ML perceptron sigmoid neuron (P3)

v0.1

Generated by Doxygen 1.13.2

Chapter 1

ML-sigmoid-neuron

1.1 Student

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1.2 Introduction

In this repository, we will implement and test a Neuron using the sigmoid function. This will be demonstrated by creating AND, OR, NOT, NOR gates aswell as an half adder. You can find the assignment here.

1.3 Documentation

For this assignment, the documentation was generated with Doxygen. The LaTeX documentation is available here and, to view the HTML documentation locally, open index.html in a browser.

1.4 Installing

Enter the test dir then

Generate build files:
```
cmake -S . -B build
```

Build the project:
```
cmake --build build
```

Run the executable:
```
./build/MLNeuronTest
```

Chapter 2

ML-backpropation

2.1 Student

Name: Stan Merlijn

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2.2 Introduction

In this repository, we implement and test the backpropagation algorithm for training a neural network. Building upon a previously implemented neuron network, the project extends the model by incorporating error calculations, gradient computations, and simultaneous weight and bias updates using backpropagation. The network is trained using an online training approach and evaluated through various tasks including learning AND and XOR gates, constructing a half adder, and classifying both the Iris and Digit datasets. Performance is assessed by measuring classification accuracy and training efficiency. You can find the assignment `here`

2.3 Documentation

For this assignment, documentation was generated using Doxygen. The LaTeX documentation can be found `here` and if you want to run the HTML local website, you can open the `index.html` in a browser.

2.4 Installing

Enter the test dir then

Generate build files:

```
cmake -S . -B build
```

Build the project:

```
cmake --build build
```

For enhanced build performance, it's recommended to compile in parallel using:

```
cmake --build build --parallel <n threads>
```

Run the executable:

```
./build/MLPerceptronTest
```

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

Chapter 4

Class Index

4.1 Class List

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

Chapter 5

File Index

5.1 File List

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

Chapter 6

Class Documentation

6.1 digitData< T > Struct Template Reference

A structure to hold the features and targets read from a CSV file. This is for the digit data set.

```
#include <common.hpp>
```

Public Attributes

- std::vector< T > images
- std::vector< T > targets

6.1.1 Detailed Description

template<typename T>
struct digitData< T >

A structure to hold the features and targets read from a CSV file. This is for the digit data set.

This structure contains two members:

- images: A Vector of ints where each 64 elements represent an image of a digit(8x8 image).
- targets: A vector of integers where each element represents the target value corresponding to the features.

Definition at line 47 of file common.hpp.

6.1.2 Member Data Documentation

6.1.2.1 images

```
template<typename T>
std::vector<T> digitData< T >::images
```

Definition at line 49 of file common.hpp.

6.1.2.2 targets

```
template<typename T>
std::vector<T> digitData< T >::targets
```

Definition at line 50 of file common.hpp.

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

- common.hpp

6.2 irisData Struct Reference

A structure to hold the features and targets read from a CSV file. This is fdor the iris data set.

```
#include <common.hpp>
```

Public Attributes

- std::vector< std::vector< float > > features
- std::vector< float > targets

6.2.1 Detailed Description

A structure to hold the features and targets read from a CSV file. This is fdor the iris data set.

This structure contains two members:

- features: A 2D vector of floats where each inner vector represents a set of features for a single data point.
- targets: A vector of integers where each element represents the target value corresponding to the features.

Definition at line 33 of file common.hpp.

6.2.2 Member Data Documentation

6.2.2.1 features

```
std::vector<std::vector<float> > irisData::features
```

Definition at line 35 of file common.hpp.

6.2.2.2 targets

```
std::vector<float> irisData::targets
```

Definition at line 36 of file common.hpp.

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

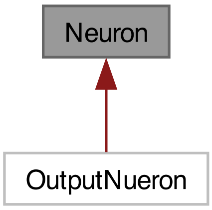
- common.hpp

6.3 Neuron Class Reference

Represents a single neuron in a neural network.

```
#include <neuron.hpp>
```

Inheritance diagram for Neuron:



Public Member Functions

- Neuron (int nSizeWeights, float initialWeight, float initialBias)

  constructer Neuron object.
- Neuron (const std::vector< float > &weights, float bias, float learningRate=0.1)

  Constructs a Neuron with the given weights and bias.
- float sigmoid (float x)

  Computes the sigmoid activation function.
- float activate (const std::vector< float > &inputs)

  Performs an activation operation.
- float predict (const std::vector< float > &inputs)

