocate_batch_specific_temporaries(batch.size());
    VectorBatch batch_output( batch.inputs().item_size(),batch.size() );
    feedForward(batch.inputs(),batch_output);
    backPropagate(batch.inputs(),batch.labels(),batch_output);

        // User chosen optimizer
        current_learning_rate = current_learning_rate / (1 + decay() * j);
        optimize.at(Optimizer)(current_learning_rate, momentum_value);

      }
      auto loss = calculateLoss(test_data);
      cout « " Loss: " « loss « endl;
      auto acc = accuracy(test_data);
      cout « " Accuracy on trest set: " « acc « endl;
    }

}
```

### 4.6.4 Member Data Documentation

#### 4.6.4.1 optimize

```
std::vector< std::function< void(float lr, float momentum) > > Net::optimize
```

**Initial value:**

```
{
    [this] ( float lr, float momentum ) { SGD(lr, momentum); },
    [this] ( float lr, float momentum ) { RMSprop(lr, momentum); }
  }
```

Definition at line 128 of file net.h.

The documentation for this class was generated from the following files:

- net.h
- net.cpp

## 4.7 Vector Class Reference

### Public Member Functions

- Vector (int n)
- Vector (std::vector< float > vals)
- Vector (int size, int init)
- int size () const
- void show ()
- void add (const Vector &v1)
- void set_ax (float a, Vector &x)
- std::vector< float > & values ()
- const std::vector< float > & values () const
- void copy_from (const VectorBatch &)
- float * data ()
- const float * data () const
- void zeros ()
- void square ()
- float & operator[ ] (int i)
- float operator[ ] (int i) const
- Vector operator- ()
- Vector & operator= (const Vector &m2)
- Vector operator+ (const Vector &m2)
- Vector operator* (const Vector &m2)
- Vector operator/ (const Vector &m2)
- Vector operator/= (float x)
- Vector operator- (const Vector &m2)
- bool positive () const

  *Test that all elements are positive.*

### Public Attributes

- int r
- int c =1

### Friends

- class VectorBatch
- class Matrix
- Vector operator- (const float &c, const Vector &m)
- Vector operator* (const float &c, const Vector &m)

### 4.7.1 Detailed Description

Definition at line 23 of file vector.h.

### 4.7.2 Constructor & Destructor Documentation

#### 4.7.2.1 Vector() [1/4]

Vector::Vector ( )

Definition at line 27 of file vector.cpp.

```
00027               {
00028 }
```

#### 4.7.2.2 Vector() [2/4]

Vector::Vector (
int *n* ) [inline]

Definition at line 30 of file vector.h.

```
00031     : vals(std::vector<float>(n)) {};
```

#### 4.7.2.3 Vector() [3/4]

Vector::Vector (
std::vector< float > *vals* )

Definition at line 32 of file vector.cpp.

```
00033   : vals(vals) {
00034   r = vals.size();
00035   c = 1;
00036 };
```

#### 4.7.2.4 Vector() [4/4]

Vector::Vector (
int *size*,
int *init* )

Definition at line 24 of file vector_impl_blis.cpp.

```
00024                             {
00025     r = s;
00026   vals = std::vector<float>(s);
00027   float scal_fac = 0.05;
00028   if (init==0){
00029     float zero = 0.0;
00030     bli_ssetv( BLIS_NO_CONJUGATE, s, &zero, &vals[0], 1);
00031   }else if (init==1)
00032     bli_srandv(s, &vals[0], 1);
00033     bli_sscalv( BLIS_NO_CONJUGATE, s, &scal_fac, &vals[0], 1 );
00034 }
```

### 4.7.3 Member Function Documentation

### 4.7.3.1 add()

```
void Vector::add (
        const Vector & v1 )
```

Definition at line 36 of file vector_impl_blis.cpp.

```
00036                                    {
00037   assert(v1.size()==this->size());
00038   bli_saddv( BLIS_NO_CONJUGATE, size(), const_cast<float*>(&v1.vals[0]), 1, &vals[0], 1 );
00039 }
```

### 4.7.3.2 copy_from()

```
void Vector::copy_from (
        const VectorBatch & batch )
```

Definition at line 38 of file vector.cpp.

```
00038                                                  {
00039     const auto& batch_vals = batch.data();
00040     assert( batch.nelements()>=vals.size() );
00041     for (int i=0; i<vals.size(); i++) {
00042     vals[i] = batch_vals[i];
00043     }
00044 };
```

### 4.7.3.3 data() [1/2]

```
float * Vector::data ( )  [inline]
```

Definition at line 42 of file vector.h.

```
00042 { return vals.data(); };
```

### 4.7.3.4 data() [2/2]

```
const float * Vector::data ( ) const  [inline]
```

Definition at line 43 of file vector.h.

```
00043 { return vals.data(); };
```

### 4.7.3.5 operator*()

```
Vector Vector::operator* (
        const Vector & m2 )
```

Definition at line 99 of file vector.cpp.

```
00099                                          { // Hadamard product
00100     Vector out(m2.size(), 0);
00101     for (int i = 0; i < m2.size(); i++) {
00102         out.vals[i] = this->vals[i] * m2.vals[i];
00103     }
00104     return out;
00105 }
```

#### 4.7.3.6 operator+()

```
Vector Vector::operator+ (
        const Vector & m2 )
```

Definition at line 57 of file vector.cpp.

```
00057                                              {
00058     assert(m2.size()==this->size());
00059     Vector out(m2.size(),0);
00060     for (int i=0;i<m2.size();i++) {
00061         out.vals[i] = this->vals[i] + m2.vals[i];
00062     }
00063     return out;
00064 }
```

#### 4.7.3.7 operator-() [1/2]

```
Vector Vector::operator- ( )
```

Definition at line 115 of file vector.cpp.

```
00115                              {
00116     Vector result = *this;
00117     for (int i = 0; i < size(); i++){
00118         result.vals[i] = -vals[i];
00119     }
00120 
00121     return result;
00122 };
```

#### 4.7.3.8 operator-() [2/2]

```
Vector Vector::operator- (
        const Vector & m2 )
```

Definition at line 66 of file vector.cpp.

```
00066                                              {
00067     assert(m2.size()==this->size());
00068     Vector out(m2.size(),0);
00069     for (int i=0;i<m2.size();i++) {
00070         out.vals[i] = this->vals[i] - m2.vals[i];
00071     }
00072     return out;
00073 }
```

#### 4.7.3.9 operator/()

```
Vector Vector::operator/ (
        const Vector & m2 )
```

Definition at line 107 of file vector.cpp.

```
00107                                              { // Element wise division
00108     Vector out(m2.size(), 0);
00109     for (int i = 0; i < m2.size(); i++) {
00110         out.vals[i] = this->vals[i] / m2.vals[i];
00111     }
00112     return out;
00113 }
```

### 4.7.3.10 operator/=()

```
Vector Vector::operator/= (
            float x )
```

Definition at line 92 of file vector.cpp.

```
00092                                 {
00093     for (int i=0;i<vals.size();i++) {
00094         vals[i] = vals[i] / c;
00095     }
00096     return *this;
00097 }
```

### 4.7.3.11 operator=()

```
Vector & Vector::operator= (
            const Vector & m2 )
```

Definition at line 50 of file vector.cpp.

```
00050                                         { // Overloading the = operator
00051     vals = m2.vals;
00052     return *this;
00053 }
```

### 4.7.3.12 operator[]() [1/2]

```
float & Vector::operator[] (
            int i ) [inline]
```

Definition at line 46 of file vector.h.

```
00046 { return vals[i]; };
```

### 4.7.3.13 operator[]() [2/2]

```
float Vector::operator[] (
            int i ) const [inline]
```

Definition at line 47 of file vector.h.

```
00047 { return vals[i]; };
```

### 4.7.3.14 positive()

```
bool Vector::positive ( ) const [inline]
```

Test that all elements are positive.

Definition at line 60 of file vector.h.

```
00060                         {
00061     return all_of
00062       ( vals.begin(),vals.end(),
00063     [] (float e) { return e>0; }
00064     );
00065   }
```

#### 4.7.3.15 set_ax()

```
void Vector::set_ax (
            float a,
            Vector & x )
```

Definition at line 41 of file vector_impl_blis.cpp.

```
00041                              {
00042   assert(x.size()==this->size());
00043
00044     float b = static_cast<float>(a);
00045     bli_sscal2v(BLIS_NO_CONJUGATE, this->size(),&b,&x.vals[0],1,&(this->vals)[0], 1);
00046 }
```

#### 4.7.3.16 show()

```
void Vector::show ( )
```

Definition at line 55 of file vector_impl_blis.cpp.

```
00055                 {
00056
00057     char sp[8] = " ";
00058     char format[8] = "%4.4f";
00059     bli_sprintm( sp, size(), 1, &vals[0], 1, size(), format, sp );
00060 }
```

#### 4.7.3.17 size()

```
int Vector::size ( ) const
```

Definition at line 30 of file vector.cpp.

```
00030 { return vals.size(); };
```

#### 4.7.3.18 square()

```
void Vector::square ( )
```

Definition at line 46 of file vector.cpp.

```
00046                  {
00047     std::for_each(vals.begin(), vals.end(), [](auto &n) {n*=n;});
00048 }
```

#### 4.7.3.19 values() [1/2]

```
std::vector< float > & Vector::values ( )  [inline]
```

Definition at line 39 of file vector.h.

```
00039 { return vals; };
```

#### 4.7.3.20 values() [2/2]

```
const std::vector< float > & Vector::values ( ) const [inline]
```

Definition at line 40 of file vector.h.

```
00040 { return vals; };
```

#### 4.7.3.21 zeros()

```
void Vector::zeros ( )
```

Definition at line 49 of file vector_impl_blis.cpp.

```
00049                     {
00050 
00051     float zero = 0.0;
00052     bli_ssetv( BLIS_NO_CONJUGATE, size(), &zero, &vals[0], 1 ); // Set all values to 0
00053 }
```

### 4.7.4 Friends And Related Function Documentation

#### 4.7.4.1 Matrix

```
friend class Matrix [friend]
```

Definition at line 25 of file vector.h.

#### 4.7.4.2 operator*

```
Vector operator* (
            const float & c,
            const Vector & m ) [friend]
```

Definition at line 84 of file vector.cpp.

```
00084                                                  {
00085     Vector o=m;
00086     for (int i=0;i<m.size();i++) {
00087         o.vals[i] = c * o.vals[i];
00088     }
00089     return o;
00090 }
```

#### 4.7.4.3 operator-

```
Vector operator- (
            const float & c,
            const Vector & m )  [friend]
```

Definition at line 76 of file vector.cpp.

```
                                                        {
    Vector o=m;
    for (int i=0;i<m.size();i++) {
        o.vals[i] = c - o.vals[i];
    }
    return o;
}
```

#### 4.7.4.4 VectorBatch

```
friend class VectorBatch  [friend]
```

Definition at line 24 of file vector.h.

### 4.7.5 Member Data Documentation

#### 4.7.5.1 c

```
int Vector::c =1
```

Definition at line 35 of file vector.h.

#### 4.7.5.2 r

```
int Vector::r
```

Definition at line 35 of file vector.h.

The documentation for this class was generated from the following files:

- vector.h
- vector.cpp
- vector_impl_blis.cpp
- vector_impl_reference.cpp

## 4.8 VectorBatch Class Reference

### Public Member Functions

- VectorBatch (int itemsize)

  *Construct and set the vector size.*
- VectorBatch (int nRows, int nCols, bool rand=false)
- VectorBatch (const Vector &)

  *Construct from a single vector.*
- void allocate (int, int)

  *resize the vals array*
- int size () const
- void resize (int m, int n)

  *resize the values vector*
- float normf () const

  *Frobenius norm.*
- bool positive () const

  *Test that all elements are positive.*
- bool notnan () const

  *Test that there are no NaN elements.*
- bool notinf () const

  *Test that there are no Inf elements.*
- int item_size () const

  *The size of any vector in the batch.*
- void set_item_size (int n)

  *Set the vector size.*
- int batch_size () const

  *How many vectors are there in this batch.*
- void set_batch_size (int n)

  *Set the batch size.*
- int nelements () const

  *Total number of eleements in the whole batch.*
- std::vector< float > & vals_vector ()

  *Return the values vector, for write.*
- const std::vector< float > & vals_vector () const

  *Return the values vector, for read only.*
- float * data ()

  *Return the float data. This is for the BLAS interface.*
- const float * data () const

  *Return the float data. This is for the BLAS interface.*
- const float * data (int disp) const

  *Return the float data with an offset. This is for the BLAS interface.*
- void v2mp (const Matrix &x, VectorBatch &y) const
- void v2tmp (const Matrix &x, VectorBatch &y) const
- void v2mtp (const Matrix &x, VectorBatch &y) const
- void outer2 (const VectorBatch &x, Matrix &y) const
- void add_vector (const std::vector< float > &v)

  *Extend the batch with a new vector.*
- float at (int i, int j) const

  *Return element i of the j'th vector in the batch, with bound checking.*
- void set_col (int j, const std::vector< float > &v)

*Copy a vector into batch j.*

- std::vector< float > get_col (int j) const
- void set_row (int j, const std::vector< float > &v)
- std::vector< float > get_row (int j) const
- std::vector< float > extract_vector (int v) const
- std::vector< float > get_vector (int v) const
- void set_vector (const Vector &v, int j)

  *Copy vector elements into vector j of this batch.*
- void **set_vector** (const std::vector< float > &v, int j)
- Vector get_vectorObj (int j) const

  *Extract one vector from the batch.*
- void show () const
- void display (std::string) const

  *Crude output.*
- void copy_from (const VectorBatch &in)

  *Copy a whole batch into this one.*
- void addh (const Vector &y)
- void **addh** (const VectorBatch &y)
- Vector meanh () const
- VectorBatch operator- ()
- VectorBatch & operator= (const VectorBatch &m2)
- void hadamard (const VectorBatch &m1, const VectorBatch &m2)
- VectorBatch operator* (const VectorBatch &m2)
- VectorBatch operator/ (const VectorBatch &m2)
- void scaleby (float)
- VectorBatch operator- (const VectorBatch &m2) const

## Friends

- class Matrix
- class Vector
- VectorBatch operator/ (const VectorBatch &m, const float &c)
- VectorBatch operator* (const float &c, const VectorBatch &m)

### 4.8.1 Detailed Description

Definition at line 32 of file vector2.h.

### 4.8.2 Constructor & Destructor Documentation

#### 4.8.2.1 VectorBatch() [1/4]

```
VectorBatch::VectorBatch ( )
```

Definition at line 34 of file vector2.cpp.

```
00034                           { // Default constructor
00035 }
```

### 4.8.2.2 VectorBatch() [2/4]

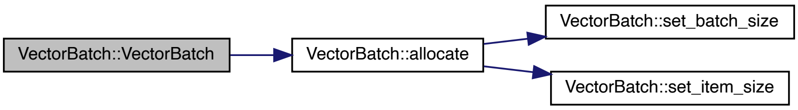
```
VectorBatch::VectorBatch (
            int itemsize )
```

Construct and set the vector size.

Definition at line 38 of file vector2.cpp.

```
00038                                   {
00039   allocate(0,vs);
00040 }
```

Here is the call graph for this function:




### 4.8.2.3 VectorBatch() [3/4]

```
VectorBatch::VectorBatch (
            int nRows,
            int nCols,
            bool rand = false )
```

Definition at line 29 of file vectorbatch_impl_blis.cpp.

```
00029                                                               {
00030   allocate(nRows,nCols);
00031   const int r=nRows, c=nCols;
00032 
00033   float scal_fac = 0.05; // randomize between (-scal;scal)
00034   if (not random){
00035     float zero = 0.0;
00036     bli_ssetm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
00037            r, c, &zero, &vals[0], c, 1);
00038   } else if (random){
00039     bli_srandm(0, BLIS_DENSE, r, c, &vals[0], c, 1);
00040     bli_sscalm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
00041         r, c, &scal_fac, &vals[0], c, 1);
00042   }
00043 }
```

#### 4.8.2.4 VectorBatch() [4/4]

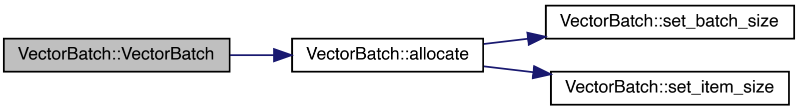
```
VectorBatch::VectorBatch (
            const Vector & v )
```

Construct from a single vector.

Definition at line 43 of file vector2.cpp.

```
00043                                    {
00044     int s = v.size();
00045     allocate(1,s);
00046     copy( v.vals.begin(),v.vals.end(),vals.begin() );
00047     // for ( int i=0; i<s; i++ )
00048     //  vals[i] = v[i];
00049 };
```

Here is the call graph for this function:




### 4.8.3 Member Function Documentation

#### 4.8.3.1 add_vector()

```
void VectorBatch::add_vector (
            const std::vector< float > & v )
```

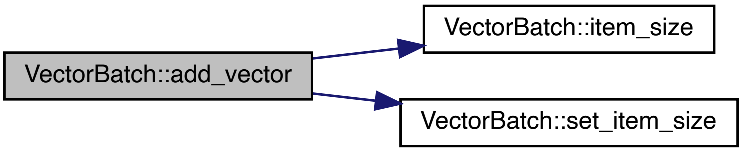
Extend the batch with a new vector.

**Todo** use the allocate method

Definition at line 83 of file vector2.cpp.

```
00083                                                  {
00084   const int Nelements = vals.size();
00085   const int vector_length = v.size();
00086   if (Nelements==0)
00087     set_item_size(vector_length);
00088   else {
00089     assert( vector_length==item_size() );
00090     assert( Nelements%vector_length==0 );
00091   }
00092   const int m = Nelements/vector_length;
00093   vals.resize(Nelements+vector_length); nvectors++;
00094   for (int i = 0; i < vector_length; i++) {
00095     vals.at( m * vector_length + i ) = v.at(i);
00096   };
00097 };
```

Here is the call graph for this function:




#### 4.8.3.2 addh()

```
void VectorBatch::addh (
             const Vector & y )
```

Definition at line 162 of file vector2.cpp.

```
00162                                      { // Add y to every row
00163   const int r = item_size(), c = batch_size();
00164   assert( r==y.size() );
00165   for (int j=0; j<c; j++ ) {
00166     for (int i=0; i<r; i++) {
00167       vals.at( INDEXc(i,j,r,c) ) += y.vals[i];
00168     }
00169   }
00170 }
```

#### 4.8.3.3 allocate()

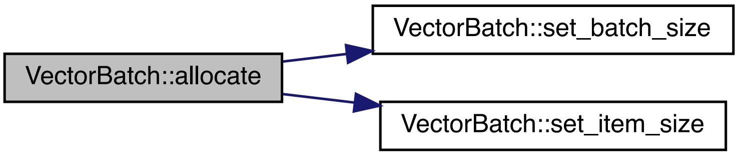
```
void VectorBatch::allocate (
             int batchsize,
             int itemsize )
```

resize the vals array

Definition at line 52 of file vector2.cpp.

```
00052                                                   {
00053   // we allow a batchsize of zero
00054   assert(batchsize>=0);
00055   assert(itemsize>0);
00056   vals.resize(batchsize*itemsize);
00057   set_batch_size(batchsize);
00058   set_item_size(itemsize);
00059 };
```

Here is the call graph for this function:




#### 4.8.3.4 at()

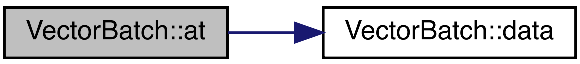
```
float VectorBatch::at (
            int i,
            int j ) const  [inline]
```

Return element i of the j'th vector in the batch, with bound checking.

Definition at line 120 of file vector2.h.

```
00120                                 {
00121       assert( i>=0 ); assert( i<vector_size );
00122       assert( j>= 0 ); assert( j<nvectors );
00123       return *data( i + j*vector_size );
00124       };
```

Here is the call graph for this function:




#### 4.8.3.5 batch_size()

```
int VectorBatch::batch_size ( ) const  [inline]
```

How many vectors are there in this batch.

Definition at line 87 of file vector2.h.

```
00087 { return nvectors; };
```

#### 4.8.3.6 copy_from()

```
void VectorBatch::copy_from (
            const VectorBatch & in ) [inline]
```

Copy a whole batch into this one.

Definition at line 155 of file vector2.h.

```
00155                                        {
00156     assert( vals.size()==in.vals.size() );
00157     std::copy( in.vals.begin(),in.vals.end(),vals.begin() );
00158     // for ( int i=0; i<vals.size(); i++)
00159     //   vals[i] = in.vals[i];
00160   };
```

#### 4.8.3.7 data() [1/3]

```
float * VectorBatch::data ( ) [inline]
```

Return the float data. This is for the BLAS interface.

Definition at line 102 of file vector2.h.

```
00102 { return vals.data(); };
```

#### 4.8.3.8 data() [2/3]

```
const float * VectorBatch::data ( ) const [inline]
```

Return the float data. This is for the BLAS interface.

Definition at line 104 of file vector2.h.

```
00104 { return vals.data(); };
```

#### 4.8.3.9 data() [3/3]

```
const float * VectorBatch::data (
            int disp ) const [inline]
```

Return the float data with an offset. This is for the BLAS interface.

Definition at line 106 of file vector2.h.

```
00106 { return vals.data()+disp; };
```

#### 4.8.3.10 display()

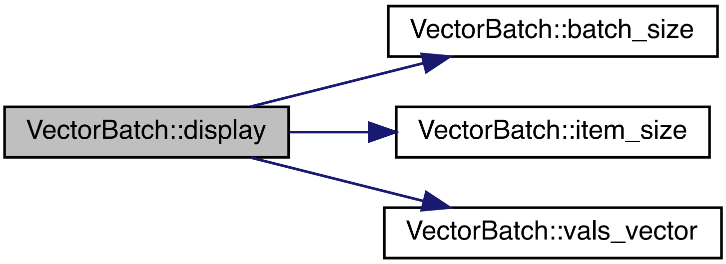
```
void VectorBatch::display (
            std::string  ) const
```

Crude output.

Definition at line 62 of file vector2.cpp.

```
00062                                                    {
00063   cout « header « "\n";
00064   for (int j=0; j<batch_size(); j++) {
00065     for (int i=0; i<item_size(); i++)
00066       cout « setprecision(5)
00067        « vals_vector().at( INDEXc(i,j,item_size(),batch_size()) )
00068        « " ";
00069     cout « "\n";
00070   }
00071 };
```

Here is the call graph for this function:




#### 4.8.3.11 extract_vector()

```
std::vector< float > VectorBatch::extract_vector (
            int v ) const
```

Definition at line 125 of file vector2.cpp.

```
00125                                                              {
00126   assert( j<batch_size() );
00127   const int m = item_size();
00128   std::vector<float> v(m);
00129   for (int i = 0; i < m; i++)
00130     v.at(i) = vals.at( INDEXc(i,j,m,batch_size()) );  // (j * n + i );
00131   return v;
00132   //  return get_row(v);
00133 };
```

#### 4.8.3.12 get_col()

```
std::vector< float > VectorBatch::get_col (
            int j ) const
```

Definition at line 99 of file vector2.cpp.

```
00099                                                   {
00100   assert( j<batch_size() );
00101   const int c = item_size();
00102   std::vector<float> col(c);
00103   for (int i=0; i<c; i++)
00104     col.at(i) = vals.at( j + c*i );
00105   return col;
00106 };
```

#### 4.8.3.13 get_row()

```
std::vector< float > VectorBatch::get_row (
            int j ) const
```

Definition at line 116 of file vector2.cpp.

```
00116                                                   {
00117   assert( j<batch_size() );
00118   const int n = item_size();
00119   std::vector<float> row(n);
00120   for (int i = 0; i < n; i++)
00121     row.at(i) = vals.at( j * n + i );
00122   return row;
00123 };
```

#### 4.8.3.14 get_vector()

```
std::vector< float > VectorBatch::get_vector (
            int v ) const
```

Definition at line 144 of file vector2.cpp.

```
00144                                                      {
00145   return extract_vector(v);
00146 };
```

#### 4.8.3.15 get_vectorObj()

```
Vector VectorBatch::get_vectorObj (
            int j ) const  [inline]
```

Extract one vector from the batch.

Definition at line 141 of file vector2.h.

```
00141                                        {
00142     Vector vec(vector_size);
00143     std::copy( vals.begin()+j*vector_size,vals.begin()+(j+1)*vector_size,
00144            vec.vals.begin() );
00145     // for (int i = 0; i < vector_size; i++ )
00146     //   vec.vals.at(i) = vals.at( j * vector_size + i );
00147     return vec;
00148   }
```

### 4.8.3.16 hadamard()

```
void VectorBatch::hadamard (
            const VectorBatch & m1,
            const VectorBatch & m2 )
```

Definition at line 232 of file vector2.cpp.

```
00232                                                           {
00233   const int r = item_size(), c = batch_size();
00234   assert( r==m1.item_size() ); assert( c==m1.batch_size() );
00235   assert( r==m2.item_size() ); assert( c==m2.batch_size() );
00236
00237   const auto& m1vals = m1.vals_vector();
00238   const auto& m2vals = m2.vals_vector();
00239   for (int i=0; i<r*c; i++) {
00240     vals.at(i) = m1vals.at(i) * m2vals.at(i);
00241     if ( isinf(vals.at(i)) )
00242       cout « "inf from " « m1vals.at(i) « " * " « m2vals.at(i) « "\n";
00243   }
00244   if (trace_progress()) {
00245     assert( m1.notinf() ); assert( m1.notnan() ); assert( m1.normf()!=0.f );
00246     assert( m2.notinf() ); assert( m2.notnan() ); assert( m2.normf()!=0.f );
00247     assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
00248   }
00249   if (trace_scalars()) {
00250     cout « "delta: "
00251      « m1.normf() « "x" « m2.normf() « " => " « this->normf() « "\n";
00252   }
00253 }
```

### 4.8.3.17 item_size()

```
int VectorBatch::item_size ( ) const  [inline]
```

The size of any vector in the batch.

Definition at line 83 of file vector2.h.

```
00083 { return vector_size; };
```

### 4.8.3.18 meanh()

```
Vector VectorBatch::meanh ( ) const
```

Definition at line 183 of file vector2.cpp.

```
00183                             { // Returns a vector of row-wise means
00184   const int r = item_size(), c = batch_size();
00185   Vector mean(r, 0);
00186   for (int i=0; i<r; i++) {
00187     float avg = 0.f;
00188     for ( int j=0; j<c; j++ ) {
00189       avg += vals.at( INDEXc(i,j,r,v) );
00190     }
00191     mean.vals[i] = avg/static_cast<float>( item_size() );
00192   }
00193   return mean;
00194 }
```

#### 4.8.3.19 nelements()

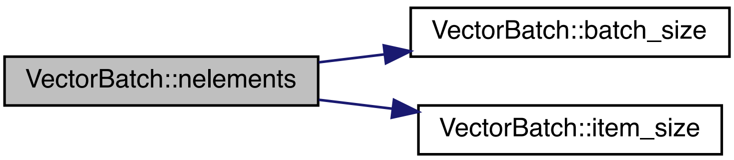
```
int VectorBatch::nelements ( ) const  [inline]
```

Total number of eleements in the whole batch.

Definition at line 91 of file vector2.h.

```
00091                            {
00092       int n = vals.size();
00093       assert( n==item_size()*batch_size() );
00094       return n;
00095     };
```

Here is the call graph for this function:




#### 4.8.3.20 normf()

```
float VectorBatch::normf ( ) const  [inline]
```

Frobenius norm.

Definition at line 53 of file vector2.h.

```
00053                          {
00054       float norm{0.f}; int count{0};
00055       for ( auto e : vals ) {
00056     norm += e*e; count++;
00057       }
00058       //std::cout « "norm squared over " « count « " elements: " « norm « "\n";
00059       return sqrt(norm);
00060     };
```

#### 4.8.3.21 notinf()

```
bool VectorBatch::notinf ( ) const  [inline]
```

Test that there are no Inf elements.

Definition at line 76 of file vector2.h.

```
00076                          {
00077       return all_of
00078     ( vals.begin(),vals.end(),
00079       [] (float e) { return not isinf(e); }
00080     );
00081     }
```

### 4.8.3.22 notnan()

```
bool VectorBatch::notnan ( ) const  [inline]
```

Test that there are no NaN elements.

Definition at line 69 of file vector2.h.

```
00069                        {
00070       return all_of
00071     ( vals.begin(),vals.end(),
00072       [] (float e) { return not isnan(e); }
00073     );
00074     }
```

### 4.8.3.23 operator*()

```
VectorBatch VectorBatch::operator* (
              const VectorBatch & m2 )
```

Definition at line 221 of file vector2.cpp.

```
00221                                                   { // Hadamard product
00222   assert( item_size()==m2.item_size() );
00223   assert( batch_size()==m2.batch_size() );
00224   const int c = m2.item_size(), r = m2.batch_size();
00225   VectorBatch out(r, c, 0);
00226   for (int i = 0; i < nelements(); i++) {
00227       out.vals[i] = this->vals[i] * m2.vals[i];
00228     }
00229     return out;
00230 }
```

### 4.8.3.24 operator-() [1/2]

```
VectorBatch VectorBatch::operator- ( )
```

Definition at line 272 of file vector2.cpp.

```
00272                                     {
00273     VectorBatch result = *this;
00274     for (int i = 0; i < nelements(); i++) {
00275         result.vals[i] = -vals[i];
00276     }
00277 
00278     return result;
00279 };
```

### 4.8.3.25 operator-() [2/2]

```
VectorBatch VectorBatch::operator- (
              const VectorBatch & m2 ) const
```

Definition at line 210 of file vector2.cpp.

```
00210                                                         {
00211   assert( item_size()==m2.item_size() );
00212   assert( batch_size()==m2.batch_size() );
00213   const int c = m2.item_size(), r = m2.batch_size();
00214   VectorBatch out(r, c, 0);
00215     for (int i = 0; i < r * c; i++) {
00216       out.vals[i] = this->vals[i] - m2.vals[i];
00217     }
00218     return out;
00219 }
```

#### 4.8.3.26 operator/()

```
VectorBatch VectorBatch::operator/ (
            const VectorBatch & m2 )
```

Definition at line 255 of file vector2.cpp.

```
00255                                                     { // Hadamard product
00256   const int c = m2.item_size(), r = m2.batch_size();
00257   assert( item_size()==c );
00258   assert( batch_size()==r );
00259   VectorBatch out(r, c, 0);
00260   for (int i = 0; i < nelements(); i++) {
00261     out.vals[i] = this->vals[i] / m2.vals[i];
00262   }
00263   return out;
00264 }
```

#### 4.8.3.27 operator=()

```
VectorBatch & VectorBatch::operator= (
            const VectorBatch & m2 )
```

Definition at line 200 of file vector2.cpp.

```
00200                                                      { // Overloading the = operator
00201   set_item_size( m2.item_size() );
00202   set_batch_size( m2.batch_size() );
00203
00204   this->vals = m2.vals; // IM Since we're using vectors we can just use the assignment from that
00205
00206   return *this;
00207 }
```

#### 4.8.3.28 outer2()

```
void VectorBatch::outer2 (
            const VectorBatch & x,
            Matrix & y ) const
```

Definition at line 163 of file vectorbatch_impl_blis.cpp.

```
00163                                                           {
00164   const int
00165     yr = item_size(),   yc = batch_size(),   // column storage
00166     mr = m.rowsize(),   mc = m.colsize(),    // row storage
00167     xr = x.item_size(), xc = x.batch_size(); // column
00168
00169   if (trace_scalars())
00170     cout « "outer product "
00171      « xr « "x" « xc
00172      « " & "
00173      « yr « "x" « yc
00174      « " => " « mr « "x" « mc
00175      « endl;
00176
00177   assert( yc==xc );
00178   assert( xr==mr );
00179   assert( yr==mc );
00180   const auto& xvals = x.vals_vector().data();
00181   const auto& yvals =   vals_vector().data();
00182   auto        mmat  = m.values().data();
00183
00184   float alpha = 1.0;
00185   float beta = 0.0;
00186   bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_TRANSPOSE,
00187          mr,mc,yc,
00188          &alpha,
00189          const_cast<float*>(xvals), /* rsa,csa */ 1,xr,
00190          const_cast<float*>(yvals), /* rsb,csb */ 1,yr,
00191          &beta,
00192          mmat,                      /* rsc,csc */ mc,1
00193          );
00194
00195 }
```

#### 4.8.3.29 positive()

```
bool VectorBatch::positive ( ) const  [inline]
```

Test that all elements are positive.

Definition at line 62 of file vector2.h.

```
00062                             {
00063       return all_of
00064     ( vals.begin(),vals.end(),
00065       [] (float e) { return e>0; }
00066     );
00067     }
```

#### 4.8.3.30 resize()

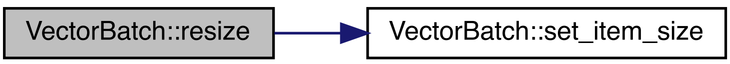
```
void VectorBatch::resize (
             int m,
             int n )  [inline]
```

resize the values vector

Definition at line 49 of file vector2.h.

```
00049                                {
00050       nvectors = m; set_item_size(n); //r = m; c = n;
00051       vals.resize(m*n); };
```

Here is the call graph for this function:




#### 4.8.3.31 scaleby()

```
void VectorBatch::scaleby (
             float f )
```

Definition at line 266 of file vector2.cpp.

```
00266                                     {
00267   for (int i = 0; i < nelements(); i++) {
00268     vals[i] *= f;
00269   }
00270 }
```

#### 4.8.3.32 set_batch_size()

```
void VectorBatch::set_batch_size (
             int n )  [inline]
```

Set the batch size.

**Todo** should be private, maybe eliminated?

Definition at line 89 of file vector2.h.

```
00089 { nvectors = n; };
```

#### 4.8.3.33 set_col()

```
void VectorBatch::set_col (
             int j,
             const std::vector< float > & v )
```

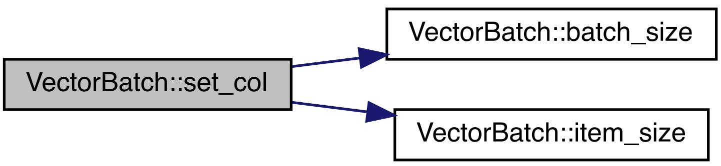
Copy a vector into batch j.

**Todo** rename to set_vector?

Definition at line 74 of file vector2.cpp.

```
00074                                                        {
00075   assert( j<batch_size() );
00076   assert( v.size()==item_size() );
00077   for (int i = 0; i<nvectors; i++) {
00078     vals.at( j + vector_size * i ) = v.at(i);
00079   };
00080 };
```

Here is the call graph for this function:



#### 4.8.3.34 set_item_size()

```
void VectorBatch::set_item_size (
            int n )  [inline]
```

Set the vector size.

**Todo** should be private, maybe eliminated?

Definition at line 85 of file vector2.h.

```
00085 { vector_size = n; };
```

#### 4.8.3.35 set_row()

```
void VectorBatch::set_row (
            int j,
            const std::vector< float > & v )
```

Definition at line 108 of file vector2.cpp.

```
00108                                                             {
00109   const int c = item_size();
00110   assert( v.size()==c );
00111   for (int i = 0; i < c; i++) {
00112     vals.at( j * c + i ) = v.at(i);
00113   };
00114 }
```

#### 4.8.3.36 set_vector()

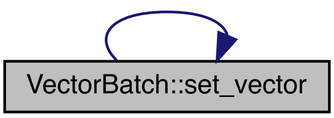
```
void VectorBatch::set_vector (
            const Vector & v,
            int j )
```

Copy vector elements into vector j of this batch.

Definition at line 150 of file vector2.cpp.

```
00150                                                      {
00151   set_vector( v.vals,j );
00152 }
```

Here is the call graph for this function:



#### 4.8.3.37 show()

```
void VectorBatch::show ( ) const
```

Definition at line 54 of file vectorbatch_impl_blis.cpp.

```
00054                                         {
00055 
00056     const int c = batch_size(), r = item_size();
00057     char e[5] = "";
00058     char forvals[8] = "%4.4f";
00059     bli_sprintm( e, r, c, const_cast<float*>(&vals[0]), c, 1, forvals, e );
00060 }
```

#### 4.8.3.38 size()

```
int VectorBatch::size ( ) const  [inline]
```

Definition at line 47 of file vector2.h.

```
00047 { return vals.size(); };
```

#### 4.8.3.39 v2mp()

```
void VectorBatch::v2mp (
              const Matrix & x,
              VectorBatch & y ) const
```

Definition at line 69 of file vectorbatch_impl_blis.cpp.

```
00069                                                                       {
00070   const int
00071     xr = item_size(),    xc = batch_size(),    // column storage
00072     mr = m.rowsize(),    mc = m.colsize(),     // row storage
00073     yr = y.item_size(), yc = y.batch_size(); // column
00074 
00075   if (trace_scalars())
00076     cout « "matrix vector product "
00077      « mr « "x" « mc
00078      « " & "
00079      « xr « "x" « xc
00080      « " => " « yr « "x" « yc
00081      « endl;
00082 
00083   assert( xc==yc );
00084   assert( yr==mr );
00085   assert( mc==xr );
00086 
00087   const auto& mmat  = m.values().data();
00088   const auto& xvals = vals_vector().data();
00089   auto  yvals       = y.vals_vector().data();
00090 
00091   float alpha = 1.0;
00092   float beta = 0.0;
00093   bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_NO_TRANSPOSE,
00094          yr,yc,mc,
00095          &alpha,
00096          const_cast<float*>(mmat),  /* rsa,csa */ mr,1,
00097          const_cast<float*>(xvals), /* rsb,csb */ 1,xr,
00098          &beta,
00099          yvals,                     /* rsc,csc */ 1,yr
00100          );
00101 }
```

#### 4.8.3.40 v2mtp()

```
void VectorBatch::v2mtp (
            const Matrix & x,
            VectorBatch & y ) const
```

Definition at line 120 of file vectorbatch_impl_blis.cpp.

```
00120                                                              {
00121   const int
00122     xr = item_size(),    xc = batch_size(),    // column storage
00123     mr = m.rowsize(),    mc = m.colsize(),     // row storage
00124     yr = y.item_size(), yc = y.batch_size(); // column
00125
00126   if (trace_scalars())
00127     cout « "matrix transpose vector product "
00128      « mr « "x" « mc
00129      « " & "
00130      « xr « "x" « xc
00131      « " => " « yr « "x" « yc
00132      « endl;
00133
00134   assert( xc==yc );
00135   assert( yr==mc );
00136   assert( mr==xr );
00137
00138   const auto& mmat  = m.values().data();
00139   const auto& xvals = vals_vector().data();
00140   auto         yvals = y.vals_vector().data();
00141
00142   float alpha = 1.0;
00143   float beta = 0.0;
00144   bli_sgemm( BLIS_TRANSPOSE, BLIS_NO_TRANSPOSE,
00145          yr,yc,mr,
00146          &alpha,
00147          const_cast<float*>(mmat),   /* rsa,csa */ mc,1,
00148          const_cast<float*>(xvals), /* rsb,csb */ 1,xr,
00149          &beta,
00150          yvals,                      /* rsc,csc */ 1,yr
00151          );
00152   if (trace_progress()) {
00153     assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
00154     assert( m.notinf() ); assert( m.notnan() ); assert( m.normf()!=0.f );
00155     assert( y.notinf() ); assert( y.notnan() ); assert( y.normf()!=0.f );
00156   }
00157
00158 }
```

#### 4.8.3.41 v2tmp()

```
void VectorBatch::v2tmp (
            const Matrix & x,
            VectorBatch & y ) const
```

Definition at line 103 of file vectorbatch_impl_blis.cpp.

```
00103                                                              {
00104
00105     const int c = batch_size(), r = item_size();
00106     assert( r==x.rowsize() );
00107     assert( c==y.batch_size() );
00108     assert( x.colsize()==y.item_size() );
00109
00110     float alpha = 1.0;
00111     float beta = 0.0;
00112     //printf("BLIS gemm %dx%dx%d\n",r,x.colsize(),c);
00113     bli_sgemm( BLIS_TRANSPOSE, BLIS_NO_TRANSPOSE,
00114            c, x.colsize(), r, &alpha, const_cast<float*>(&vals[0]),
00115            c, 1, const_cast<float*>( x.data() ),
00116            x.colsize(), 1, &beta, &y.vals[0], x.colsize(), 1);
00117 }
```

#### 4.8.3.42 vals_vector() [1/2]

```
std::vector< float > & VectorBatch::vals_vector ( ) [inline]
```

Return the values vector, for write.

Definition at line 98 of file vector2.h.

```
00098 { return vals; };
```

#### 4.8.3.43 vals_vector() [2/2]

```
const std::vector< float > & VectorBatch::vals_vector ( ) const [inline]
```

Return the values vector, for read only.

Definition at line 100 of file vector2.h.

```
00100 { return vals; };
```

### 4.8.4 Friends And Related Function Documentation

#### 4.8.4.1 Matrix

```
friend class Matrix [friend]
```

Definition at line 33 of file vector2.h.

#### 4.8.4.2 operator*

```
VectorBatch operator* (
        const float & c,
        const VectorBatch & m ) [friend]
```

Definition at line 289 of file vector2.cpp.

```
00289                                                                    {
00290     VectorBatch o = m;
00291     for (int i = 0; i < m.nelements(); i++) {
00292         o.vals[i] = o.vals[i] * c;
00293     }
00294     return o;
00295 }
```

#### 4.8.4.3 operator/

```
VectorBatch operator/ (
            const VectorBatch & m,
            const float & c )  [friend]
```

Definition at line 281 of file vector2.cpp.