  Performs a feedforward operation.
- void deltaError (const std::vector< float > &inputs, const std::vector< Neuron > &neuronsNextLayer, float target, bool isOutputNeuron)

  Calculates errors for the weights and bias of the neuron.
- void update ()

  Updates the weights and bias of the neuron. Using the previously calculated errors.
- float computeHiddenDelta (const std::vector< float > &inputs, float sum)

Calculates the error for the output layer.
- float sigmoidDerivative (float output)

  Calculates the error for the hidden layer.
- float computeOutputDelta (float target)

  Calculates the error for the output layer.
- const std::vector< float > & getWeights () const

  Returns the weights of the neuron.
- float getBias () const

  Returns the bias of the neuron.
- float getError () const

  Returns the error of the neuron.
- void __str__ () const

  Prints the neuron details.

6.3.1 Detailed Description

Represents a single neuron in a neural network.

This class models a neuron with a set of weights and a bias. It provides methods to compute the sigmoid activation function and to perform a feedforward operation given a set of inputs.

Definition at line 21 of file neuron.hpp.

6.3.2 Constructor & Destructor Documentation

6.3.2.1 Neuron() [1/2]

```
Neuron::Neuron (
            int nSizeWeights,
            float initialWeight,
            float initialBias)
```

constructer Neuron object.

Definition at line 13 of file neuron.cpp.

6.3.2.2 Neuron() [2/2]

```
Neuron::Neuron (
            const std::vector< float > & weights,
            float bias,
            float learningRate = 0.1)
```

Constructs a Neuron with the given weights and bias.

Parameters

weights	A vector of weights for the neuron.
bias	The bias term for the neuron.

Definition at line 26 of file neuron.cpp.

6.3.3 Member Function Documentation

6.3.3.1 __str__()

```
void Neuron::__str__ () const
```

Prints the neuron details.

Definition at line 86 of file neuron.cpp.

6.3.3.2 activate()

```
float Neuron::activate (
            const std::vector< float > & inputs)
```

Performs an activation operation.

Parameters

inputs	A vector of input values.

Returns

The output of the neuron after applying the weights, bias, and activation function.

Definition at line 35 of file neuron.cpp.

6.3.3.3 computeHiddenDelta()

```
float Neuron::computeHiddenDelta (
            const std::vector< float > & inputs,
            float sum)
```

Calculates the error for the output layer.

Parameters

output	The output of the neuron.
target	The target value.

Returns

The error for the ou tput layer.

Definition at line 69 of file neuron.cpp.

6.3.3.4 computeOutputDelta()

```
float Neuron::computeOutputDelta (
            float target)
```

Calculates the error for the output layer.

Parameters

output	The output of the neuron.
target	The target value.

Returns

The error for the output layer.

Definition at line 75 of file neuron.cpp.

6.3.3.5 deltaError()

```
void Neuron::deltaError (
            const std::vector< float > & inputs,
            const std::vector< Neuron > & neuronsNextLayer,
            float target,
            bool isOutputNeuron)
```

Calculates errors for the weights and bias of the neuron.

Parameters

inputs	A vector of input values.
target	The target value.

6.3.3.6 getBias()

```
float Neuron::getBias () const  [inline]
```

Returns the bias of the neuron.

Returns

The bias value.

Definition at line 111 of file neuron.hpp.

6.3.3.7 getError()

```
float Neuron::getError () const  [inline]
```

Returns the error of the neuron.

Returns

The error value.

Definition at line 117 of file neuron.hpp.

6.3.3.8 getWeights()

```
const std::vector< float > & Neuron::getWeights () const  [inline]
```

Returns the weights of the neuron.

Returns

A vector of weights.

Definition at line 105 of file neuron.hpp.

6.3.3.9 predict()

```
float Neuron::predict (
            const std::vector< float > & inputs)
```

Performs a feedforward operation.

Parameters

inputs	A vector of input values.

Returns

The output of the neuron after applying the weights, bias, and activation function.

Definition at line 52 of file neuron.cpp.

6.3.3.10 sigmoid()

```
float Neuron::sigmoid (
            float x)
```

Computes the sigmoid activation function.

Parameters

x	The input value.

Returns

The result of the sigmoid function applied to x.

Definition at line 29 of file neuron.cpp.

6.3.3.11 sigmoidDerivative()

```
float Neuron::sigmoidDerivative (
            float output)
```

Calculates the error for the hidden layer.

Parameters

output	The output of the neuron.
target	The target value.