```
                                                              {
    VectorBatch o = m;
    for (int i = 0; i < m.nelements(); i++) {
        o.vals[i] = o.vals[i] / c;
    }
    return o;
}
```

#### 4.8.4.4 Vector

```
friend class Vector  [friend]
```

Definition at line 34 of file vector2.h.

The documentation for this class was generated from the following files:

- vector2.h
- vector2.cpp
- vectorbatch_impl_blis.cpp
- vectorbatch_impl_reference.cpp

# Chapter 5

# File Documentation

## 5.1 configure.py

```
#!/usr/bin/env python3

import re
import sys

def usage():
    print("Usage: configure.py [ --blis BLIS_DIR ]")
    sys.exit(0)

args = sys.argv[1:]
if len(args)==0:
    print("No Make.inc generated")
    usage()



makeinc = open("Make.inc","w")
while len(args)>0:
    a,args = args[0],args[1:]
    if not re.match(r’--’,a):
        usage()
    elif re.match(r’--blis’,a):
        if len(args)==0:
            print("Missing blis argument")
            sys.exit(1)
        else:
            b,args = args[0],args[1:]
            if re.match(r’--’,b):
                print(f"Probably missing blis argument: «{b}»")
                sys.exit(1)
            makeinc.write(f"""CXX=clang++ -std=c++17 -fopenmp
            USE_BLIS=1
BLIS_INC_DIR={b}/include
BLIS_LIB_DIR={b}/lib
""")
    else:
        print(f"Unknown option {a}")
        sys.exit(1)

```

## 5.2 dataset.cpp

```
/****************************************************************
 ****************************************************************
 ****
 **** This text file is part of the source of
 **** ‘Introduction to High-Performance Scientific Computing’
 **** by Victor Eijkhout, copyright 2012-2021
 ****
 **** Deep Learning Network code
 **** copyright 2021 Ilknur Mustafazade
 ****
 ****************************************************************
 ****************************************************************/
```

```
#include <iostream>
using std::cout;
using std::endl;
#include <string>
using std::string;
#include <vector>
using std::vector;

#include <cstdio>
#include <cassert>
#include <algorithm>
using std::for_each;
#include <random>

#include "dataset.h"
#include "trace.h"

#define IMSIZE 28

Dataset::Dataset( int n ) : nclasses(n) {
  assert(n>=0);
};

Dataset::Dataset( std::vector<dataItem> dv ) {
  for ( const auto& v : dv )
    push_back(v);
};

void Dataset::set_lowerbound( int b ) { lowerbound = b; };
void Dataset::set_number( int b ) { number = b; };

void Dataset::push_back(dataItem it) {
  if (nclasses>0 and it.label_size()!=nclasses) {
    cout « "Set dimensionality " « nclasses
         « " does not match item size " « it.label_size() « endl;
    throw( string("Fail to add item to dataset") );
  }
  if (nclasses==0)
    nclasses = it.label_size();
  dataBatch.add_vector( it.data_values() );
  labelBatch.add_vector( it.label_values() );
  //_items.push_back(it);
};

dataItem Dataset::item(int i) const {
  return dataItem( data_vals(i),label_vals(i) );
};

int Dataset::size() const {
  int ds = dataBatch.batch_size(), ls = labelBatch.batch_size();
  assert( ds==ls );
  return ds;
}

int Dataset::data_size() const {
  if (dataBatch.batch_size()==0)
    throw( string("Can not get data size for empty dataset") );
  return dataBatch.item_size();
};

int Dataset::label_size() const {
  if (labelBatch.batch_size()==0)
    throw( string("Can not get label size for empty dataset") );
  return labelBatch.item_size();
}

const Vector& Dataset::data(int i) const {
  throw( string("Do not use Dataset::data") );
  //  return _items.at(i).data;
};
const vector<float> Dataset::data_vals(int i) const {
  return dataBatch.extract_vector(i);
};
const vector<float> Dataset::label_vals(int i) const {
  return labelBatch.extract_vector(i);
};
vector<float> Dataset::stacked_data_vals(int i) const {
  throw( string("Do not use Dataset::stacked_data_vals") );
  return dataBatch.get_row(i);
};

vector<float> Dataset::stacked_label_vals(int i) const {
  throw( string("Do not use Dataset::stacked_label_vals") );
  return labelBatch.get_row(i);
};
```

```
int Dataset::readTest(std::string dataPath) {
    /*
     * This reader is specifically for a modified MNIST dataset which
     * does not include the file header, metadata, etc.
     * Link to the dataset: http://cis.jhu.edu/~sachin/digit/digit.html
     * I chose this dataset for now to make it easy to read the data;
     * in later iterations I will generalize the read function, maybe OpenCV support
     */

    FILE *file;
    std::string fileName;
    uint8_t temp[IMSIZE * IMSIZE]; // Image buffer to read data into
    for (int dataid = 0; dataid < 10; dataid++) {
        fileName = dataPath + "/data" + std::to_string(dataid); // Put together the path
        file = fopen(fileName.c_str(), "r");


        if (!file) { // File checking
            cout « "Error opening file" « endl;
            return -2; // Arbitrary error code
        }
        for (int k = 0; k < 1000; k++) {
            Vector imageVec(IMSIZE * IMSIZE, 0); // initialize matrix to be read into
            fread(temp, 1, IMSIZE * IMSIZE, file); // Read 28*28 into buffer

            for (int i = 0; i < IMSIZE; i++) {
                for (int j = 0; j < IMSIZE; j++) {
                    // Transfer from buffer into matrix
          float *i_data = imageVec.data();
          *( i_data + i * IMSIZE + j ) // imageVec.vals[i * IMSIZE + j]
            = static_cast<float>( temp[i * IMSIZE + j] );
                }
            }
            fseek(file, k * IMSIZE * IMSIZE, SEEK_SET); // Seek to the kth image bytes

        Categorization label(10,dataid);

            dataItem x = {imageVec, label}; // Initialize an item with the data and the label in it
            push_back(x); // Store in the vector

        }
        fclose(file);
    }
    return 0;
}


void Dataset::shuffle() {
    std::random_device r;
    std::seed_seq seed{r(), r(), r(), r(), r(), r(), r(), r()}; // Seed
    std::mt19937 eng1(seed); // Randomizer engine

    throw( string("shuffling doesn't work") );
    //    std::shuffle(begin(_items), end(_items), eng1); // Shuffle the dataset
    return; // todo add return codes instead of printing
}


std::vector<Dataset> Dataset::batch(int batch_size) const {

  std::vector<Dataset> batches;
  int nitems = size(), itemsize = data_size();
  int nbatches = nitems/batch_size + ( nitems%batch_size>0 ? 1 : 0 );
  for (int b=0; b<nbatches; b++) {
    int first = b*batch_size, last= std::min( (b+1)*batch_size,nitems );
    Dataset batch; //(itemsize,last-first);
    batch.set_lowerbound(first); batch.set_number(b);
    for (int i=first; i<last; i++) {
      batch.push_back( item(i) );
    }
    batches.push_back(batch);
  }

  return batches;
}

void Dataset::stack() { // Stacks vectors horizontally (column-wise) in a Matrix object
  throw( string("Stacking no longer needed") );
    //dataBatch  = VectorBatch( data_size(),  size(), 0);
    //labelBatch = VectorBatch( label_size(), size(), 0);

    dataBatch  = VectorBatch( size(),  data_size(), 0);
    labelBatch = VectorBatch( size(), label_size(), 0);

    for (int j = 0; j < size(); j++) {
        //dataBatch.set_col( j,data_vals(j) );
        dataBatch.set_row( j, data_vals(j) );
```

```
    }

    for (int j = 0; j < size(); j++) {
        //labelBatch.set_col( j,label_vals(j) );
        labelBatch.set_row( j, label_vals(j) );
    }
}


/* forward definition, see below */ vector<int> permutation(int N);
std::pair< Dataset,Dataset > Dataset::split(float trainFraction) const {
    int dataset_size = size(); // _items.size();
    int testSize{0},trainSize;
    while ( true ) {
      trainSize= ceil( static_cast<float>( dataset_size ) * trainFraction);
      testSize = dataset_size - trainSize;
      if ( testSize>0 ) break;
      trainFraction *= .9;
    }

    auto random_index = permutation(dataset_size);
    Dataset trainSplit;
    if (trace_progress())
      cout « "split into " « trainSize « "+" « testSize « endl;
    for (int i=0; i<trainSize; i++) {
      const auto& di = item( random_index[i] );
      trainSplit.push_back(di);
    }
    Dataset testSplit;
    for (int i=trainSize; i<trainSize+testSize; i++) {
      const auto& di = item( random_index[i] );
      testSplit.push_back(di);
    }

    return std::make_pair(trainSplit,testSplit);
}

vector<int> permutation(int N) {

  std::random_device r;
  std::default_random_engine generator; // {r()};
  std::uniform_int_distribution<> distribution(0,N-1);

  vector<int> numbers(N);
  for (int i=0; i<N; i++)
    numbers[i] = i;

  for (int pass=0; pass<N; pass++) {
    int
      i = distribution(generator),
      j = distribution(generator);
    int t = numbers[i]; numbers[i] = numbers[j]; numbers[j] = t;
  }

  return numbers;
}
```

## 5.3 dataset.h

```
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 ****************************************************************/

#ifndef CODE_DATASET_H
#define CODE_DATASET_H
//#include "matrix.h"
#include "vector2.h"
#include "vector.h"
#include <vector>
#include <iostream>

class dataItem{
public: // should really be done through friends private:
    Vector data; // Data matrix
```

```
  //Vector label; // Label
    Categorization label; // Label
public:
  dataItem( Vector data,/* Vector */ Categorization label)
    : data(data),label(label) {};
  dataItem( float data,Categorization label)
    : data( std::vector<float>(data) ),label(label) {};
  dataItem( std::vector<float> indata,std::vector<float> outdata )
    : data( Vector(indata) ),label( Categorization(outdata) ) {};
  int data_size() const { return data.size(); };
  const std::vector<float>& data_values() const { return data.values(); };
  int label_size() const { return label.size(); };
  const std::vector<float>& label_values() const { return label.probabilities(); };
};

class Dataset {
private:
  int nclasses{0};
  //  std::vector<dataItem> _items; // All the data: {data, label}
private:
    VectorBatch dataBatch;
    VectorBatch labelBatch;
  int lowerbound{0},number{0};
public:
  Dataset() {};
  Dataset( int n );
  Dataset( std::vector<dataItem> );

  void set_lowerbound( int b );
  void set_number( int b );
  void push_back(dataItem it);
  int size() const;
  int data_size() const;
  int label_size() const;

  dataItem item(int i) const;
  //  const dataItem& at(int i) const { return _items.at(i); };
  //  dataItem& at(int i) { return _items.at(i); };
  const Vector& data(int i) const;
  const std::vector<float> data_vals(int i) const;
  const std::vector<float> label_vals(int i) const;
  std::vector<float> stacked_data_vals(int i) const;
  std::vector<float> stacked_label_vals(int i) const;
  //  const Categorization& label(int i) const { return _items.at(i).label; };

  //  const std::vector<dataItem>& items() const { return _items; };
  //const Vector& label(int i) const { return items.at(i).label; };

    std::string path; // Path of the dataset
public:
  const auto& inputs() const { return dataBatch; };
  const auto& labels() const { return labelBatch; };

    int readTest(std::string dataPath); // Read modified MNIST Dataset
    void shuffle(); // Mix the dataset
    std::vector<Dataset> batch(int n) const; // Divides the dataset into n batches
    void stack();
    std::pair<Dataset,Dataset> split(float trainFraction) const; // Train-test split
};


#endif //CODE_DATASET_H
```

## 5.4 funcs.cpp

```
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#include "funcs.h"
#include "trace.h"

#include <iostream>
using std::cout;
```

```
using std:: endl;
#include <iomanip>
using std::boolalpha;

#include <algorithm>
#include <numeric>
using std::accumulate;
#include <functional>
using std::function;
#include <vector>
using std::vector;

#include <cmath>
#include <cassert>

void relu_io(const VectorBatch &mm, VectorBatch &a) {

  VectorBatch m(mm);
  assert( a.item_size()==m.item_size() );
  assert( a.batch_size()==m.batch_size() );
        auto& avals = a.vals_vector();
  const auto& mvals = m.vals_vector();
  avals.assign(mvals.begin(),mvals.end());
  const float alpha = 0.01; // used for leaky relu, for regular relu, set alpha to 0.0
  for (int i = 0; i < m.batch_size() * m.item_size(); i++) {
    // values will be 0 if negative, and equal to themselves if positive
    if (avals.at(i) < 0)
      avals.at(i) *= alpha;
    //cout « i « ":" « avals.at(i) « endl;
  }
#ifdef DEBUG
  m.display("Apply RELU to");
  a.display("giving");
#endif
}

//codesnippet netsigmoid
//template <typename VectorBatch>
void sigmoid_io(const VectorBatch &m, VectorBatch &a) {

    const auto& mvals = m.vals_vector();
    auto& avals = a.vals_vector();
    avals.assign(mvals.begin(),mvals.end());
    // for (int i = 0; i < m.batch_size() * m.item_size(); i++) {
    //   avals[i] = 1 / (1 + exp(-avals[i]));
    // }
    for ( auto& e: avals ) {
      e = 1.f / ( 1.f + exp( -e ) );
      if (e<1.e-5) e = 1.e-5;
      if (e>1-1.e-5) e = 1-1.e-5;
    }
    if (trace_scalars()) {
      bool limit{true};
      float min{2.f},max{-1.f};
      for_each( avals.begin(),avals.end(),
        [&min,&max,&limit] (auto e) {
          assert( not isinf(e) ); assert( not isnan(e) );
          if (e<min) min = e; if (e>max) max = e;
          limit = limit && e>0 && e<1;
        }
        );
      cout « "sigmoid limited: " « boolalpha « limit
       « ": " « min « "--" « max « "\n";
      assert( limit );
    }
}
//codesnippet end

void softmax_io(const VectorBatch &m, VectorBatch &a) {

  const int vector_size = a.item_size(), batch_size = a.batch_size();
  assert( vector_size==m.item_size() );
  assert( batch_size==m.batch_size() );
  vector<float> nB(batch_size,0);
  vector<float> mVectorBatch(batch_size,-99);

  // compute software independently for each vector j
  for (int j = 0; j < batch_size; j++) {
    // copy a vector from m into temporary aj
    auto aj = a.extract_vector(j);
    const auto& mj = m.extract_vector(j);
    std::copy( mj.begin(),mj.end(),aj.begin() );
    // find the max
    mVectorBatch.at(j) = *max_element( aj.begin(),aj.end() );
    for_each( aj.begin(),aj.end(),
              [=] ( auto& x ) { x -= mVectorBatch.at(j); } );
    for_each( aj.begin(),aj.end(),
```

```
               [] ( auto& x ) { x = exp(x); } );
    nB.at(j) = accumulate( aj.begin(),aj.end(),0 );
    if ( nB.at(j)==0 ) throw("softmax aj is zero");
    for_each( aj.begin(),aj.end(),
               [=] ( auto& x ) { x /= nB.at(j); } );
    for_each( aj.begin(),aj.end(),
               [] ( auto& x ) {
            if (x <= 1e-7)
              x = 1e-7;
            if (x >= 1 - 1e-7)
              x = 1 - 1e-7;
               } );
    a.set_vector( aj,j );
  }

#ifdef DEBUG
  assert( a.positive() );
  m.display("Apply SoftMAX to");
  a.display("giving");
#endif
}

void softmax_io( const Vector& input, Vector& output ) {
    VectorBatch input_batch(input), output_batch(input_batch);
    softmax_io(input_batch,output_batch);
    output.copy_from( output_batch );
};

//template <typename VectorBatch>
void linear_io(const VectorBatch &m, VectorBatch &a) {
    a.vals_vector().assign(m.vals_vector().begin(),m.vals_vector().end());
}

//template <typename VectorBatch>
void reluGrad_io(const VectorBatch &m, VectorBatch &a) {
  assert( a.item_size()==m.item_size() );
        auto& avals = a.vals_vector();
  const auto& mvals = m.vals_vector();
  avals.assign(mvals.begin(),mvals.end());
  float alpha = 0.01;
  for ( auto &e : avals) {
    if (e<=0)
      e = alpha;
    else
      e = 1.0;
  }
  if (trace_progress()) {
    assert( a.normf()!=0.f );
    assert( a.notinf() );
    assert( a.notnan() );
  }
}

//template <typename VectorBatch>
void sigGrad_io(const VectorBatch &m, VectorBatch &a) {
    assert( m.size()==a.size() );

    const auto& mvals = m.vals_vector();
    auto& avals = a.vals_vector();

    avals.assign(mvals.begin(),mvals.end());
    for ( auto &e : avals )
      e = e * (1.0 - e);
    if (trace_scalars())
      cout « "sigmoid grad " « m.normf() « " => " « a.normf() « "\n";
}

//template <typename VectorBatch>
void smaxGrad_io(const VectorBatch &m, VectorBatch &a) {
  assert( m.size()==a.size() );
  throw("Unimplemented smaxGrad_io");
}

#include <limits>
void nan_io(const VectorBatch &mm, VectorBatch &a) {

  VectorBatch m(mm);
  assert( a.item_size()==m.item_size() );
  assert( a.batch_size()==m.batch_size() );
  auto& avals = a.vals_vector();
  for (int i = 0; i < a.batch_size() * a.item_size(); i++) {
     avals.at(i) = std::numeric_limits<float>::signaling_NaN();
  }
}

#ifdef USE_GSL
Matrix smaxGrad_vec( const gsl::span<float> &v)
```

```
#else
Matrix smaxGrad_vec( const std::vector<float> &v)
#endif
{
    Matrix im(v.size(),1,0); // Input but converted to a matrix

    for (int i=0; i<v.size(); i++){
      float *i_data = im.data();
      *( i_data +i ) // im.mat[i]
    = v[i];
    }

    Matrix dM = im;

    Matrix diag(dM.rowsize(),dM.rowsize(),0);

    for (int i=0,j=0; i<diag.rowsize()*diag.colsize(); i+=diag.rowsize()+1,j++) {
        // identity * dM
      float *d_data = diag.data(), *m_data = dM.data();
      *( d_data+i ) // diag.mat[i]
    = *( m_data+j ); //dM.mat[j];
    }

    // S_(i,j) dot S_(i,k)
    Matrix dMT = dM.transpose();

    Matrix S(dM.rowsize(),dMT.colsize(),0);
    dM.mmp(dMT, S);
    im = diag - S; // Jacobian
    return im;

}


//template <typename VectorBatch>
void linGrad_io(const VectorBatch &m, VectorBatch &a) {
    assert( m.size()==a.size() );
    std::fill(a.vals_vector().begin(), a.vals_vector().end(), 1.0); // gradient of a linear function
}

float id_pt( const float& x ) {
    return x;
}

float relu_pt( const float& x ) {
  float y;
  if (x < 0)
      y = 0.;
  else
      y = x;
  return y;
}

float relu_slope_pt( const float& x ) {
  const float alpha = 0.01;
  if (x < 0)
      return x * alpha;
  else
      return x;
}

float sigmoid_pt( const float& x ) {
    float y = 1.f / ( 1.f + exp( -x ) );
    if (y<1.e-5)
    return 1.e-5;
    else if (y>1-1.e-5)
    return 1-1.e-5;
    else
    return y;
}

void batch_activation
    ( function< float(const float&) > pointwise,const VectorBatch &i,VectorBatch &o,bool by_vector ) {

  assert( i.item_size()==o.item_size() );
  assert( i.batch_size()==o.batch_size() );
  const auto& ivals = i.vals_vector();
  auto& ovals = o.vals_vector();
  ovals.assign(ivals.begin(),ivals.end());
  if (by_vector) {
    throw("need to think about by-vector activation");
    for ( int v=0; v<o.batch_size(); v++ ) {
      auto vec = o.get_vector(v);
      for_each( vec.begin(),vec.end(), pointwise );
      o.set_vector(vec,v);
    }
  } else {
```

```
    for ( size_t i=0; i<o.item_size()*o.batch_size(); i++ ) {
      ovals[i] = pointwise( ivals[i] );
    }
    //    for_each( ovals.begin(),ovals.end(), pointwise );
  }
#ifdef DEBUG
  o.display("Apply pointwise function to");
  i.display("giving");
#endif

}

```

## 5.5 funcs.h

```
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#ifndef SRC_FUNCS_H
#define SRC_FUNCS_H

#include <functional>

#include "matrix.h"
#include "vector.h"
#include "vector2.h"

#ifdef USE_GSL
#include "gsl/gsl-lite.hpp"
#endif

//template <typename VectorBatch>
void relu_io    (const VectorBatch &i, VectorBatch &v);
//template <typename VectorBatch>
void sigmoid_io (const VectorBatch &i, VectorBatch &v);
//template <typename VectorBatch>
void softmax_io (const VectorBatch &i, VectorBatch &v);
void softmax_io( const Vector& input, Vector& output );
//template <typename VectorBatch>
void linear_io    (const VectorBatch &i, VectorBatch &v);
void nan_io     (const VectorBatch &i, VectorBatch &v);

//template <typename VectorBatch>
void reluGrad_io(const VectorBatch &m, VectorBatch &a);
//template <typename VectorBatch>
void sigGrad_io (const VectorBatch &m, VectorBatch &a);
//template <typename VectorBatch>
void smaxGrad_io(const VectorBatch &m, VectorBatch &a);
//template <typename VectorBatch>
void linGrad_io (const VectorBatch &m, VectorBatch &a);

#ifdef USE_GSL
Matrix smaxGrad_vec( const gsl::span<float> &v);
#else
Matrix smaxGrad_vec( const std::vector<float> &v);
#endif

enum acFunc{RELU,SIG,SMAX,NONE};

static inline std::vector< std::string > activation_names{
  "ReLU", "Sigmoid", "SoftMax", "Linear" };

template <typename V>
static inline std::vector< std::function< void(const V&, V&) > > apply_activation{
  [] ( const V &v, V &a ) { relu_io(v,a); },
    [] ( const V &v, V &a ) { sigmoid_io(v,a); },
    [] ( const V &v, V &a ) { softmax_io(v,a); },
    [] ( const V &v, V &a ) { linear_io(v,a); }
};

template <typename V>
static inline std::vector< std::function< void(const V&, V&) > > activate_gradient{
  [] (  const V &m, V &v ) { reluGrad_io(m,v); },
```

```
    [] (  const V &m,  V &v ) { sigGrad_io(m,v); },
    [] (  const V &m,  V &v ) { smaxGrad_io(m,v); },
    [] (  const V &m,  V &v ) { linGrad_io(m,v); }
};

enum lossfn{cce, mse}; // categorical cross entropy, mean squared error
inline static std::vector< std::function< float( const float& groundTruth, const float& result) > >
 lossFunctions{
  [] ( const float &gT, const float &result ) {
    assert(result>0.f);
    return gT * log(result); }, // Categorical Cross Entropy
  [] ( const float &gT, const float &result ) {
    return pow(gT - result, 2); }, // Mean Squared Error
};

inline static std::vector< std::function< VectorBatch( VectorBatch&, VectorBatch&) > > d_lossFunctions
  {
  [] ( VectorBatch &gT, VectorBatch &result ) -> VectorBatch {
    std::cout « "Ambiguous operator\n" ; throw(27);
    //return -gT / ( result/ static_cast<float>( result.batch_size() ) );
  },
  [] ( VectorBatch &gT, VectorBatch &result ) -> VectorBatch {
    std::cout « "Ambiguous operator\n" ; throw(27);
    //return -2 * ( gT-result)/ static_cast<float>( result.batch_size() );
  },
};

float id_pt( const float &x );
float relu_pt( const float &x );
float relu_slope_pt( const float &x );
float sigmoid_pt( const float &x );
void batch_activation
    ( std::function< float(const float&) > pointwise,
      const VectorBatch &i,VectorBatch &o,bool=false );

#endif //SRC_FUNCS_H
```

## 5.6 layer.cpp

```
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#include "layer.h"
#include "trace.h"

#include <iostream>
using std::cout;
using std::endl;

Layer::Layer() {};
Layer::Layer(int insize,int outsize)
  : weights( Matrix(outsize,insize,1) ),
    dw      ( Matrix(outsize,insize, 0) ),
    //dW( Matrix(outsize,insize, 0) ),
    dw_velocity( Matrix(outsize,insize, 0) ),
    biases( Vector(outsize, 1 ) ),
    // biased_product( Vector(outsize, 0) ),
    activated( Vector(outsize, 0) ),
    d_activated( Vector(outsize, 0) ),
    delta( VectorBatch(outsize,1) ),
    // biased_productm( VectorBatch(outsize,insize,0) ),
    //    activated_batch( VectorBatch(outsize,1, 0) ),
    //    d_activated_batch ( VectorBatch(outsize,insize, 0) ),
    db( Vector(insize, 0) ),
    // delta_mean( Vector(insize, 0) ),
    dl( VectorBatch(insize, 1) ),
    db_velocity( Vector(insize, 0) ) {};

/*
 * Resize temporaries to reflect current batch size
 */
void Layer::allocate_batch_specific_temporaries(int batchsize) {
  const int insize = weights.colsize(), outsize = weights.rowsize();
```

```
  biased_batch.allocate( batchsize,outsize );
  input_batch.allocate( batchsize,insize );
  //  activated_batch.allocate( batchsize,outsize );
  d_activated_batch.allocate( batchsize,outsize );
  dl.allocate( batchsize, outsize );
  delta.allocate( batchsize,outsize );
};

void Layer::set_activation(acFunc f) {
  activation = f;
  apply_activation_batch  = apply_activation<VectorBatch>.at(f);
  activate_gradient_batch = activate_gradient<VectorBatch>.at(f);
};

Layer& Layer::set_activation
    (
     std::function< float(const float&) > activate_pt,
     std::function< float(const float&) > gradient_pt,
     std::string name
     ) {
    set_activation
    (
     [activate_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
         batch_activation( activate_pt,i,o ); },
     [gradient_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
         batch_activation( gradient_pt,i,o ); },
     name );
  return *this;
};

Layer& Layer::set_activation
    ( std::function< void(const VectorBatch&,VectorBatch&) > apply,
      std::function< void(const VectorBatch&,VectorBatch&) > activate,
      std::string name ) {
  activation = acFunc::RELU;
  apply_activation_batch  = apply;
  activate_gradient_batch = activate;
  return *this;
};

Layer& Layer::set_uniform_weights(float v) {
  for ( auto& e : weights.values() )
    e = v;
  return *this;
};

Layer& Layer::set_uniform_biases(float v) {
  for ( auto& e : biases.values() )
    e = v;
  return *this;
};

//codesnippet layerforward
void Layer::forward( const VectorBatch& input, VectorBatch& output) {
  assert( input.batch_size()==output.batch_size() );
  if (trace_progress()) {
    cout « "Forward layer " « layer_number
     « ": " « input_size() « "->" « output_size() « endl;
  }

  allocate_batch_specific_temporaries(input.batch_size());
  input_batch.copy_from(input);
  if (trace_progress()) {
    assert( input_batch.notnan() ); assert( input_batch.notinf() );
    assert( weights.notnan() ); assert( weights.notinf() );
  }
  input_batch.v2mp( weights, biased_batch );
  if (trace_progress()) {
    assert( biased_batch.notnan() ); assert( biased_batch.notinf() );
  }

  biased_batch.addh(biases); // Add the bias
  if (trace_progress()) {
    assert( biased_batch.notnan() ); assert( biased_batch.notinf() );
  }

  apply_activation_batch(biased_batch, output);
  //cout « "layer output: " « output.data()[0] « "\n";
  if (trace_progress()) {
    assert( output.notnan() ); assert( output.notinf() );
  }
  //return activated_batch;
}
//codesnippet end

const VectorBatch& Layer::intermediate() const { return biased_batch; };
```

```
void Layer::backward
    (const VectorBatch &prev_delta, const Matrix &W, const VectorBatch &prev_output) {

  // compute delta ell
  activate_gradient_batch(prev_output, d_activated_batch);
  prev_delta.v2mtp( W, dl );

   // delta  = Dl . sigma
  if (trace_progress())
    cout « "L-" « layer_number « " delta\n";
  delta.hadamard( d_activated_batch,dl ); // Derivative of the current layer

  // prev_output.outer2( delta, dw );
  // if (trace_scalars())
  //   cout « "L-" « layer_number « " dw: "
  //     « delta.normf() « "x" « prev_output.normf() « " => " « dw.normf() « "\n";

  update_dw(delta, prev_output);
  // weights.axpy( 1.,dw );
  // db = delta.meanh();
  // biases.add( db );
}

void Layer::update_dw( const VectorBatch &delta, const VectorBatch& prev_output) {
   prev_output.outer2( delta, dw );
   if (trace_scalars())
     cout « "L-" « layer_number « " dw: "
      « delta.normf() « "x" « prev_output.normf() « " => " « dw.normf() « "\n";

  // Delta W = delta here X activated prevous
  weights.axpy( 1.,dw );
  db = delta.meanh();
  biases.add( db );
}

void Layer::set_topdelta( const VectorBatch& gTruth,const VectorBatch& output ) {

    // top delta ell is different
   activate_gradient_batch(output, d_activated_batch);
   dl = output - gTruth;
   dl.scaleby( 1.f / gTruth.batch_size() );
   // delta  = Dl . sigma
   delta.hadamard( d_activated_batch,dl );
   if (trace_scalars())
     cout « "L-" « layer_number « " top delta: "
      « d_activated_batch.normf() « "x" « dl.normf() « " => " « delta.normf() « "\n";

   //  update_dw(delta, prev_output);
};
```

## 5.7 layer.h

```
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 ****************************************************************
 ****************************************************************/

#ifndef SRC_LAYER_H
#define SRC_LAYER_H

#include <functional>

#include "vector.h"
//#include "matrix.h"
#include "funcs.h"
#include "vector2.h"

class Net; // forward definition for friending
class Layer {
  friend class Net;
public:
    /*
     * Construction
     */
```

```
    Layer();
    Layer(int insize, int outsize);
    Layer& set_uniform_weights(float);
    Layer& set_uniform_biases(float);

    /*
     * Forward stuff
     */
private: // but note that Net is a 'friend' class!
    Vector biases; // Biases which come before the layer
    acFunc activation; // Activation functions of the layer
    //Vector biased_product; // Values in the layer n after multiplying vals from n-1 and weights
    Matrix weights; // Weights which come before the layer
    Vector activated;
    VectorBatch input_batch, biased_batch; //,activated_batch;
public:
    auto& input() { return input_batch; };
    const auto& input() const { return input_batch; };

    /*
     * Backward stuff
     */
private:
    VectorBatch delta,wdelta,dl,Dscale;
    Vector d_activated; // for backpropagation
    //VectorBatch biased_productm;
    VectorBatch d_activated_batch;
    Matrix dw;         // cumulative dw
    Matrix dw_velocity; // For SGD with Momentum, RMSprop
    Vector db_velocity;
    Vector db;         // cumulative deltas

    //Vector delta_mean; // mean of the deltas used in batch training
public:

    /*
     * Stats
     */
private:
    int layer_number{-1};
public:
    Layer& set_number(int n) { layer_number = n; return *this; };

public:
    int input_size() const { return weights.colsize(); };
    int output_size() const { return weights.rowsize(); };
  //    void set_initial_deltas( const Matrix&, const Vector& );
    void set_recursive_deltas( Vector &, const Layer&,const Layer& );
    void set_topdelta( const VectorBatch&,const VectorBatch& );
    void allocate_batch_specific_temporaries(int batchsize);

    /*
     * Action
     */
    void forward( const VectorBatch&,VectorBatch& );
    const VectorBatch& intermediate() const;
    void backward(const VectorBatch &delta, const Matrix &W, const VectorBatch &prev);
    void backward_update( const VectorBatch&, const VectorBatch& ,bool=false );
    void update_dw(const VectorBatch &delta, const VectorBatch& prevValues);


    /*
     * Activation function
     */
private:
  std::function< void(const VectorBatch&,VectorBatch&) > apply_activation_batch{
    [] ( const VectorBatch &v, VectorBatch &a ) { nan_io(v,a); } };
  std::function< void(const VectorBatch&,VectorBatch&) > activate_gradient_batch{
    [] ( const VectorBatch &v, VectorBatch &a ) { nan_io(v,a); } };
public:
  std::string activation_name{"custom"};
  void set_activation(acFunc f);
  Layer& set_activation
      ( std::function< void(const VectorBatch&,VectorBatch&) > apply,
    std::function< void(const VectorBatch&,VectorBatch&) > activate,
    std::string name=std::string("custom")
    );
    Layer& set_activation
      (
       std::function< float(const float&) > activate_pt,
       std::function< float(const float&) > gradient_pt,
       std::string name=std::string("custom")
       );
};


#endif //SRC_LAYER_H
```

## 5.8 Make.inc

```
USE_BLIS=0
BLIS_INC_DIR=/Users/eijkhout/Installation/blis/installation-git/include
BLIS_LIB_DIR=/Users/eijkhout/Installation/blis/installation-git/lib

USE_GSL=0
GSL_INC_DIR=../gsl-lite/include

CXX = clang++ -g -std=c++17 -fopenmp
CXXOPTS = ${HOME}/Installation/cxxopts/installation

DEBUG = 0
```

## 5.9 matrix.cpp

```
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 ****************************************************************/

#include "matrix.h"
#include <iostream>
#include <vector>
#include <algorithm>
#include <cassert>

using std::vector;

Matrix::Matrix() { // Default constructor
    r = 0;
    c = 0;
    mat.clear();
}

// void Matrix::flatten() { // Matrices are initialized in a coalesced flat 1D representation, so
 changing the dimension values are enough
//      r = r * c;
//      c = 1;
// }


float* Matrix::data() { return mat.data(); };
const float* Matrix::data() const { return mat.data(); };

Matrix &Matrix::operator=(const Matrix &m2) { // Overloading the = operator
    r = m2.r;
    c = m2.c;

    this->mat = m2.mat; // IM Since we're using vectors we can just use the assignment from that

    return *this;
}

Matrix Matrix::operator+(const Matrix &m2) const {
    Matrix out(m2.r, m2.c, 0);
    for (int i = 0; i < m2.r * m2.c; i++) {
        out.mat[i] = this->mat[i] + m2.mat[i];
    }
    return out;
}

Matrix Matrix::operator-(const Matrix &m2) {
    Matrix out(m2.r, m2.c, 0);
    for (int i = 0; i < m2.r * m2.c; i++) {
        out.mat[i] = this->mat[i] - m2.mat[i];
    }
    return out;
}



Matrix operator*(const float &c, const Matrix &m) {
    Matrix o = m;
    assert(o.mat.size()==o.r*o.c);
```

```
    for (int i = 0; i < o.r * o.c; i++) {
        o.mat[i] = c * o.mat[i];
    }
    return o;
}

Matrix operator/(const Matrix &m, const float &c) {
    Matrix o = m;
    for (int i = 0; i < o.r * o.c; i++) {
        o.mat[i] = o.mat[i] / c;
    }
    return o;
}


Matrix Matrix::operator*(const Matrix &m2) { // Hadamard product
    Matrix out(m2.r, m2.c, 0);
    assert(out.mat.size()==m2.r * m2.c);
    for (int i = 0; i < m2.r * m2.c; i++) {
        out.mat[i] = this->mat[i] * m2.mat[i];
    }
    return out;
}

Matrix Matrix::operator/(const Matrix &m2) { // Hadamard product
    Matrix out(m2.r, m2.c, 0);
    for (int i = 0; i < m2.r * m2.c; i++) {
        out.mat[i] = this->mat[i] / m2.mat[i];
    }
    return out;
}

Matrix Matrix::operator-() {
    Matrix result = *this;
    for (int i = 0; i < r * c; i++) {
        result.mat[i] = -mat[i];
    }

    return result;
};

void Matrix::addvh(const Vector &y) {
    for (int j = 0; j < c; j++) {
        for (int i = 0; i < y.size(); i++) {
            mat[j + c * i] += y.vals[i];
        }
    }
}

Vector Matrix::meanv() { // Returns a vector of column-wise means
    Vector mean(r, 0);
    float avg;
    for (int i = 0; i < r; i++) {
        avg = 0.0;
        for (int j = 0; j < c; j++) {
            avg += mat[i * c + j];
        }
        mean.vals[i] = avg;
    }
    return mean;
}


void Matrix::zeros() {
    std::fill(mat.begin(), mat.end(), 0);
}

void Matrix::square() {
    std::for_each(mat.begin(), mat.end(), [](auto &n) { n *= n;});
}
```

## 5.10 matrix.h

```
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```

```
 *****************************************************************
 *****************************************************************/

#ifndef CODE_MAT_H
#define CODE_MAT_H

#include <vector>
#include "vector.h"
//#include "vector2.h"
#include <initializer_list>

class Matrix{
private: // should really become private
    std::vector<float> mat;
    int r;
    int c;
public:
    Matrix();
    Matrix(int nRows, int nCols, int rand);
    // for mpl
    std::vector<float> &values() { return mat; };
    const std::vector<float> &values() const { return mat; };
    float* data() ;
    const float* data() const;
    int nelements() const {
      return mat.size();
    };
    int rowsize() const { return r; };
    int colsize() const { return c; };
    Matrix transpose() const;
    void show() const;
    //void flatten();
    void mvpt( const Vector &x, Vector &y ) const;
    void mvp( const Vector &x, Vector &y ) const;
    void addvh( const Vector &y); // Add a vector to each column

    void mmp( const Matrix &x, Matrix &y) const;
    void outerProduct( const Vector &x, const Vector &y );
    Vector meanv();
    void zeros();
    void square();
    float normf() const;

    bool notnan() const {
      return all_of
    ( mat.begin(),mat.end(),
      [] (float e) { return not isnan(e); }
    );
    }
    bool notinf() const {
      return all_of
    ( mat.begin(),mat.end(),
      [] (float e) { return not isinf(e); }
    );
    }
    //vector2 methods
    // Moving these to VectorBatch object
    //void mv2p( const VectorBatch &x, VectorBatch &y) const;
    //void mv2pt( const VectorBatch &x, VectorBatch &y ) const;
    //void outer2( const VectorBatch &x, const VectorBatch &y );


    Matrix operator-(); // Unary negate operator
    Matrix& operator=(const Matrix& m2); // Copy constructor
    Matrix operator+(const Matrix &m2) const; // Element-wise addition
    Matrix operator*(const Matrix &m2); // Hadamard Product Element-wise multiplication
    Matrix operator/(const Matrix &m2); // Element-wise division
    Matrix operator-(const Matrix &m2); // Element-wise subtraction
    friend Matrix operator*(const float &c, const Matrix &m); // for constant-matrix multiplication
    friend Matrix operator/(const Matrix &m, const float &c); // for matrix-constant division
  void axpy( float a,const Matrix &x );

};



#endif
```

## 5.11 matrix_impl_blis.cpp

```
/*****************************************************************
 *****************************************************************
 ****
```

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****************************************************************
****************************************************************/

#include "matrix.h"
#include <iostream>
#include <vector>
#include <algorithm>
#include <cassert>

using std::vector;

#ifdef BLISNN
#include "blis/blis.h"
#endif

Matrix::Matrix(int nRows, int nCols, int random = 0)
        : r(nRows), c(nCols) {

    mat = vector<float>(nRows * nCols);
    float scal_fac = 0.05; // randomize between (-1;1)
    if (random==0){
        float zero = 0.0;
        bli_ssetm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
                r, c, &zero, &mat[0], c, 1);
    } else if (random==1){
        bli_srandm(0, BLIS_DENSE, r, c, &mat[0], c, 1);
        bli_sscalm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
                r, c, &scal_fac, &mat[0], c, 1);
    }
}

Matrix Matrix::transpose() const {
    Matrix result(c, r, 0); // Initialize a new matrix with inverted dimension values

    // m = r, n = c
    // rs = 1, cs = m, rsf = 1, csf = n
    //printf("BLIS copy %dx%d\n",c,r);
    bli_scopym( 0, BLIS_NONUNIT_DIAG, BLIS_DENSE, BLIS_TRANSPOSE,
        c, r, const_cast<float*>(&mat[0]), c, 1, &result.mat[0], r, 1);
    return result;
}

void Matrix::show() const {

    char e[5] = "";
    char format[8] = "%4.4f";
    bli_sprintm( e, r, c, const_cast<float*>(&mat[0]), c, 1, format, e );
}


void Matrix::mvp(const Vector &x, Vector &y) const {
    assert( c==x.size() );
    assert( r==y.size() );

    float alpha = 1.0;
    float beta = 0.0;
    //printf("BLIS gemv %dx%d\n",c,r);
    bli_sgemv( BLIS_NO_TRANSPOSE, BLIS_NO_CONJUGATE,
           r, c, &alpha, const_cast<float*>(&mat[0]),
           c, 1, const_cast<float*>( x.data() ) /* &t.vals[0] */,
           // c, 1, &t.vals[0] ,
           1, &beta, &y.vals[0], 1 );

}

void Matrix::mvpt(const Vector &x, Vector &y) const {
    assert( r==x.size() );
    assert( c==y.size() );

    float alpha = 1.0;
    float beta = 0.0;
    //printf("BLIS gemv %dx%d\n",c,r);
    bli_sgemv( BLIS_TRANSPOSE, BLIS_NO_CONJUGATE,
           r, c, &alpha, const_cast<float*>(&mat[0]), // test if r and c need to be flipped
           //c, 1, &t.vals[0],
           c, 1, const_cast<float*>( x.data() ),
           1, &beta, &y.vals[0], 1 );
}


```

```
void Matrix::outerProduct(const Vector &x, const Vector &y) {
    assert( x.size() == r );
    assert( y.size() == c );
    float val = 1.0;

    //printf("BLIS gemm (outer) %dx%d\n",r,c);
    bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_TRANSPOSE,
            r, c, 1, &val,
            const_cast<float*>(x.data()), 1, 1,
            const_cast<float*>(y.data()), c, 1, &val, &mat[0], c, 1);

}


void Matrix::mmp(const Matrix &x, Matrix &y) const { // In place matrix matrix multiplication
    assert( c==x.r );
    assert( r==y.r );
    assert( x.c==y.c );

    float alpha = 1.0;
    float beta = 0.0;
    // m = r, n = x.c, k = c
    //printf("BLIS gemm %dx%dx%d\n",r,x.c,c);
    bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_NO_TRANSPOSE,
           r, x.c, c, &alpha, const_cast<float*>(&mat[0]),
           //c, 1, &t.mat[0],
           c, 1, const_cast<float*>( x.data() ),
           x.c, 1, &beta, &y.mat[0], x.c, 1);
}

void Matrix::axpy( float a,const Matrix &x ) {
  assert( r==x.r );
  assert( c==x.c );
  const int n = nelements();
  assert( n==x.nelements() );

  bli_saxpyv( BLIS_NO_CONJUGATE,
          n, &a, const_cast<float*>( x.data() ),1,
          data(),1 );
};

float Matrix::normf() const {
  float norm;
  auto r = rowsize(), c = colsize();
  const auto mval = values().data();
  bli_snormfv( r*c, const_cast<float*>(mval), 1, &norm );
  return norm;
};
```

## 5.12 matrix_impl_reference.cpp

```
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 ****************************************************************
 ****************************************************************/

#include "matrix.h"
#include <iostream>
#include <vector>
#include <algorithm>
#include <cassert>

using std::vector;

Matrix::Matrix(int nRows, int nCols, int random = 0)
  : r(nRows), c(nCols) {

  mat = vector<float>(nRows * nCols);
  int i, j;
  if (random==0) {
    std::fill(mat.begin(), mat.end(), 0);
  } else if (random==1) {
    //std::fill(mat.begin(), mat.end(), .5);
    for (i=0; i<nRows * nCols;i++){
      //mat[i] = -0.1 + static_cast <float> (rand()) /( static_cast <float>(RAND_MAX/(0.1-(-0.1))));
```

```
            mat[i] = -0.1 + static_cast <float> (rand()) /( static_cast <float>(RAND_MAX) );
        }
    }

}

Matrix Matrix::transpose() const {
    Matrix result(c, r, 0); // Initialize a new matrix with inverted dimension values
    int i1, i2; // Old and new index
    for (int i = 0; i < r; i++) {
        for (int j = 0; j < c; j++) {
            i1 = i * c + j; // Old indexing
            i2 = j * r + i; // New indexing

            result.mat[i2] = mat[i1]; // Move transposed values to new array
        }
    }

    return result;
}

void Matrix::show() const {

    int i, j;
    for (i = 0; i < r; i++) {
        for (j = 0; j < c; j++) {
            std::cout « mat[i * c + j] « ' ';
        }
        std::cout « std::endl;
    }
    std::cout « std::endl;

}


void Matrix::mvp(const Vector &x, Vector &y) const {
    assert( c==x.size() );
    assert( r==y.size() );
    for (int i = 0; i < r; i++) {
        float sum = 0.0;
        for (int j = 0; j < c; j++) {
            sum += x.vals[j] * mat[i * c + j];
        }
        y.vals[i] = sum;
    }