Returns

The error for the hidden layer.

Definition at line 81 of file neuron.cpp.

6.3.3.12 update()

```
void Neuron::update ()
```

Updates the weights and bias of the neuron. Using the previously calculated errors.

Definition at line 58 of file neuron.cpp.

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

- neuron.hpp
- neuron.cpp

6.4 NeuronLayer Class Reference

Represents a layer of neurons in a neural network.

```
#include <neuronLayer.hpp>
```

Public Member Functions

- NeuronLayer (std::vector< Neuron > neurons)

    Constructs a NeuronLayer with the given neurons.
- NeuronLayer (int nNeurons, int nSizeWeights)

    Constructs a NeuronLayer with the given number of neurons and size of weights.
- std::vector< float > & feedForward (const std::vector< float > &inputs)

    Performs a feedforward operation.
- void computeOutputErros (const std::vector< float > &targets)

    Computes the output errors for the layer.
- void computeHiddenErrors (const std::vector< float > &inputs, const std::vector< Neuron > &neurons↩ NextLayer)

    Computes the hidden errors for the layer.
- void update ()

    Updates the neurons in the layer.
- const std::vector< Neuron > & getNeurons ()

    Returns the neurons in the layer.
- const std::vector< float > & getOutput () const

    Returns the output of the layer.
- void __str__ () const

    Prints the layer details.

6.4.1 Detailed Description

Represents a layer of neurons in a neural network.

The NeuronLayer class has a collection of neurons and provides methods to perform feedforward operations and to represent the layer as a string.

Definition at line 23 of file neuronLayer.hpp.

6.4.2 Constructor & Destructor Documentation

6.4.2.1 NeuronLayer() [1/2]

```
NeuronLayer::NeuronLayer (
             std::vector< Neuron > neurons)
```

Constructs a NeuronLayer with the given neurons.

Parameters

neurons	A vector of neurons for the layer.

Definition at line 13 of file neuronLayer.cpp.

6.4.2.2 NeuronLayer() [2/2]

```
NeuronLayer::NeuronLayer (
             int nNeurons,
             int nSizeWeights)
```

Constructs a NeuronLayer with the given number of neurons and size of weights.

Parameters

nNeurons	The number of neurons in the layer.
nSizeWeights	The size of the weights for each neuron.

Definition at line 16 of file neuronLayer.cpp.

6.4.3 Member Function Documentation

6.4.3.1 __str__()

```
void NeuronLayer::__str__ () const
```

Prints the layer details.

Definition at line 81 of file neuronLayer.cpp.

6.4.3.2 computeHiddenErrors()

```
void NeuronLayer::computeHiddenErrors (
             const std::vector< float > & inputs,
             const std::vector< Neuron > & neuronsNextLayer)
```

Computes the hidden errors for the layer.

Parameters

inputs	A vector of input values.
neuronsNextLayer	A vector of neurons in the next layer.

Definition at line 56 of file neuronLayer.cpp.

6.4.3.3 computeOutputErros()

```
void NeuronLayer::computeOutputErros (
            const std::vector< float > & targets)
```

Computes the output errors for the layer.

Parameters

targets	A vector of target values.

Definition at line 48 of file neuronLayer.cpp.

6.4.3.4 feedForward()

```
std::vector< float > & NeuronLayer::feedForward (
            const std::vector< float > & inputs)
```

Performs a feedforward operation.

Parameters

inputs	A vector of input values.

Returns

The output of the layer.

Definition at line 36 of file neuronLayer.cpp.

6.4.3.5 getNeurons()

```
const std::vector< Neuron > & NeuronLayer::getNeurons () [inline]
```

Returns the neurons in the layer.

Returns

A vector of neurons.

Definition at line 71 of file neuronLayer.hpp.

6.4.3.6 getOutput()

```
const std::vector< float > & NeuronLayer::getOutput () const [inline]
```

Returns the output of the layer.

Returns

A vector of floats.

Definition at line 77 of file neuronLayer.hpp.

6.4.3.7 update()

```
void NeuronLayer::update ()
```

Updates the neurons in the layer.

Definition at line 73 of file neuronLayer.cpp.