}

void Matrix::mvpt(const Vector &x, Vector &y) const {
    assert( r==x.size() );
    assert( c==y.size() );
    for (int i = 0; i < r; i++) {
        float sum = 0.0;
        for (int j = 0; j < c; j++) {
            sum += x.vals[j] * mat[i * c + j];
        }
        y.vals[i] = sum;
    }

}


void Matrix::outerProduct(const Vector &x, const Vector &y) {
    assert( x.size() == r );
    assert( y.size() == c );
    float val = 1.0;
    for (int i = 0; i < x.size(); i++) {
        for (int j = 0; j < y.size(); j++) {
            mat[i * c + j] = x.vals[i] * y.vals[j];
        }
    }

}

void Matrix::mmp(const Matrix &x, Matrix &y) const {
    assert( c==x.r );
    assert( r==y.r );
    assert( x.c==y.c );
    float sum;
    for (int i = 0; i < r; i++) { // Matrix multiplication subroutine
        for (int j = 0; j < x.c; j++) {
            sum = 0.0;
            for (int k = 0; k < x.r; k++) {
                sum += mat[i * c + k] * x.mat[k * x.c + j];
            }
            y.mat[i * y.c + j] = sum;
        }
```

```
    }
}

void Matrix::axpy( float a,const Matrix &x ) {
  assert( r==x.r );
  assert( c==x.c );
  const int n = nelements();
  assert( n==x.nelements() );

  float *ydata = this->data();
  const auto& xdata = x.data();
  for (int i=0; i<n; i++) {
    ydata[i] += a * xdata[i];
  }

};

float Matrix::normf() const {
  float norm{0.f};
  // auto r = rowsize(), c = colsize();
  // const auto mval = values().data();
  for ( auto e : values() )
    norm += e*e;
  return sqrt(norm);
};
```

## 5.13 net.cpp

```
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 ****
 *******************************************************************
 *******************************************************************/

#include <iostream>
using std::cout;
using std::endl;
#include <fstream>

#include <algorithm>
#include <string>
using std::string;

#include <cmath>

#include "vector.h"
#include "net.h"
#include "trace.h"

Net::Net(int s) { // Input vector size
    this->inR = s;
    this->inC = 1;
    samples = 0;
}

Net::Net( const Dataset &data ) {
  this->inR = data.data_size(); //data.items.at(0).data.size();
  this->inC = 1;
  samples = 0;
}

void Net::addLayer( int outputsize,
            std::function< float(const float&) > activate_pt,
            std::function< float(const float&) > gradient_pt,
            string name ) {
    addLayer
    ( outputsize,
      [activate_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
          batch_activation( activate_pt,i,o ); },
      [gradient_pt] ( const VectorBatch& i,VectorBatch& o ) -> void {
          batch_activation( gradient_pt,i,o ); },
      name );
};

void Net::addLayer( int outputsize,
            std::function< void(const VectorBatch&,VectorBatch&) > apply_activation_batch,
```

```
          std::function< void(const VectorBatch&,VectorBatch&) > activate_gradient_batch,
          string name
          ) {
    // Initialize layer object and add the necessary parameters
    Layer layer(inputsize(layers.size()), outputsize);
    layer.set_activation(apply_activation_batch,activate_gradient_batch);
    layer.set_number( layers.size() );
    layer.activation_name = name;
    push_layer(layer);
};

void Net::push_layer( const Layer& layer ) {
    if (trace_progress())
    cout « "Creating layer " « layers.size()
         « " of size " « layer.output_size() « "x" « layer.input_size()
        //       « " with " « name « " activation"
         « endl;
    layers.push_back(layer);
};

void Net::addLayer(int l, acFunc f) {
  addLayer( l,
        apply_activation<VectorBatch>.at(f),
        activate_gradient<VectorBatch>.at(f),
        activation_names.at(f)
        );
}

void Net::set_lossfunction( lossfn lossFuncName ) {
  lossFunction = lossFunctions.at(lossFuncName);
  d_lossFunction = d_lossFunctions.at(lossFuncName);
};

void Net::set_uniform_weights(float v) {
  for ( auto& l : layers )
    l.set_uniform_weights(v);
};

void Net::set_uniform_biases(float v) {
  for ( auto& l : layers )
    l.set_uniform_biases(v);
};

//codesnippet netforward
void Net::feedForward( const VectorBatch& input,VectorBatch& output ) {
  if (trace_progress())
    cout « "Feed forward batch of size " « input.batch_size() « endl;
  allocate_batch_specific_temporaries(input.batch_size());

  if (layers.size()==1) {
    layers.front().forward(input,output);
    //cout « "single layer output: " « output.data()[0] « "\n";
  } else {
    layers.front().forward( input, layers.at(1).input() );
    cout « " first layer : "
     « input.data()[0] « " -> " « layers.at(1).input().data()[0] « "\n";
    for (unsigned i = 1; i<layers.size()-1; i++) {
      layers.at(i).forward
    (layers.at(i).input(),
     layers.at(i+1).input()
     );
    }
    layers.back().forward(layers.back().input(),output);
    cout « "last layer : "
     « layers.back().input().data()[0] « " -> " « output.data()[0] « "\n";
  }
};
//codesnippet end

void Net::feedForward( const Vector& input, Vector& output ) {
    VectorBatch input_batch(input), output_batch(input_batch);
    feedForward(input_batch,output_batch);
    const auto& in_data = input_batch.data();
    const auto& out_data = output_batch.data();
    //    cout « "net forward: " « in_data[0] « " -> " « out_data[0] « "\n";
    output.copy_from( output_batch );
};

void Net::show() {
    for (unsigned i = 0; i < layers.size(); i++) {
        cout « "Layer " « i « " weights" « endl;
        layers.at(i).weights.show();
    }
}

void Net::calculate_initial_delta(VectorBatch &input, VectorBatch &gTruth) {
    VectorBatch d_loss = d_lossFunction( gTruth, input);
```

```

    if (layers.back().activation_name == "SoftMax" ) { // Softmax derivative function
        Matrix jacobian( input.item_size(), input.item_size(), 0 );
        for(int i = 0; i < input.batch_size(); i++ ) {
          auto one_column = input.get_vector(i);
          jacobian = smaxGrad_vec( one_column );
          Vector one_vector( jacobian.rowsize(), 0 );
          Vector one_grad = d_loss.get_vectorObj(i);
          jacobian.mvp( one_grad, one_vector );
          layers.back().d_activated_batch.set_vector(one_vector,i);
        }
    }
    /* Will add the rest of the code here, not done yet
    */
}

void Net::backPropagate
    (const VectorBatch &input, const VectorBatch& output, const VectorBatch &gTruth) {

  if (layers.size()==1) {
    throw(string("single layer case does not work"));
      // const VectorBatch& prev = input;
      // layers.back().update_dw(delta, prev);
      // return;
  } else {

    if (trace_progress()) cout « "Layer-" « layers.back().layer_number « "\n";
    layers.back().set_topdelta( gTruth,output );
    const VectorBatch& prev = layers.back().input();
    layers.back().update_dw(layers.back().delta, prev);


    for (unsigned i = layers.size() - 2; i > 0; i--) {
      if (trace_progress()) cout « "Layer-" « layers.at(i).layer_number « "\n";
      layers.at(i).backward
      ( layers.at(i+1).delta, layers.at(i+1).weights, layers.at(i).input());
    }

    if (trace_progress()) cout « "Layer-" « layers.at(0).layer_number « "\n";
    layers.at(0).backward(layers.at(1).delta, layers.at(1).weights, input);

  }
}

void Net::SGD(float lr, float momentum) {
    assert( layers.size()>0 );
    int samplesize = layers.front().input().batch_size();
    for (int i = 0; i < layers.size(); i++) {
        // Normalize gradients to avoid exploding gradients
    Matrix deltaW = layers.at(i).dw / static_cast<float>(samplesize);
        Vector deltaB = layers.at(i).db / static_cast<float>(samplesize);

        // Gradient descent
        if (momentum > 0.0) {
            layers.at(i).dw_velocity = momentum * layers.at(i).dw_velocity - lr * deltaW;
            //layers.at(i).weights = layers.at(i).weights + layers.at(i).dw_velocity;
        layers.at(i).weights.axpy( 1.f,layers.at(i).dw_velocity );
        } else {
      //layers.at(i).weights = layers.at(i).weights - lr * deltaW;
      layers.at(i).weights.axpy( -lr,deltaW );
        }

        layers.at(i).biases = layers.at(i).biases - lr * deltaB;

        // Reset the values of delta sums
        layers.at(i).dw.zeros();
        layers.at(i).db.zeros();
    }
}

void Net::RMSprop(float lr, float momentum) {
    for (int i = 0; i < layers.size(); i++) {
        // Get average over all the gradients
        Matrix deltaWsq = layers.at(i).dw;
        Vector deltaBsq = layers.at(i).db;

    // Gradient step
        deltaWsq.square(); // dW^2
        deltaBsq.square(); // db^2
        // Sdw := m*Sdw + (1-m) * dW^2

    layers.at(i).dw_velocity = momentum * layers.at(i).dw_velocity + (1 - momentum) * deltaWsq;
        layers.at(i).db_velocity = momentum * layers.at(i).db_velocity + (1 - momentum) * deltaBsq;

    Matrix sqrtSdw = layers.at(i).dw_velocity;
        std::for_each(sqrtSdw.values().begin(), sqrtSdw.values().end(),
              [](auto &n) {
```

```
            n = sqrt(n);
            if(n==0) n= 1-1e-7;
              });
    Vector sqrtSdb = layers.at(i).db_velocity;
        std::for_each(sqrtSdb.values().begin(), sqrtSdb.values().end(),
              [](auto &n) {
            n = sqrt(n);
            if(n==0) n= 1-1e-7;
              });

        // W := W - lr * dW / sqrt(Sdw)
        layers.at(i).weights = layers.at(i).weights - lr * layers.at(i).dw / sqrtSdw;
        layers.at(i).biases = layers.at(i).biases - lr * layers.at(i).db / sqrtSdb;

        // Reset the values of delta sums
        layers.at(i).dw.zeros();
        layers.at(i).db.zeros();
    }
}

// this function no longer used
// void Net::calcGrad(VectorBatch data, VectorBatch labels) {
//     feedForward(data);
//     backPropagate(data, labels);
// }


void Net::train( const Dataset &train_data,const Dataset &test_data,
         int epochs, int batchSize ) {

    const int Optimizer = optimizer();
    cout « "Optimizing with ";
    switch (Optimizer) {
    case sgd:  cout « "Stochastic Gradient Descent\n";  break;
    case rms:  cout « "RMSprop\n"; break;
    }

    std::vector<Dataset> batches = train_data.batch(batchSize);
    float lrInit = learning_rate();
    const float momentum_value = momentum();

    for (int i_epoch = 0; i_epoch < epochs; i_epoch++) {
      // Iterate through the entire dataset for each epoch
      cout « endl « "Epoch " « i_epoch+1 « "/" « epochs « endl;
      float current_learning_rate = lrInit; // Reset the learning rate to undo decay

      for (int j = 0; j < batches.size(); j++) {
    // Iterate through all batches within dataset
    auto& batch = batches.at(j);
#ifdef DEBUG
    cout « ".. batch " « j « "/" « batches.size() « " of size " « batch.size() « "\n";
#endif
    //  allocate_batch_specific_temporaries(batch.size());
    VectorBatch batch_output( batch.inputs().item_size(),batch.size() );
    feedForward(batch.inputs(),batch_output);
    backPropagate(batch.inputs(),batch.labels(),batch_output);

        // User chosen optimizer
        current_learning_rate = current_learning_rate / (1 + decay() * j);
        optimize.at(Optimizer)(current_learning_rate, momentum_value);

      }
      auto loss = calculateLoss(test_data);
      cout « " Loss: " « loss « endl;
      auto acc = accuracy(test_data);
      cout « " Accuracy on trest set: " « acc « endl;
    }

}

void Net::allocate_batch_specific_temporaries(int batchsize) {
#ifdef DEBUG
  cout « "allocating temporaries for batch size " « batchsize « endl;
#endif
  for ( auto& layer : layers )
    layer.allocate_batch_specific_temporaries(batchsize);
}

//codesnippet netloss
float Net::calculateLoss(const Dataset &testSplit) {

#ifdef DEBUG
  cout « "Loss calculation\n";
#endif
  //  allocate_batch_specific_temporaries(testSplit.inputs().batch_size());
  VectorBatch result = this->create_output_batch( testSplit.inputs().batch_size() );
  feedForward( testSplit.inputs(),result );
```

```
  assert( result.notnan() );

    float loss = 0.0;
    auto tmp_labels =  testSplit.labels();
    if (trace_arrays()) {
      cout « "Compare results\n"; result.show();
      cout « " to label\n"; tmp_labels.show();
    }
    for (int vec=0; vec<result.batch_size(); vec++) { // iterate over all items
      const auto& one_result = result.extract_vector(vec); // VLE figure out const span !!!
      auto one_label  = tmp_labels.get_vector(vec);
      assert( one_result.size()==one_label.size() );
      for (int i=0; i<one_result.size(); i++) { // Calculate loss of result
    auto this_label = one_label[i], this_result = one_result[i];
    assert( not std::isnan(this_label) );
    assert( not std::isnan(this_result) );
    auto oneloss = lossFunction( this_label, this_result );
    assert( not std::isnan(oneloss) );
    loss += oneloss;
      }
    }
    const int bs = result.batch_size();
    assert( bs>0 );
    auto scale = 1.f / static_cast<float>(bs);
    loss = loss * scale;

    return loss;
}
//codesnippet end


#if 0
    const auto& result_vals = result.vals_vector();
    const auto& label_vals  = testSplit.labelBatch.vals_vector();
    for (int j = 0; j < result.r * result.c; j++) {
      loss += lossFunction( label_vals[j], result_vals[j] );
    }
#else
#endif

float Net::accuracy( const Dataset &test_set ) {
  if (trace_progress())
    cout « "Accuracy calculation\n";

  int correct = 0;
  int incorrect = 0;

  assert( test_set.size()>0 );
  const auto& test_inputs = test_set.inputs();
  const auto& test_labels = test_set.labels();
  assert( test_inputs.batch_size()==test_labels.batch_size() );
  assert( test_inputs.batch_size()>0 );

  //      allocate_batch_specific_temporaries(test_inputs.batch_size());
  if (trace_arrays()) {
      cout « "inputs:\n"; test_inputs.show();
  }
  assert( test_inputs.normf()!=0.f );
  auto output_batch = this->create_output_batch(test_labels.batch_size());
  feedForward(test_inputs,output_batch);
  if (trace_arrays()) {
      cout « "outputs:\n"; output_batch.show();
  }
  assert( output_batch.notnan() );

  for(int idx=0; idx < output_batch.batch_size(); idx++ ) {
      Vector oneItem = output_batch.get_vectorObj(idx);
      Categorization result( oneItem );
      result.normalize();
      if ( result.close_enough( test_labels.extract_vector(idx) ) ) {
      correct++;
      } else {
      incorrect++;
      }
  }
  assert( correct+incorrect==test_set.size() );

  float acc = static_cast<float>( correct ) / static_cast<float>( test_set.size() );
  return acc;
}



void Net::saveModel(std::string path){
    /*
    1. Size of matrix m x n, activation function
    2. Values of weight matrix
```

```
    3. Values of bias vector
    4. Repeat for all layers
    */
    std::ofstream file;
    file.open( path, std::ios::binary );

    float temp;
    int no_layers = layers.size();
    file.write( reinterpret_cast<char *>(&no_layers), sizeof(no_layers) );
    for ( auto l : layers ) {
        int insize = l.input_size(), outsize = l.output_size();
        file.write( reinterpret_cast<char *>(&outsize), sizeof(int) );
        file.write( reinterpret_cast<char *>(&insize), sizeof(int) );
        file.write( reinterpret_cast<char *>(&l.activation), sizeof(int) );

        const auto& weights = l.weights;
        file.write(reinterpret_cast<const char *>(weights.data()), sizeof(float)*weights.nelements());
        // const float* weights_data = l.weights.data();
        // file.write(reinterpret_cast<char *>(&weights_data), sizeof(temp)*insize*outsize);

        const auto& biases = l.biases;
        file.write(reinterpret_cast<const char*>(biases.data()), sizeof(float) * biases.size());
        //file.write(reinterpret_cast<char *>(&l.biases.vals[0]), sizeof(temp) * l.biases.size());
    }
    cout « endl;

    file.close();
}

void Net::loadModel(std::string path){
    std::ifstream file(path);
    std::string buffer;

    int no_layers;
    file.read( reinterpret_cast<char *>(&no_layers), sizeof(no_layers) );

    float temp;
    layers.resize(no_layers);
    for ( int i=0; i < layers.size(); i++ ) {
        int insize,outsize;
        file.read( reinterpret_cast<char *>(&outsize), sizeof(int) );
        file.read( reinterpret_cast<char *>(&insize), sizeof(int) );

        file.read( reinterpret_cast<char *>(&layers[i].activation), sizeof(int) );

        layers[i].weights = Matrix( outsize, insize, 0 );
        float *w_data = layers[i].weights.data();
        file.read(reinterpret_cast<char *>( w_data ), //(&layers[i].weights.mat[0]),
              sizeof(temp) * insize*outsize);

        layers[i].biases = Vector( outsize, 0 );
        float *b_data = layers[i].biases.data();
        file.read(reinterpret_cast<char *>( b_data ), //(&layers[i].biases.vals[0]),
              sizeof(temp) * layers[i].biases.size());
    }
}


void Net::info() {
    cout « "Model info\n---------------\n";

    for ( auto l : layers ) {
        cout « "Weights: " « l.output_size() « " x " « l.input_size() « "\n";
        cout « "Biases: " « l.biases.size() « "\n";
        cout « "Activation: " « l.activation_name « "\n";

        // switch (l.activation) {
        //  case RELU: cout « "RELU\n"; break;
        //  case SIG: cout « "Sigmoid\n"; break;
        //  case SMAX: cout « "Softmax\n"; break;
        //  case NONE: break;
        // }
        cout « "---------------\n";
    }

}

void loadingBar(int currBatch, int batchNo, float acc, float loss) {
    cout  « "[";
    int pos = 50 * currBatch/(batchNo-1);
    for (int k=0; k < 50; ++k) {
    if (k < pos) cout « "=";
    else if (k == pos) cout « ">";
    else cout « " ";
    }
    cout « "] " « int(float(currBatch)/float(batchNo-1)*100) « "% " « "loss: " « loss « " acc: " « acc
 « " \r";
```

```
    cout « std::flush;
}
```

## 5.14 net.h

```
/****************************************************************
 ****************************************************************
 ****
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 **** 'Introduction to High-Performance Scientific Computing'
 **** by Victor Eijkhout, copyright 2012-2021
 ****
 **** Deep Learning Network code
 **** copyright 2021 Ilknur Mustafazade
 ****
 ****************************************************************
 ****************************************************************/

#ifndef CODE_NET_H
#define CODE_NET_H

#include <vector>
#include "vector.h"
#include "matrix.h"
#include "dataset.h"
#include "layer.h"
#include <cmath>

enum opt{sgd, rms}; // Gradient descent, RMSprop

class Net {
private:
    int inR; // input dimensions
    int inC;
    int samples;
    std::vector<Layer> layers;
    std::function<float( const float& groundTruth, const float& result)> lossFunction{
      [] ( const float& groundTruth, const float& result) -> float {
    throw(std::string("no loss function defined")); } };
    std::function<VectorBatch( VectorBatch& groundTruth, VectorBatch& result )> d_lossFunction{
      [] ( VectorBatch& groundTruth, VectorBatch& result ) -> VectorBatch {
    throw(std::string("no d_lossfunction defined")); } };
public:
    Net(int s); // input shape
    Net( const Dataset &d );
    void addLayer(int l, acFunc activation); // length of the dense layer
    void addLayer( int l,
           std::function< float(const float&) > activate_pt,
           std::function< float(const float&) > gradient_pt,
           std::string name=std::string("custom")
           );
    void addLayer( int l,
           std::function< void(const VectorBatch&,VectorBatch&) > apply_activation_batch,
           std::function< void(const VectorBatch&,VectorBatch&) > activate_gradient_batch,
           std::string name=std::string("custom")
           );
    void push_layer( const Layer& layer );
    /*
     * Stats
     */
    int outputsize() const {
    assert( layers.size()>0 );
    return layers.back().output_size();
    };
    int inputsize( int layer ) const {
    assert(layer>=0); assert(layer<=layers.size());
    if (layers.empty())
        return inR; // Input's row size for the first layer
    else
        return layers.at(layer-1).output_size(); // Previous layer's row size
    };
    VectorBatch create_output_batch( int batchsize ) {
    return VectorBatch( outputsize(),batchsize );
    };
    /*
     * Direct layer access
     */
    Layer& backlayer() {
    assert(layers.size()>0); return layers.back(); };
    const Layer& backlayer() const {
    assert(layers.size()>0); return layers.back(); };
    const Layer& layer(int i) const { return layers.at(i); };
    const Layer& at(int i) const { return layers.at(i); };
```

```
    Layer& at(int i) { return layers.at(i); };

    void show(); // Show all weights
    Categorization output_vector() const;
    const VectorBatch &outputs() const;
    void set_lossfunction( lossfn lossFuncName );
    void set_uniform_weights(float);
    void set_uniform_biases(float);

    //void feedForward( const Vector& );
    void feedForward( const Vector&,Vector& );
    //void feedForward( const VectorBatch& );
    void feedForward( const VectorBatch&,VectorBatch& );

    void allocate_batch_specific_temporaries(int batchsize);
    void calcGrad(Dataset data);
    void calcGrad(VectorBatch data, VectorBatch labels);

    void backPropagate(const Vector &input, const Vector &gTruth, const Vector &output);
    void backPropagate(const VectorBatch &input, const VectorBatch &gTruth, const VectorBatch &output);

    void calculate_initial_delta( VectorBatch& result, VectorBatch& gTruth);

    void SGD(float lr, float momentum);
    void RMSprop(float lr, float momentum);

  /*
   * Various settings
   */
private:
  float _lr{0.05};
public:
  void set_learning_rate(float lr) { _lr=lr; };
  float learning_rate() const { return _lr; };
private:
  float _decay{0.05}; // high decay causes very small training
public:
  void set_decay(float d) { _decay = d; };
  float decay() const { return _decay; };
private:
  float _momentum{0.0}; // 0.9 works well
public:
  void set_momentum(float m) { _momentum = m; };
  float momentum() const { return _momentum; };
private:
  int _optimizer;
public:
  void set_optimizer(int m) { _optimizer = m; };
  int optimizer() const { return _optimizer; };
  std::vector< std::function< void(float lr, float momentum) > > optimize{
    [this] ( float lr, float momentum ) { SGD(lr, momentum); },
    [this] ( float lr, float momentum ) { RMSprop(lr, momentum); }
  };

  void train( const Dataset& train,const Dataset& test, int epochs, int batchSize);
#if MPINN
    void trainmpi(Dataset &trainData, Dataset &testData, float lr, int epochs, opt Optimizer, lossfn lossFunc, int batchSize, float momentum = 0.0, float decay = 0.0);
#endif
    float calculateLoss(const Dataset &testSplit);
    float accuracy( const Dataset& valSet );


    void saveModel(std::string path);
    void loadModel(std::string path);

    void info();
};

void loadingBar(int currBatch, int batchNo, float acc, float loss);

#endif //CODE_NET_H
```

## 5.15 net_mpi.cpp

```
/****************************************************************
 ****************************************************************
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 ****
```

```
 **** Deep Learning Network code
 **** copyright 2021 Ilknur Mustafazade
 ****
 *****************************************************************
 *****************************************************************/

#include <mpl/mpl.hpp>

void Net::trainmpi(Dataset &data, Dataset &testData, float lr, int epochs, opt Optimizer, lossfn lossFuncName, int batchSize, float momentum, float decay) {
    const mpl::communicator &comm_world(mpl::environment::comm_world());
    lossFunction = lossFunctions.at(lossFuncName);
    int rank = comm_world.rank();
    int size = comm_world.size();
    if(rank==0) {
    std::cout « "Optimizing with ";
      switch (Optimizer) {
      case sgd:  std::cout « "Stochastic Gradient Descent\n";  break;
      case rms:  std::cout « "RMSprop\n"; break;
      }
    }
    int ssize = batchSize;//data.items.size();
    std::vector<Dataset> batches = data.batch(ssize);
    for (int i = 0; i < batches.size(); i++) {
        batches.at(i).stack(); // Put batch items into one matrix
    }

    float loss, acc;
    float lrInit = lr;

    for (int i_epoch = 0; i_epoch < epochs; i_epoch++) {
      // Iterate through the entire dataset for each epoch
      if(rank==0)
        std::cout « std::endl « "Epoch " « i_epoch+1 « "/" « epochs;
      lr = lrInit; // Reset the learning rate to undo decay
      int batchStart = batches.size() * rank / comm_world.size();
      int batchEnd = batches.size() * (rank + 1) / comm_world.size();

      for(int idx=batchStart; idx<batchEnd; idx++) {
        calcGrad(batches.at(idx).dataBatch, batches.at(idx).labelBatch);
        for(auto &layer : this->layers) {
          mpl::contiguous_layout<float> dw_layout(layer.dw.r * layer.dw.c);
          mpl::contiguous_layout<float> db_layout(layer.db.size());
          if(rank==0) {
            Matrix tempdw(layer.dw.r, layer.dw.c, 0);
            Vector tempdb(layer.db.size(), 0);
            Matrix currdw = layer.dw;
            Vector currdb = layer.db;
            comm_world.reduce(mpl::plus<float>(), 0, tempdw.data(), layer.dw.data(), dw_layout);
            comm_world.reduce(mpl::plus<float>(), 0, tempdb.data(), layer.db.data(), db_layout);
            layer.dw = layer.dw + currdw; // IM the on-rank values get discarded when reducing, or may be a misinterpretation on my side
            layer.db = layer.db + currdb;
            layer.dw = layer.dw / size;
            layer.db = layer.db / size;
          } else {
            comm_world.reduce(mpl::plus<float>(), 0, layer.dw.data(), dw_layout);
            comm_world.reduce(mpl::plus<float>(), 0, layer.db.data(), db_layout);
          }
        }
        comm_world.barrier(); //sync before processing the next batch
        if(rank==0) {
            lr = lr / (1 + decay * idx);
            optimize.at(Optimizer)(lr, momentum);
        }
      }
    }
}
```

## 5.16 test_linear.cpp

```
/*****************************************************************
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 **** Deep Learning Network code
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 ****
 *****************************************************************
 *****************************************************************/
```

```

#include <iostream>
#include <chrono>
#include <vector>
#include <time.h>

#include "cxxopts.hpp"

#include "net.h"
#include "dataset.h"
#include "vector.h"
#include "funcs.h"
#include "trace.h"

using namespace std;

int main(int argc,char **argv){
  //    srand(time(NULL));

  try {
    using myclock = std::chrono::high_resolution_clock;

    // IM attempt to use cxxopts to specify location
    cxxopts::Options options("EduDL", "FFNNs w BLIS");

    options.add_options()
      ("h,help","usage information")
      ("l,levels", "Number of levels in the network",cxxopts::value<int>()->default_value("2"))
      ("s,sizes","Sizes of the levels",cxxopts::value<std::vector<int»())
      ("o,optimizer", "Optimizer to be used, 0: SGD, 1: RMSprop",cxxopts::value<int>()->default_value("0"))
      ("e,epochs", "Number of epochs to train the network", cxxopts::value<int>()->default_value("1"))
      ("r,learningrate", "Learning rate for the optimizer", cxxopts::value<float>()->default_value("0.001"))
      ("b,batchsize", "Batch size for the training data", cxxopts::value<int>()->default_value("5"))
      ("t,tracing","Level of tracing: 0=default 1=scalars 2=arrays",cxxopts::value<int>()->default_value("0"))
      ;

    auto result = options.parse(argc,argv);
    if (result.count("help")) {
      std::cout « options.help() « std::endl;
      return 1;
    }

    std::vector<int> level_sizes{12,12};

    if (result.count("sizes")) {
      level_sizes = result["s"].as< std::vector<int> >();
    } else if (result.count("levels")) {
      int number_of_levels = result["l"].as<int>();
      level_sizes = std::vector<int>(number_of_levels,12);
    }

    set_trace_level( result["t"].as<int>() );
    int network_optimizer = result["o"].as<int>();
    int epochs = epochs = result["e"].as<int>();
    float lr = result["r"].as<float>();
    int batchSize = result["b"].as<int>();

    /*
     * Input data set:
     * y = 2 x + 1
     */
    cout « "Creating data set\n";
    Dataset data(1);
    for (int input=0; input<5; input++) {
      float x = 1.f + 1.f*input, y = 2*x+1;
      std::vector<float> i(1,x), o(1,y);
      dataItem thisitem{i,o};
      data.push_back(thisitem);
    }
    cout  « "Number of data points: " « data.size() « endl; // Show size
    //    data.stack();

    {
      /*
       * First test a perfect net
       */
      Net test_net( data );
      test_net.addLayer(1,NONE);
      test_net.set_uniform_weights(1.f);
      test_net.set_uniform_biases(0.f);
      test_net.set_lossfunction(mse);

      auto loss = test_net.calculateLoss(data);
      cout « " Loss: " « loss « endl;
```

```
      auto acc = test_net.accuracy(data);
      std::cout « "Accuracy: " « acc « "\n";
      test_net.info();

      auto [train_data,test_data] = data.split(0.9);
      assert( train_data.data_size()!=0 );
      assert( test_data.data_size()!=0 );
      cout « "Initial accuracy: " « test_net.accuracy(test_data) « "\n";
      test_net.train(train_data,test_data, epochs, batchSize);
      cout « "Final Accuracy over test data: " « acc « "\n";

    }

  } catch ( string e ) {
    cout « "Error «" « e « "» \n";
  } catch ( std::out_of_range ) {
    cout « "Out of range error\n";
  } catch ( ... ) {
    cout « "Uncaught exception\n";
  }

    return 0;
}
```

## 5.17 test_mnist.cpp

```
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 ****************************************************************
 ****************************************************************/

/*
 * A simple test neural network
 *
 * Test data set: http://cis.jhu.edu/~sachin/digit/digit.html
 */

#include <iostream>
using std::cout;
using std::endl;
#include <chrono>
#include <string>
using std::string;
#include <vector>
using std::vector;
#include <time.h>

#include "cxxopts.hpp"

#include "net.h"
#include "dataset.h"
#include "vector.h"
#include "trace.h"

using namespace std;
static int trace_level;

#if 1
int main(int argc,char **argv){
  try {
    using myclock = std::chrono::high_resolution_clock;

    // IM attempt to use cxxopts to specify location
    cxxopts::Options options("EduDL", "FFNNs w BLIS");

    options.add_options()
      ("h,help","usage information")
      ("d,dir", "Dataset directory",cxxopts::value<std::string>())
      ("l,levels", "Number of levels in the network",cxxopts::value<int>()->default_value("2"))
      ("s,sizes","Sizes of the levels",cxxopts::value<std::vector<int»())
      ("o,optimizer", "Optimizer to be used, 0: SGD, 1:
 RMSprop",cxxopts::value<int>()->default_value("0"))
      ("e,epochs", "Number of epochs to train the network", cxxopts::value<int>()->default_value("1"))
      ("r,learningrate", "Learning rate for the optimizer",
 cxxopts::value<float>()->default_value("0.001"))
```

```
      ("b,batchsize", "Batch size for the training data", cxxopts::value<int>()->default_value("256"))
      ("t,tracing","Level of tracing: 0=default 1=scalars
2=arrays",cxxopts::value<int>()->default_value("0"))
      ;

    auto result = options.parse(argc,argv);
    if (result.count("help")) {
      cout « options.help() « endl;
      return 1;
    }

    std::vector<int> level_sizes{12,12};

    if (result.count("sizes")) {
      level_sizes = result["s"].as< std::vector<int> >();
      if (result.count("levels")) {
    cout « "Option for number of levels ignored when level sizes are given" « endl;
      }
    } else if (result.count("levels")) {
      int number_of_levels = result["l"].as<int>();
      level_sizes = std::vector<int>(number_of_levels,12);
    }

    set_trace_level( result["t"].as<int>() );
    int network_optimizer = result["o"].as<int>();
    int epochs = epochs = result["e"].as<int>();
    float lr = result["r"].as<float>();
    int batchSize = result["b"].as<int>();

    /*
     * Input data set handling
     */
    if (!result.count("dir")) {
      cout « "Must specify directory with -d/--dir option" « endl;
      return 1;
    }
    string mnist_loc = result["dir"].as<string>();
    Dataset data;
    data.readTest(mnist_loc.data()); // Placed MNIST in a neighbor directory

    // Parent
    //   |__mnist
    //   |      |_data0
    //   |      |_...
    //   |      |_data9
    //   |__src
    //          |_test.cpp  [You are here]


    cout « "Dataset size: " « data.size() « endl; // Show size

    Net test_net(data);
    if (level_sizes.size()==2) {
      test_net.addLayer(16, RELU);
      test_net.addLayer(10, SIG ); //SMAX);
    } else {
      for ( auto level_size : level_sizes ) {
    cout « "Adding level of size " « level_size « endl;
    test_net.addLayer(level_size,RELU);
      }
      test_net.addLayer(10, SIG ); //SMAX);
    }

    test_net.set_learning_rate(lr);
    test_net.set_decay(0.0);
    test_net.set_momentum(0.9);
    test_net.set_optimizer(network_optimizer);
      test_net.set_uniform_weights(.5f);
      test_net.set_uniform_biases(.1f);
      test_net.set_lossfunction(mse);

    /*
     * Train / Test
     */
    auto start_time = myclock::now();
    auto [train_data,test_data] = data.split(0.8);
    cout « "Initial accuracy: " « test_net.accuracy(test_data) « "\n";

    test_net.train(train_data,test_data, epochs, batchSize);
    auto duration = myclock::now()-start_time;

    int
      microsec_duration = std::chrono::duration_cast<std::chrono::microseconds>(duration).count(),
      seconds = microsec_duration/1000000,
      micros  = microsec_duration - 1000000*seconds;
    while (micros>=1000) micros /= 10;
    auto acc = test_net.accuracy(test_data);
```

```
    cout « "Final Accuracy over test data: " « acc « "\n"
     « "    attained in " « seconds « "." « micros « " sec" « "\n";

    test_net.saveModel("weights.bin");
    test_net.info();

  } catch ( string e ) {
    cout « "ERROR «" « e « "»\n";
  } catch ( std::out_of_range ) {
    cout « "Uncaught out of range error\n";
  } catch ( ... ) {
    cout « "Uncaught exception\n";
  }

    return 0;
}
#else
int main(){

    VectorBatch a(3,4,1); // Two feature vectors, each vector sized 4
    VectorBatch b(3,5,1);
    a.show();

    Net model(4);
    model.addLayer(2,RELU);
    model.addLayer(5,SMAX);

    model.show();
    model.feedForward(a);
    model.backPropagate(a, b);

    return 0;
}
#endif
```

## 5.18 test_mpi.cpp

```
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 ******************************************************************/

#include <iostream>
#include <chrono>
#include <vector>
#include <time.h>

#include "cxxopts.hpp"

#include "net.h"
#include "dataset.h"

#include <mpl/mpl.hpp>
using namespace std;

#if 0
int main(){
    srand(time(NULL));

    Net bar(0);
    bar.loadModel("weights.bin");
    bar.info();

    return 0;
}
#else
int main(int argc,char **argv){
    using myclock = std::chrono::high_resolution_clock;
    srand(time(NULL));

    const mpl::communicator &comm_world(mpl::environment::comm_world());
    // IM attempt to use cxxopts to specify location
    cxxopts::Options options("EduDL", "FFNNs w BLIS");

    options.add_options()
```

```
      ("h,help","usage information")
      ("d,dir", "Dataset directory",cxxopts::value<std::string>())
      ("l,levels", "Number of levels in the network",cxxopts::value<int>()->default_value("2"))
      ("s,sizes","Sizes of the levels",cxxopts::value<std::vector<int»())
      ("o,optimizer", "Optimizer to be used, 0: SGD, 1:
   RMSprop",cxxopts::value<int>()->default_value("0"))
      ("e,epochs", "Number of epochs to train the network", cxxopts::value<int>()->default_value("1"))
      ("r,learningrate", "Learning rate for the optimizer",
   cxxopts::value<float>()->default_value("0.001"))
      ("b,batchsize", "Batch size for the training data", cxxopts::value<int>()->default_value("256"))
      ;

    auto result = options.parse(argc,argv);
    if (result.count("help")) {
      std::cout « options.help() « std::endl;
      return 1;
    }

    std::vector<int> level_sizes{12,12};

    if (result.count("sizes")) {
      level_sizes = result["s"].as< std::vector<int> >();
    } else if (result.count("levels")) {
      int number_of_levels = result["l"].as<int>();
      level_sizes = std::vector<int>(number_of_levels,12);
    }

    int network_optimizer = result["o"].as<int>();

    int epochs = epochs = result["e"].as<int>();

    float lr = result["r"].as<float>();

    int batchSize = result["b"].as<int>();

    /*
     * Input data set handling
     */
    if (!result.count("dir")) {
      std::cout « "Must specify directory with -d/--dir option" « std::endl;
      return 1;
    }
    string mnist_loc = result["dir"].as<string>();
    //std::cout « mnist_loc « std::endl;
    Dataset data;
    data.readTest(mnist_loc.data()); // Placed MNIST in a neighbor directory

    // Parent
    //    |__mnist
    //    |       |_data0
    //    |       |_...
    //    |       |_data9
    //    |__src
    //            |_test.cpp  [You are here]

    if(comm_world.rank()==0)
      cout « data.items.size() « endl; // Show size

    data.shuffle();

    //    Vector v1 = data.items.at(0).data;
    //    Vector gT = data.items.at(0).label;

    Net test_net(data); //v1.size());
    //test_net.addLayer(256, RELU);
    //test_net.addLayer(64, RELU);
    //test_net.addLayer(32, RELU);
    if (level_sizes.size()==2) {
      test_net.addLayer(16, RELU);
      test_net.addLayer(10, SMAX);
    } else {
      for ( auto level_size : level_sizes ) {
    std::cout « "Adding level of size " « level_size « std::endl;
    test_net.addLayer(level_size,RELU);
      }
      test_net.addLayer(10, SMAX);
    }

    auto [trainSplit,testSplit] = data.split(0.95);
    if(comm_world.rank()==0)
      std::cout « "Split " « trainSplit.items.size() « " " « testSplit.items.size() « "\n";
    auto start_time = myclock::now();
//    std::cout « test_net.accuracy(data) « "\n";

    test_net.trainmpi(trainSplit,testSplit,
    lr, epochs, (opt)network_optimizer, cce,  batchSize, 0.9);

```

```
    comm_world.barrier();
    auto duration = myclock::now()-start_time;
    auto microsec_duration = std::chrono::duration_cast<std::chrono::microseconds>(duration);

    if(comm_world.rank()==0){
      std::cout « "\nFinal Accuracy over all data: " « test_net.accuracy(data) « "\n"
          « "    attained in " « microsec_duration.count() « "usec" « "\n";

      test_net.saveModel("weights.bin");
      test_net.info();
    }
    return 0;
}
#endif
```

## 5.19 test_posneg.cpp

```
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#include <iostream>
#include <chrono>
#include <vector>
#include <time.h>

#include "cxxopts.hpp"

#include "net.h"
#include "dataset.h"
#include "vector.h"
#include "funcs.h"
#include "trace.h"

using namespace std;

int main(int argc,char **argv){

  try {
    using myclock = std::chrono::high_resolution_clock;

    // IM attempt to use cxxopts to specify location
    cxxopts::Options options("EduDL", "FFNNs w BLIS");

    options.add_options()
      ("h,help","usage information")
      ("l,levels", "Number of levels in the network",cxxopts::value<int>()->default_value("2"))
      ("s,sizes","Sizes of the levels",cxxopts::value<std::vector<int»())
      ("o,optimizer", "Optimizer to be used, 0: SGD, 1: RMSprop",cxxopts::value<int>()->default_value("0"))
      ("e,epochs", "Number of epochs to train the network", cxxopts::value<int>()->default_value("1"))
      ("r,learningrate", "Learning rate for the optimizer", cxxopts::value<float>()->default_value("0.001"))
      ("b,batchsize", "Batch size for the training data", cxxopts::value<int>()->default_value("5"))
      ("t,tracing","Level of tracing: 0=default 1=scalars 2=arrays",cxxopts::value<int>()->default_value("0"))
      ;

    auto result = options.parse(argc,argv);
    if (result.count("help")) {
      std::cout « options.help() « std::endl;
      return 1;
    }

    std::vector<int> level_sizes{12,12};

    if (result.count("sizes")) {
      level_sizes = result["s"].as< std::vector<int> >();
    } else if (result.count("levels")) {
      int number_of_levels = result["l"].as<int>();
      level_sizes = std::vector<int>(number_of_levels,12);
    }

    set_trace_level( result["t"].as<int>() );
```

```
    int network_optimizer = result["o"].as<int>();
    int epochs = epochs = result["e"].as<int>();
    float lr = result["r"].as<float>();
    int batchSize = result["b"].as<int>();

    /*
     * Input data set handling
     */
    Dataset data(2);
    for (float item=-99.5; item<100; item+=1) {
      if (item<0) {
    // negative numbers are yes/no
    dataItem thisitem{std::vector<float>{item},std::vector<float>{1,0}};
    data.push_back(thisitem);
      } else {
    // positive numbers are no/yes
    dataItem thisitem{std::vector<float>{item},std::vector<float>{0,1}};
    data.push_back(thisitem);
      }
    }
    cout « "Dataset size: " « data.size() « endl; // Show size

    Net test_net( data );
    if (level_sizes.size()==2) {
      test_net.addLayer(16, RELU);
      test_net.addLayer(2, SIG); // SMAX );
    } else {
      for ( auto level_size : level_sizes ) {
    std::cout « "Adding level of size " « level_size « std::endl;
    test_net.addLayer(level_size,RELU);
      }
      test_net.addLayer(2, SIG); // SMAX );
    }

    test_net.set_learning_rate(lr);
    test_net.set_decay(0.9);
    test_net.set_momentum(0.9);
    test_net.set_optimizer(network_optimizer);
    test_net.set_lossfunction(mse);

    auto start_time = myclock::now();
    auto [train_data,test_data] = data.split(0.9);
    cout « "Initial accuracy: " « test_net.accuracy(test_data) « "\n";

    test_net.train(train_data,test_data, epochs, batchSize);
    auto duration = myclock::now()-start_time;
    auto microsec_duration = std::chrono::duration_cast<std::chrono::microseconds>(duration);
    std::cout « "Final Accuracy over test data: " « test_net.accuracy(data) « "\n"
          « "    attained in " « microsec_duration.count() « "usec" « "\n";

    //test_net.saveModel("weights.bin");
    test_net.info();

  } catch ( string e ) {
    cout « "Error «" « e « "» \n";
  } catch ( std::out_of_range ) {
    cout « "Out of range error\n";
  } catch ( ... ) {
    cout « "Uncaught exception\n";
  }

    return 0;
}
```

## 5.20 trace.cpp

```
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 ****************************************************************/

#include "trace.h"

int trace_level;

```

```
void set_trace_level(int ell) { trace_level = ell; };
bool trace_progress() { return trace_level>=1; };
bool trace_scalars() { return trace_level>=2; };
bool trace_arrays()  { return trace_level>=3; };
```

## 5.21 trace.h

```
/****************************************************************
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 ****************************************************************
 ****************************************************************/

bool trace_progress();
bool trace_scalars();
bool trace_arrays();
void set_trace_level(int);
```

## 5.22 unittest.cpp

```
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 ****
 ****************************************************************
 ****************************************************************/

#include <iostream>
using std::cout;
#include <vector>
using std::vector;

#define CATCH_CONFIG_MAIN
#include "catch2/catch_all.hpp"

#include "funcs.h"
#include "net.h"

TEST_CASE( "functions","[1]" ) {
  /*
   * ReLU is linear >0, zero <0
   */
  {
    auto highpass = [] ( const float &x ) -> float {
      return relu_pt(x); };
    auto x = GENERATE( -5., -.5, .5, 2.5 );
    float y;
    REQUIRE_NOTHROW( y = highpass(x) );
    if (x<0)
      REQUIRE( y==Catch::Approx(0.) );
    else
      REQUIRE( y==Catch::Approx(x) );
  }

  /*
   * relu_slope avoids zero'ing the negative inputs
   */
  {
    auto leak = [] ( const float &x ) -> float {
      return relu_slope_pt(x); };
    auto x = GENERATE( -5., -.5, .5, 2.5 );
    float y;
    REQUIRE_NOTHROW( y = leak(x) );
    if (x<0)
      REQUIRE( y<0 );
    else
```

```
      REQUIRE( y==Catch::Approx(x) );
  }
}

TEST_CASE( "batch activation","[2]" ) {
  Vector values( vector<float>{1,2,.5} ), maxes(3);
  REQUIRE_NOTHROW( softmax_io( values,maxes ) );
  REQUIRE( maxes.positive() );
  const auto& maxvalues = maxes.values();
  INFO( "maxes: " « maxvalues[0] « "," « maxvalues[1] « "," « maxvalues[2] );
  auto maxit = maxvalues.begin();
  REQUIRE_NOTHROW( maxit = find( maxvalues.begin(),maxvalues.end(),
                   *max_element( maxvalues.begin(),maxvalues.end() ) ) );
  REQUIRE( maxit!=maxvalues.end() );
  int maxloc{-1};
  REQUIRE_NOTHROW( maxloc = distance( maxvalues.begin(),maxit ) );
  REQUIRE( maxloc==1 );
}

TEST_CASE( "scalar layer","[layer][11]" ) {
    Layer multiply(1,1);
    REQUIRE_NOTHROW
    (
     multiply
     .set_uniform_weights(1.)
     .set_uniform_biases(0.)
     .set_activation(
             [] (const float &x ) -> float { return id_pt(x); },
             [] (const float &x ) -> float { return 1; },
             "id"
             )
      );
    float input_number = 2.5f;
    VectorBatch
    scalar_in( Vector( vector<float>( {input_number} ) ) ),
    scalar_out( Vector( vector<float>( {1.2f} ) ) );
    REQUIRE( scalar_in.batch_size()==1 );
    REQUIRE( scalar_in.item_size()==1 );
    REQUIRE( scalar_out.batch_size()==1 );
    REQUIRE( scalar_out.item_size()==1 );
    REQUIRE( multiply.input_size()==1 );
    REQUIRE( multiply.output_size()==1 );
    float correct_result;
    SECTION( "identity" ) {
    correct_result = input_number;
    }
    SECTION( "scale by 2" ) {
    float multiplier = 2.f;
    REQUIRE_NOTHROW( multiply.set_uniform_weights(multiplier) );
    correct_result = multiplier * input_number;
    }
    SECTION( "shift by 2" ) {
    float shift = 2.f;
    REQUIRE_NOTHROW( multiply.set_uniform_biases(shift) );
    correct_result = shift + input_number;
    }
    REQUIRE_NOTHROW( multiply.forward(scalar_in,scalar_out) );
    REQUIRE( scalar_out.at(0,0) ==Catch::Approx( correct_result ) );
}

TEST_CASE( "highpass net: batch version","[net][21]" ) {
  Net highpass(1);
  REQUIRE_NOTHROW( highpass.addLayer
           (1,
            [] (const float &x ) -> float { return relu_pt(x); },
            [] (const float &x ) -> float { return x; },
            "highpass" ) );
  REQUIRE_NOTHROW( highpass.backlayer()
           .set_uniform_weights(1.)
           .set_uniform_biases(0.)
           );
  VectorBatch input(1,1),output(1,1);
  auto x = GENERATE( -.5, -5, .5, 1.5 );
  input.data()[0] = x;
  REQUIRE_NOTHROW( highpass.feedForward(input,output) );
  auto y = output.data()[0];
  INFO( "Input = " « x « "-> output = " « y );
  if ( x>0 )
      REQUIRE( y>0 );
  else
      REQUIRE( y==Catch::Approx(0.0) );
}

TEST_CASE( "highpass net: vector version","[net][22]" ) {
  Net highpass(1);
  REQUIRE_NOTHROW( highpass.addLayer
           (1,
```

```
            [] (const float &x ) -> float { return relu_pt(x); },
            [] (const float &x ) -> float { return x; },
            "highpass" ) );
  REQUIRE_NOTHROW( highpass.backlayer()
           .set_uniform_weights(1.)
           .set_uniform_biases(0.)
           );
  Vector input(1),output(1);
  auto x = GENERATE( -.5, -5, .5, 1.5 );
  input[0] = x;
  REQUIRE_NOTHROW( highpass.feedForward(input,output) );
  INFO( "Input = " « input[0] « "-> output = " « output[0] );
  if ( x>0 )
      REQUIRE( output[0]>0 );
  else
      REQUIRE( output[0]==Catch::Approx(0.0) );
}

TEST_CASE( "low pass net: vector version","[net][23]" ) {
  Net lowpass(1);
  REQUIRE_NOTHROW( lowpass.addLayer
           (1,
            [] (const float &x ) -> float { return relu_pt(1-x); },
            [] (const float &x ) -> float { return x; },
            "lowpass" ) );
  REQUIRE_NOTHROW( lowpass.backlayer()
           .set_uniform_weights(1.)
           .set_uniform_biases(0.)
           );
  Vector input(1),output(1);
  auto x = GENERATE( -.5, -5, .5, 1.5 );
  input[0] = x;
  REQUIRE_NOTHROW( lowpass.feedForward(input,output) );
  INFO( "Input = " « input[0] « "-> output = " « output[0] );
  if ( x<1 )
      REQUIRE( output[0]>0 );
  else
      REQUIRE( output[0]==Catch::Approx(0.0) );
}

```

## 5.23 vector.cpp

```
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 ****************************************************************
 ****************************************************************/

#include <algorithm>
#include <iostream>
#include <cassert>

#include "vector.h"
#include "vector2.h"

/*
 * These are the vector routines that do not have a optimized implementation,
 * such as using BLIS.
 */


Vector::Vector(){
}

int Vector::size() const { return vals.size(); };

Vector::Vector( std::vector<float> vals )
  : vals(vals) {
  r = vals.size();
  c = 1;
};

void Vector::copy_from( const VectorBatch& batch ) {
    const auto& batch_vals = batch.data();
    assert( batch.nelements()>=vals.size() );
```

```
    for (int i=0; i<vals.size(); i++) {
    vals[i] = batch_vals[i];
    }
};

void Vector::square() {
    std::for_each(vals.begin(), vals.end(), [](auto &n) {n*=n;});
}

Vector& Vector::operator=(const Vector &m2) { // Overloading the = operator
    vals = m2.vals;
    return *this;
}

// Note: no element-wise, non destructive operations in BLIS, so no implementations for those yet
// There are element wise operations in MKL I believe
Vector Vector::operator+(const Vector &m2) {
    assert(m2.size()==this->size());
    Vector out(m2.size(),0);
    for (int i=0;i<m2.size();i++) {
        out.vals[i] = this->vals[i] + m2.vals[i];
    }
    return out;
}

Vector Vector::operator-(const Vector &m2) {
    assert(m2.size()==this->size());
    Vector out(m2.size(),0);
    for (int i=0;i<m2.size();i++) {
        out.vals[i] = this->vals[i] - m2.vals[i];
    }
    return out;
}


Vector operator-(const float &c, const Vector &m) {
    Vector o=m;
    for (int i=0;i<m.size();i++) {
        o.vals[i] = c - o.vals[i];
    }
    return o;
}

Vector operator*(const float &c, const Vector &m) {
    Vector o=m;
    for (int i=0;i<m.size();i++) {
        o.vals[i] = c * o.vals[i];
    }
    return o;
}

Vector Vector::operator/=( float c ) {
    for (int i=0;i<vals.size();i++) {
        vals[i] = vals[i] / c;
    }
    return *this;
}

Vector Vector::operator*(const Vector &m2) { // Hadamard product
    Vector out(m2.size(), 0);
    for (int i = 0; i < m2.size(); i++) {
        out.vals[i] = this->vals[i] * m2.vals[i];
    }
    return out;
}

Vector Vector::operator/(const Vector &m2) { // Element wise division
    Vector out(m2.size(), 0);
    for (int i = 0; i < m2.size(); i++) {
        out.vals[i] = this->vals[i] / m2.vals[i];
    }
    return out;
}

Vector Vector::operator-() {
    Vector result = *this;
    for (int i = 0; i < size(); i++){
        result.vals[i] = -vals[i];
    }

    return result;
};
```

## 5.24 vector.h

```
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 ****************************************************************/

#ifndef SRC_VECTOR_H
#define SRC_VECTOR_H
#include <algorithm>
#include <vector>
#include <cassert>
#include <cmath>

class VectorBatch; // forward for friending
class Matrix; // forward for friending
class Vector {
  friend class VectorBatch;
  friend class Matrix;
private:
    std::vector<float> vals;
public:
    Vector();
    Vector( int n )
    : vals(std::vector<float>(n)) {};
    Vector( std::vector<float> vals );
    Vector(int size, int init);
    int size() const;
    int r; int c=1; /* VLE these need to go! */
    void show();
    void add( const Vector &v1);
    void set_ax( float a, Vector &x );
    std::vector<float>& values() { return vals; };
    const std::vector<float>& values() const { return vals; };
    void copy_from( const VectorBatch& );
    float *data() { return vals.data(); };
    const float *data() const { return vals.data(); };
    void zeros();
    void square();
    float& operator[](int i) { return vals[i]; };
    float operator[](int i) const { return vals[i]; };
    Vector operator-(); // Unary negate operator
    Vector& operator=(const Vector& m2); // Copy constructor
    Vector operator+(const Vector &m2); // Element-wise addition
    Vector operator*(const Vector &m2); // Hadamard Product Element-wise multiplication
    Vector operator/(const Vector &m2); // Element-wise division
    Vector operator/=(float x);
    Vector operator-(const Vector &m2); // Element-wise subtraction
    friend Vector operator-(const float &c, const Vector &m); // for constant
    friend Vector operator*(const float &c, const Vector &m); // for constant-matrix multiplication
    //friend Vector operator/(const Vector &m, const float &c); // for matrix-constant division

  bool positive() const {
    return all_of
      ( vals.begin(),vals.end(),
    [] (float e) { return e>0; }
    );
  }
};

class Categorization {
private:
  std::vector<float> _probabilities;
public:
  Categorization( Vector v )
    : _probabilities(v.values()) {};
  Categorization( std::vector<float> p)
    : _probabilities(p) {};
  Categorization(int n)
    : _probabilities( std::vector<float>(n) ) {};
  Categorization(int n,int i)
    : _probabilities( std::vector<float>(n) ) {
    _probabilities.at(i) = 1.;
  };
  const std::vector<float>& probabilities() const { return _probabilities; };
  int size() const { return _probabilities.size(); };
  void normalize() {
    auto it = std::max_element(_probabilities.begin(), _probabilities.end());
    std::fill(_probabilities.begin(), _probabilities.end(), 0);
```

```
    *it = 1;
  };
  bool close_enough( const Categorization& approx ) const {
    return close_enough( approx.probabilities() );
  };
  bool close_enough( const std::vector<float>& approx ) const {
    assert( size()==approx.size() );
    //return _probabilities==approx;
    bool close{true};
    for ( int i=0; i<size(); i++) {
      close = close and
    ( ( _probabilities.at(i)==approx.at(i) )
      or ( approx.at(i)==0. and ( std::abs(_probabilities.at(i))<1.e-5 ) )
      or ( std::abs( (_probabilities.at(i)-approx.at(i))/approx.at(i) )<1.e-5 )
      );
    }
    return close;
  };
};

#endif //SRC_VECTOR_H
```

## 5.25 vector2.cpp

```
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#include <iostream>
using std::cout;
using std::endl;
#include <iomanip>
using std::setprecision;
#include <string>
using std::string;
#include <vector>
#include <algorithm>
#include <cassert>
using std::vector;

#include "trace.h"
#include "vector2.h"

/*
 * These are the vector batch routines that do not have a optimized implementation,
 * such as using BLIS.
 */

VectorBatch::VectorBatch() { // Default constructor
}

VectorBatch::VectorBatch( int vs ) {
  allocate(0,vs);
}

VectorBatch::VectorBatch( const Vector& v ) {
    int s = v.size();
    allocate(1,s);
    copy( v.vals.begin(),v.vals.end(),vals.begin() );
    // for ( int i=0; i<s; i++ )
    //  vals[i] = v[i];
};

void VectorBatch::allocate(int batchsize,int itemsize) {
  // we allow a batchsize of zero
  assert(batchsize>=0);
  assert(itemsize>0);
  vals.resize(batchsize*itemsize);
  set_batch_size(batchsize);
  set_item_size(itemsize);
};

void VectorBatch::display( string header) const {
  cout « header « "\n";
```

```
  for (int j=0; j<batch_size(); j++) {
    for (int i=0; i<item_size(); i++)
      cout « setprecision(5)
       « vals_vector().at( INDEXc(i,j,item_size(),batch_size()) )
       « " ";
    cout « "\n";
  }
};

void VectorBatch::set_col(int j,const std::vector<float> &v ) {
  assert( j<batch_size() );
  assert( v.size()==item_size() );
  for (int i = 0; i<nvectors; i++) {
    vals.at( j + vector_size * i ) = v.at(i);
  };
};

void VectorBatch::add_vector( const std::vector<float> &v ) {
  const int Nelements = vals.size();
  const int vector_length = v.size();
  if (Nelements==0)
    set_item_size(vector_length);
  else {
    assert( vector_length==item_size() );
    assert( Nelements%vector_length==0 );
  }
  const int m = Nelements/vector_length;
  vals.resize(Nelements+vector_length); nvectors++;
  for (int i = 0; i < vector_length; i++) {
    vals.at( m * vector_length + i ) = v.at(i);
  };
};

std::vector<float> VectorBatch::get_col(int j) const {
  assert( j<batch_size() );
  const int c = item_size();
  std::vector<float> col(c);
  for (int i=0; i<c; i++)
    col.at(i) = vals.at( j + c*i );
  return col;
};

void VectorBatch::set_row( int j, const std::vector<float> &v ) {
  const int c = item_size();
  assert( v.size()==c );
  for (int i = 0; i < c; i++) {
    vals.at( j * c + i ) = v.at(i);
  };
}

std::vector<float> VectorBatch::get_row(int j) const {
  assert( j<batch_size() );
  const int n = item_size();
  std::vector<float> row(n);
  for (int i = 0; i < n; i++)
    row.at(i) = vals.at( j * n + i );
  return row;
};

std::vector<float> VectorBatch::extract_vector(int j) const {
  assert( j<batch_size() );
  const int m = item_size();
  std::vector<float> v(m);
  for (int i = 0; i < m; i++)
    v.at(i) = vals.at( INDEXc(i,j,m,batch_size()) );  // (j * n + i );
  return v;
  //  return get_row(v);
};
#ifdef USE_GSL
gsl::span<float> VectorBatch::get_vector(int v) {
  const int c = item_size();
  return gsl::span<float>( &vals[v*c], c );
};
// const gsl::span<float> VectorBatch::get_vector(int v) const {
//   const int c = item_size();
//   return gsl::span<float>( data(v*c) /* &vals[v*c] */, c );
// };
#else
std::vector<float> VectorBatch::get_vector(int v) const {
  return extract_vector(v);
};
#endif

void VectorBatch::set_vector( const Vector &v, int j) {
  set_vector( v.vals,j );
}

```

```
void VectorBatch::set_vector( const vector<float> &v, int j) {
  const int c = item_size();
  assert( v.size()==c );
  for (int i=0; i<c; i++)
    vals.at( j * c + i ) = v.at(i);
}

void VectorBatch::addh(const Vector &y) { // Add y to every row
  const int r = item_size(), c = batch_size();
  assert( r==y.size() );
  for (int j=0; j<c; j++ ) {
    for (int i=0; i<r; i++) {
      vals.at( INDEXc(i,j,r,c) ) += y.vals[i];
    }
  }
}

// void VectorBatch::add(const VectorBatch &y) { // Add y to every row
//   const int r = item_size(), c = batch_size();
//   assert( r==y.size() );
//   asserr( c==y.batch_size() );
//   for (int j=0; j<c; j++ ) {
//     for (int i=0; i<r; i++) {
//       vals.at( INDEXc(i,j,r,c) ) += y.vals.at( INDEXc(i,j,r,c) );
//     }
//   }
// }

Vector VectorBatch::meanh() const { // Returns a vector of row-wise means
  const int r = item_size(), c = batch_size();
  Vector mean(r, 0);
  for (int i=0; i<r; i++) {
    float avg = 0.f;
    for ( int j=0; j<c; j++ ) {
      avg += vals.at( INDEXc(i,j,r,v) );
    }
    mean.vals[i] = avg/static_cast<float>( item_size() );
  }
  return mean;
}


/*
 * VLE dangerous. et rid of this one
 */
VectorBatch &VectorBatch::operator=(const VectorBatch &m2) { // Overloading the = operator
  set_item_size( m2.item_size() );
  set_batch_size( m2.batch_size() );

  this->vals = m2.vals; // IM Since we're using vectors we can just use the assignment from that

  return *this;
}


VectorBatch VectorBatch::operator-(const VectorBatch &m2) const {
  assert( item_size()==m2.item_size() );
  assert( batch_size()==m2.batch_size() );
  const int c = m2.item_size(), r = m2.batch_size();
  VectorBatch out(r, c, 0);
    for (int i = 0; i < r * c; i++) {
        out.vals[i] = this->vals[i] - m2.vals[i];
    }
    return out;
}

VectorBatch VectorBatch::operator*(const VectorBatch &m2) { // Hadamard product
  assert( item_size()==m2.item_size() );
  assert( batch_size()==m2.batch_size() );
  const int c = m2.item_size(), r = m2.batch_size();
  VectorBatch out(r, c, 0);
  for (int i = 0; i < nelements(); i++) {
        out.vals[i] = this->vals[i] * m2.vals[i];
    }
    return out;
}

void VectorBatch::hadamard(const VectorBatch& m1,const VectorBatch& m2) {
  const int r = item_size(), c = batch_size();
  assert( r==m1.item_size() ); assert( c==m1.batch_size() );
  assert( r==m2.item_size() ); assert( c==m2.batch_size() );

  const auto& m1vals = m1.vals_vector();
  const auto& m2vals = m2.vals_vector();
  for (int i=0; i<r*c; i++) {
    vals.at(i) = m1vals.at(i) * m2vals.at(i);
    if ( isinf(vals.at(i)) )
```

```
      cout « "inf from " « m1vals.at(i) « " * " « m2vals.at(i) « "\n";
  }
  if (trace_progress()) {
    assert( m1.notinf() ); assert( m1.notnan() ); assert( m1.normf()!=0.f );
    assert( m2.notinf() ); assert( m2.notnan() ); assert( m2.normf()!=0.f );
    assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
  }
  if (trace_scalars()) {
    cout « "delta: "
     « m1.normf() « "x" « m2.normf() « " => " « this->normf() « "\n";
  }
}

VectorBatch VectorBatch::operator/(const VectorBatch &m2) { // Hadamard product
  const int c = m2.item_size(), r = m2.batch_size();
  assert( item_size()==c );
  assert( batch_size()==r );
  VectorBatch out(r, c, 0);
  for (int i = 0; i < nelements(); i++) {
    out.vals[i] = this->vals[i] / m2.vals[i];
  }
  return out;
}

void VectorBatch::scaleby( float f) {
  for (int i = 0; i < nelements(); i++) {
    vals[i] *= f;
  }
}

VectorBatch VectorBatch::operator-() {
    VectorBatch result = *this;
    for (int i = 0; i < nelements(); i++) {
        result.vals[i] = -vals[i];
    }

    return result;
};

VectorBatch operator/(const VectorBatch &m, const float &c) {
    VectorBatch o = m;
    for (int i = 0; i < m.nelements(); i++) {
        o.vals[i] = o.vals[i] / c;
    }
    return o;
}

VectorBatch operator*(const float &c, const VectorBatch &m) {
    VectorBatch o = m;
    for (int i = 0; i < m.nelements(); i++) {
        o.vals[i] = o.vals[i] * c;
    }
    return o;
}
```

## 5.26 vector2.h

```
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 ****************************************************************
 ****************************************************************/

#ifndef CODE_VEC2_H
#define CODE_VEC2_H

#include <vector>
#include "vector.h"
#include "matrix.h"
#include <iostream>
#ifdef BLISNN
#include "blis/blis.h"
#endif

#ifdef USE_GSL
#include "gsl/gsl-lite.hpp"
```

```
#endif

#define INDEXr(i,j,m,n) (i)*(n)+(j)
#define INDEXc(i,j,m,n) (i)+(j)*(m)

class VectorBatch{
  friend class Matrix;
  friend class Vector;

private: //private:
  std::vector<float> vals;
  int nvectors{0},vector_size{0};
public:
    VectorBatch();
    VectorBatch( int itemsize );
    // this one is in the blis/reference file
    VectorBatch(int nRows, int nCols, bool rand=false);
    VectorBatch( const Vector& );
    void allocate(int,int);

    int size() const { return vals.size(); };
    void resize(int m,int n) {
      nvectors = m; set_item_size(n); //r = m; c = n;
      vals.resize(m*n); };
    float normf() const {
      float norm{0.f}; int count{0};
      for ( auto e : vals ) {
    norm += e*e; count++;
      }
      //std::cout « "norm squared over " « count « " elements: " « norm « "\n";
      return sqrt(norm);
    };
    bool positive() const {
      return all_of
    ( vals.begin(),vals.end(),
      [] (float e) { return e>0; }
    );
    }
    bool notnan() const {
      return all_of
    ( vals.begin(),vals.end(),
      [] (float e) { return not isnan(e); }
    );
    }
    bool notinf() const {
      return all_of
    ( vals.begin(),vals.end(),
      [] (float e) { return not isinf(e); }
    );
    }
    int item_size() const { return vector_size; };
    void set_item_size(int n) { vector_size = n; };
    int batch_size() const { return nvectors; };
    void set_batch_size(int n) { nvectors = n; };
    int nelements() const {
      int n = vals.size();
      assert( n==item_size()*batch_size() );
      return n;
    };

    std::vector<float>& vals_vector() { return vals; };
    const std::vector<float>& vals_vector() const { return vals; };
    float *data() { return vals.data(); };
    const float *data() const { return vals.data(); };
    const float *data( int disp ) const { return vals.data()+disp; };


    void v2mp( const Matrix &x, VectorBatch &y) const;
    void v2tmp( const Matrix &x, VectorBatch &y ) const;
    void v2mtp( const Matrix &x, VectorBatch &y ) const;
    void outer2( const VectorBatch &x, Matrix &y ) const;

  void add_vector( const std::vector<float> &v );

    /*
     * Indexing
     */
    float at(int i,int j) const {
    assert( i>=0 ); assert( i<vector_size );
    assert( j>= 0 ); assert( j<nvectors );
    return *data( i + j*vector_size );
    };
    void set_col(int j,const std::vector<float> &v );
    std::vector<float> get_col(int j) const;
    void set_row( int j, const std::vector<float> &v );
    std::vector<float> get_row(int j) const;
    std::vector<float> extract_vector(int v) const;
```

```
#ifdef USE_GSL
  gsl::span<float> get_vector(int v);
  //  const gsl::span<float> get_vector(int v) const;
  void set_vector( const gsl::span<float> &v, int j);
#else
  std::vector<float> get_vector(int v) const;
#endif
  void set_vector( const Vector &v, int j);
  void set_vector( const std::vector<float>&v, int j);

  Vector get_vectorObj(int j) const {
    Vector vec(vector_size);
    std::copy( vals.begin()+j*vector_size,vals.begin()+(j+1)*vector_size,
           vec.vals.begin() );
    // for (int i = 0; i < vector_size; i++ )
    //   vec.vals.at(i) = vals.at( j * vector_size + i );
    return vec;
  }


  void show() const;
  void display(std::string) const;

  void copy_from( const VectorBatch& in ) {
    assert( vals.size()==in.vals.size() );
    std::copy( in.vals.begin(),in.vals.end(),vals.begin() );
    // for ( int i=0; i<vals.size(); i++)
    //   vals[i] = in.vals[i];
  };

  void addh(const Vector &y);
  void addh(const VectorBatch &y);
  Vector meanh() const;

  VectorBatch operator-(); // Unary negate operator
  VectorBatch& operator=(const VectorBatch& m2); // Copy constructor
  void hadamard(const VectorBatch& m1,const VectorBatch& m2);
  VectorBatch operator*(const VectorBatch &m2); // Hadamard Product Element-wise multiplication
  VectorBatch operator/(const VectorBatch &m2); // Element-wise division
  void scaleby( float );
  VectorBatch operator-(const VectorBatch &m2) const; // Element-wise subtraction
  friend VectorBatch operator/(const VectorBatch &m, const float &c); // for matrix-constant division
  friend VectorBatch operator*(const float &c, const VectorBatch &m); // for matrix-constant division
};


#endif

#if 0
  // hm. this doesn't work
  friend void relu_io    (const Vector &i, Vector &v);
  friend void sigmoid_io (const Vector &i, Vector &v);
  friend void softmax_io (const Vector &i, Vector &v);
  friend void none_io    (const Vector &i, Vector &v);
  friend void reluGrad_io(const Vector &m, Vector &a);
  friend void sigGrad_io (const Vector &m, Vector &a);

  friend void relu_io    (const VectorBatch &i, VectorBatch &v);
  friend void sigmoid_io (const VectorBatch &i, VectorBatch &v);
  friend void softmax_io (const VectorBatch &i, VectorBatch &v);
  friend void none_io    (const VectorBatch &i, VectorBatch &v);
  friend void reluGrad_io(const VectorBatch &m, VectorBatch &a);
  friend void sigGrad_io (const VectorBatch &m, VectorBatch &a);
#endif

```

## 5.27 vector_impl_blis.cpp

```
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 *****************************************************************
 *****************************************************************/

#include <algorithm>
#include "vector.h"
```

```
#include <iostream>

#include <cassert>

#ifdef BLISNN
#include "blis/blis.h"
#endif

Vector::Vector(int s, int init) {
    r = s;
  vals = std::vector<float>(s);
  float scal_fac = 0.05;
  if (init==0){
    float zero = 0.0;
    bli_ssetv( BLIS_NO_CONJUGATE, s, &zero, &vals[0], 1);
  }else if (init==1)
    bli_srandv(s, &vals[0], 1);
    bli_sscalv( BLIS_NO_CONJUGATE, s, &scal_fac, &vals[0], 1 );
}

void Vector::add( const Vector &v1 ) {
  assert(v1.size()==this->size());
  bli_saddv( BLIS_NO_CONJUGATE, size(), const_cast<float*>(&v1.vals[0]), 1, &vals[0], 1 );
}

void Vector::set_ax( float a, Vector &x) {
  assert(x.size()==this->size());

    float b = static_cast<float>(a);
    bli_sscal2v(BLIS_NO_CONJUGATE, this->size(),&b,&x.vals[0],1,&(this->vals)[0], 1);
}


void Vector::zeros() {

    float zero = 0.0;
    bli_ssetv( BLIS_NO_CONJUGATE, size(), &zero, &vals[0], 1 ); // Set all values to 0
}

void Vector::show() {

    char sp[8] = " ";
    char format[8] = "%4.4f";
    bli_sprintm( sp, size(), 1, &vals[0], 1, size(), format, sp );
}


```

## 5.28 vector_impl_reference.cpp

```
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 ****************************************************************
 ****************************************************************/

#include <algorithm>
#include "vector.h"
#include <iostream>

#include <cassert>

Vector::Vector(int s, int init) {
    r = s;
  vals = std::vector<float>(s);
  if (init==0){
    std::fill(vals.begin(),vals.end(), 0);
  }else if (init==1){
    for (int i=0; i<size(); i++){
      vals[i] = -0.1 + static_cast <float> (rand()) /( static_cast <float> (RAND_MAX/(0.1-(-0.1))));
    }
  }

}

void Vector::add( const Vector &v1 ) {
```

```
  assert(v1.size()==this->size());
  for (int i=0; i<size(); i++){
    vals[i] += v1.vals[i];
  }
}

void Vector::set_ax( float a, Vector &x) {
  assert(x.size()==this->size());
    for (int i=0; i<size(); i++){
        vals[i] = a * x.vals[i];
    }

}


void Vector::zeros() {
    std::fill(vals.begin(),vals.end(),0);

}

void Vector::show() {
    int i;
    for (i=0;i<size();i++) {
        std::cout « vals[i] « '\n';
    }
    std::cout « '\n';

}


```

## 5.29 vectorbatch_impl_blis.cpp

```
/*****************************************************************
 *****************************************************************
 ****
 **** This text file is part of the source of
 **** `Introduction to High-Performance Scientific Computing'
 **** by Victor Eijkhout, copyright 2012-2021
 ****
 **** Deep Learning Network code
 **** copyright 2021 Ilknur Mustafazade
 ****
 *****************************************************************
 *****************************************************************/

#include <iostream>
using std::cout;
using std::endl;
#include <vector>
using std::vector;
#include <algorithm>
#include "trace.h"

#include "trace.h"
#include "vector2.h"

#ifdef BLISNN
#include "blis/blis.h"
#endif

VectorBatch::VectorBatch(int nRows, int nCols, bool random) {
  allocate(nRows,nCols);
  const int r=nRows, c=nCols;

  float scal_fac = 0.05; // randomize between (-scal;scal)
  if (not random){
    float zero = 0.0;
    bli_ssetm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
           r, c, &zero, &vals[0], c, 1);
  } else if (random){
    bli_srandm(0, BLIS_DENSE, r, c, &vals[0], c, 1);
    bli_sscalm( BLIS_NO_CONJUGATE, 0, BLIS_NONUNIT_DIAG, BLIS_DENSE,
        r, c, &scal_fac, &vals[0], c, 1);
  }
}

// VectorBatch VectorBatch::transpose() const {
//     const int c = batch_size(), r = item_size();
//     VectorBatch result(c, r, 0); // Initialize a new matrix with inverted dimension values

//  bli_scopym( 0, BLIS_NONUNIT_DIAG, BLIS_DENSE, BLIS_TRANSPOSE,
//          c, r, const_cast<float*>(&vals[0]), c, 1, &result.vals[0], r, 1);
```

```
//     return result;
// }

void VectorBatch::show() const {

    const int c = batch_size(), r = item_size();
    char e[5] = "";
    char forvals[8] = "%4.4f";
    bli_sprintm( e, r, c, const_cast<float*>(&vals[0]), c, 1, forvals, e );
}


/*
 * For explanation of the BLIS routines, see
 * https://github.com/flame/blis/blob/master/docs/BLISTypedAPI.md#gemm
 * and
 * https://github.com/flame/blis/blob/master/docs/BLISTypedAPI.md#computational-function-reference
 */
void VectorBatch::v2mp(const Matrix &m, VectorBatch &y) const {
  const int
    xr = item_size(),   xc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    yr = y.item_size(), yc = y.batch_size(); // column

  if (trace_scalars())
    cout « "matrix vector product "
     « mr « "x" « mc
     « " & "
     « xr « "x" « xc
     « " => " « yr « "x" « yc
     « endl;

  assert( xc==yc );
  assert( yr==mr );
  assert( mc==xr );

  const auto& mmat  = m.values().data();
  const auto& xvals = vals_vector().data();
  auto  yvals       = y.vals_vector().data();

  float alpha = 1.0;
  float beta = 0.0;
  bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_NO_TRANSPOSE,
         yr,yc,mc,
         &alpha,
         const_cast<float*>(mmat),  /* rsa,csa */ mr,1,
         const_cast<float*>(xvals), /* rsb,csb */ 1,xr,
         &beta,
         yvals,                     /* rsc,csc */ 1,yr
         );
}

void VectorBatch::v2tmp(const Matrix &x, VectorBatch &y) const {

    const int c = batch_size(), r = item_size();
    assert( r==x.rowsize() );
    assert( c==y.batch_size() );
    assert( x.colsize()==y.item_size() );

    float alpha = 1.0;
    float beta = 0.0;
    //printf("BLIS gemm %dx%dx%d\n",r,x.colsize(),c);
    bli_sgemm( BLIS_TRANSPOSE, BLIS_NO_TRANSPOSE,
           c, x.colsize(), r, &alpha, const_cast<float*>(&vals[0]),
           c, 1, const_cast<float*>( x.data() ),
           x.colsize(), 1, &beta, &y.vals[0], x.colsize(), 1);
}

// matrix transpose x self => y
void VectorBatch::v2mtp(const Matrix &m, VectorBatch &y) const {
  const int
    xr = item_size(),   xc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    yr = y.item_size(), yc = y.batch_size(); // column

  if (trace_scalars())
    cout « "matrix transpose vector product "
     « mr « "x" « mc
     « " & "
     « xr « "x" « xc
     « " => " « yr « "x" « yc
     « endl;

  assert( xc==yc );
  assert( yr==mc );
  assert( mr==xr );

```

```
  const auto& mmat  = m.values().data();
  const auto& xvals = vals_vector().data();
  auto        yvals = y.vals_vector().data();

  float alpha = 1.0;
  float beta = 0.0;
  bli_sgemm( BLIS_TRANSPOSE, BLIS_NO_TRANSPOSE,
         yr,yc,mr,
         &alpha,
         const_cast<float*>(mmat),  /* rsa,csa */ mc,1,
         const_cast<float*>(xvals), /* rsb,csb */ 1,xr,
         &beta,
         yvals,                     /* rsc,csc */ 1,yr
         );
  if (trace_progress()) {
    assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
    assert( m.notinf() ); assert( m.notnan() ); assert( m.normf()!=0.f );
    assert( y.notinf() ); assert( y.notnan() ); assert( y.normf()!=0.f );
  }

}

/*
 * x times self => m
 */
void VectorBatch::outer2(const VectorBatch &x, Matrix &m) const {
  const int
    yr = item_size(),   yc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    xr = x.item_size(), xc = x.batch_size(); // column

  if (trace_scalars())
    cout « "outer product "
     « xr « "x" « xc
     « " & "
     « yr « "x" « yc
     « " => " « mr « "x" « mc
     « endl;

  assert( yc==xc );
  assert( xr==mr );
  assert( yr==mc );
  const auto& xvals = x.vals_vector().data();
  const auto& yvals =   vals_vector().data();
  auto        mmat  = m.values().data();

  float alpha = 1.0;
  float beta = 0.0;
  bli_sgemm( BLIS_NO_TRANSPOSE, BLIS_TRANSPOSE,
         mr,mc,yc,
         &alpha,
         const_cast<float*>(xvals), /* rsa,csa */ 1,xr,
         const_cast<float*>(yvals), /* rsb,csb */ 1,yr,
         &beta,
         mmat,                      /* rsc,csc */ mc,1
         );

}
```

## 5.30 vectorbatch_impl_reference.cpp

```
/****************************************************************
 ****************************************************************
 ****
 **** This text file is part of the source of
 **** 'Introduction to High-Performance Scientific Computing'
 **** by Victor Eijkhout, copyright 2012-2021
 ****
 **** Deep Learning Network code
 **** copyright 2021 Ilknur Mustafazade
 ****
 ****************************************************************
 ****************************************************************/

#include "trace.h"
#include "vector2.h"
#include <iostream>
using std::cout;
using std::endl;
#include <vector>
using std::vector;
#include <algorithm>

```

```
#ifdef DEBUG
#define ELEMENTc(X,I,J,M,N) X.at( INDEXc(I,J,M,N) )
#define ELEMENTr(X,I,J,M,N) X.at( INDEXr(I,J,M,N) )
#else
#define ELEMENTc(X,I,J,M,N) X[ INDEXc(I,J,M,N) ]
#define ELEMENTr(X,I,J,M,N) X[ INDEXr(I,J,M,N) ]
#endif

VectorBatch::VectorBatch(int batchsize, int itemsize, bool random) {
  allocate(batchsize,itemsize);

  int i, j;
  if (not random){
    std::fill(vals.begin(), vals.end(), 0);
  }else if (random){
    for (i=0; i<batchsize * itemsize;i++){
      vals[i] = -0.1 + static_cast <float> (rand()) /( static_cast <float>(RAND_MAX/(0.1-(-0.1))));
    }
  }
}

// VectorBatch VectorBatch::transpose() const {
//     const int c = batch_size(), r = item_size();
//      // Initialize a new matrix with inverted dimension values
//     VectorBatch result(item_size(),batch_size(), 0);
//     int i1, i2; // Old and new index
//     for (int i = 0; i < r; i++) {
//         for (int j = 0; j < c; j++) {
//             i1 = i * c + j; // Old indexing
//             i2 = j * r + i; // New indexing

//             result.vals[i2] = vals[i1]; // Move transposed values to new array
//         }
//     }
//     return result;
// }

void VectorBatch::show() const {
    const int c = batch_size(), r = item_size();
    int i, j;
    for (i = 0; i < r; i++) {
        for (j = 0; j < c; j++) {
            std::cout « vals[i * c + j] « ' ';
        }
        std::cout « std::endl;
    }
    std::cout « std::endl;
}


// y = x x
void VectorBatch::v2mp(const Matrix &m, VectorBatch &y) const {
  const int
    xr = item_size(),   xc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    yr = y.item_size(), yc = y.batch_size(); // column

  if (trace_scalars())
    cout « "matrix vector product "
     « mr « "x" « mc
     « " & "
     « xr « "x" « xc
     « " => " « yr « "x" « yc
     « endl;

  assert( xc==yc );
  assert( yr==mr );
  assert( mc==xr );

  const auto& mmat = m.values();
  const auto& xvals = vals_vector();
  auto& yvals = y.vals_vector();
  int xi{0},yi{0},mi{0};
  for (int i = 0; i < yr; i++) { // Matrix multiplication subroutine
    for (int j = 0; j < yc; j++) {
      float sum = 0.0;
      for (int k = 0; k < mc; k++) {
    sum += ELEMENTr( mmat,i,k,mr,mc ) * ELEMENTc( xvals,k,j,xr,xc ) ;
    mi = INDEXr( i,k,mr,mc ); xi = INDEXc( k,j,xr,xc ) ;
    //sum += mmat.at( INDEXr(i,k,mr,mc) ) * xvals.at( INDEXc(k,j,xr,xc) ) ;
      }
      //yvals.at( INDEXc(i,j,yr,yc) ) = sum;
      ELEMENTc( yvals,i,j,yr,yc ) = sum;
      yi = INDEXc( i,j,yr,yc );
    }
  }
  assert( xi==xvals.size()-1 );
```

```
  assert( yi==yvals.size()-1 );
  assert( mi==mmat.size()-1 );
}


// matrix transpose x self => y
void VectorBatch::v2mtp(const Matrix &m, VectorBatch &y) const {
  const int
    xr = item_size(),   xc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    yr = y.item_size(), yc = y.batch_size(); // column

  if (trace_scalars())
    cout « "matrix transpose vector product "
     « mr « "x" « mc
     « " & "
     « xr « "x" « xc
     « " => " « yr « "x" « yc
     « endl;

  assert( xc==yc ); assert( yr==mc ); assert( mr==xr );

  const auto& mmat  = m.values();
  const auto& xvals = vals_vector();
  auto&       yvals = y.vals_vector();
  for (int i = 0; i < yr; i++) { // Matrix multiplication subroutine
    for (int j = 0; j < yc; j++) {
      float sum = 0.0;
      for (int k = 0; k < mr; k++) {
    //sum += mmat[ INDEXr(k,i,mc,mr) ] * xvals[ INDEXc(k,j,xr,xc) ];
    // matrix is by rows, so transpose by columns!
    sum += ELEMENTc( mmat,i,k,mc,mr ) * ELEMENTc( xvals,k,j,xr,xc );
      }
      yvals.at( INDEXc(i,j,yr,yc) )  = sum;
    }
  }
  if (trace_progress()) {
    assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
    assert( m.notinf() ); assert( m.notnan() ); assert( m.normf()!=0.f );
    assert( y.notinf() ); assert( y.notnan() ); assert( y.normf()!=0.f );
  }
  if (trace_scalars()) {
    cout « "v2mtp (computes dl): "
        « this->normf() « "x" « m.normf() « " => " « y.normf() « "\n";
  }
}

/*
 * x times self => m
 */
void VectorBatch::outer2(const VectorBatch &x, Matrix &m ) const {
  const int
    yr = item_size(),   yc = batch_size(),   // column storage
    mr = m.rowsize(),   mc = m.colsize(),    // row storage
    xr = x.item_size(), xc = x.batch_size(); // column

  if (trace_scalars())
    cout « "outer product "
     « xr « "x" « xc
     « " & "
     « yr « "x" « yc
     « " => " « mr « "x" « mc
     « endl;

  assert( yc==xc );
  assert( xr==mr );
  assert( yr==mc );
  const auto& xvals = x.vals_vector();
  const auto& yvals =   vals_vector();
  auto& mmat = m.values();
    for (int i = 0; i < mr; i++) { // Matrix multiplication subroutine
      for (int j = 0; j < mc; j++) {
        float sum = 0.0;
            for (int k = 0; k < yc; k++) {
          /*
           * index (k,j) in Y transpose => (j,k) in Y
           */
          //sum += yvals[ INDEXc(i,k,yr,yc) ] * xvals[ INDEXc(j,k,xr,xc) ];
          sum += xvals.at( INDEXc(i,k,xr,xc) ) * yvals.at( INDEXc(j,k,yr,yc) );
            }
            //mmat[ INDEX(i,j,mr,mc) ] = sum;
            mmat.at( INDEXr(i,j,mr,mc) ) = sum;
        }
    }
  if (trace_progress()) {
    assert( this->notinf() ); assert( this->notnan() ); assert( this->normf()!=0.f );
    assert( x.notinf() ); assert( x.notnan() ); assert( x.normf()!=0.f );
```

```
    assert( m.notinf() ); assert( m.notnan() ); assert( m.normf()!=0.f );
  }
  if (trace_arrays()) {
    cout « "Outer2 left input:\n"; this->show();
    cout « "Outer2 right input:\n"; x.show();
    cout « "Outer2 output:\n"; m.show();
  }
}
```

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