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

- neuronLayer.hpp
- neuronLayer.cpp

6.5 NeuronNetwork Class Reference

Represents a neural network with multiple layers of neurons.

```
#include <neuronNetwork.hpp>
```

Public Member Functions

- NeuronNetwork (std::vector< NeuronLayer > layers)

  Constructs a NeuronNetwork with the given layers.
- NeuronNetwork (std::vector< int > layers)

  Performs a feedforward operation. On all the layers sequentially.
- const std::vector< float > & feedForward (const std::vector< float > &inputs)

  Performs a feedforward operation. On all the layers sequentially.
- std::vector< float > predict (const std::vector< float > &input)

  Performs a prediction operation. On all the layers sequentially.
- void backPropagation (const std::vector< float > &targets)

  Performs a backpropagation operation. On all the layers sequentially.
- void maskTarget (float target)
- void update ()

  Updates the neurons in the network.
- void trainInputs2D (const std::vector< std::vector< float > > &inputs, const std::vector< std::vector< float > > &targets, int epochs)

  Trains the network on a set of inputs and targets.
- std::vector< NeuronLayer > getLayers () const

  Returns the layers in the network.
- void setTarget (std::vector< float > &targets)

  Sets the target values in the network.
- void __str__ () const

  Prints the network details.

6.5.1 Detailed Description

Represents a neural network with multiple layers of neurons.

The NeuronNetwork class has a collection of neuron layers and provides methods to perform feedforward operations and to represent the network as a string.

Definition at line 22 of file neuronNetwork.hpp.

6.5.2 Constructor & Destructor Documentation

6.5.2.1 NeuronNetwork() [1/2]

```
NeuronNetwork::NeuronNetwork (
            std::vector< NeuronLayer > layers)
```

Constructs a NeuronNetwork with the given layers.

Parameters

layers	A vector of neuron layers for the network.

Definition at line 13 of file neuronNetwork.cpp.

6.5.2.2 NeuronNetwork() [2/2]

```
NeuronNetwork::NeuronNetwork (
            std::vector< int > layers)
```

Performs a feedforward operation. On all the layers sequentially.

Parameters

inputs	A vector of input values.

Returns

The output of the network.

Definition at line 16 of file neuronNetwork.cpp.

6.5.3 Member Function Documentation

6.5.3.1 __str__()

```
void NeuronNetwork::__str__ () const
```

Prints the network details.

Definition at line 153 of file neuronNetwork.cpp.

6.5.3.2 backPropagation()

```
void NeuronNetwork::backPropagation (
            const std::vector< float > & targets)
```

Performs a backpropagation operation. On all the layers sequentially.

Definition at line 57 of file neuronNetwork.cpp.

6.5.3.3 feedForward()

```
const std::vector< float > & NeuronNetwork::feedForward (
            const std::vector< float > & inputs)
```

Performs a feedforward operation. On all the layers sequentially.

Parameters

inputs	A vector of input values.

Returns

The output of the network.

Definition at line 39 of file neuronNetwork.cpp.

6.5.3.4 getLayers()

```
std::vector< NeuronLayer > NeuronNetwork::getLayers () const  [inline]
```

Returns the layers in the network.

Returns

A vector of neuron layers.

Definition at line 84 of file neuronNetwork.hpp.

6.5.3.5 maskTarget()

```
void NeuronNetwork::maskTarget (
            float target)
```

Definition at line 135 of file neuronNetwork.cpp.

6.5.3.6 predict()

```
std::vector< float > NeuronNetwork::predict (
            const std::vector< float > & input)
```

Performs a prediction operation. On all the layers sequentially.

Parameters

inputs	A vector of input values.

Returns

The output of the network.

Definition at line 52 of file neuronNetwork.cpp.

6.5.3.7 setTarget()

```
void NeuronNetwork::setTarget (
            std::vector< float > & targets) [inline]
```

Sets the target values in the network.

Parameters

targets	The target values to set.

Definition at line 91 of file neuronNetwork.hpp.

6.5.3.8 trainInputs2D()

```
void NeuronNetwork::trainInputs2D (
            const std::vector< std::vector< float > > & inputs,
            const std::vector< std::vector< float > > & targets,
            int epochs)
```

Trains the network on a set of inputs and targets.

Parameters

inputs	A vector of input values.
targets	A vector of target values.
inputSize	The size of the input values.
maxTrainingSamples	The maximum number of training samples.

Definition at line 81 of file neuronNetwork.cpp.

6.5.3.9 update()

```
void NeuronNetwork::update ()
```

Updates the neurons in the network.

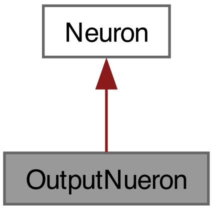
Definition at line 74 of file neuronNetwork.cpp.

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

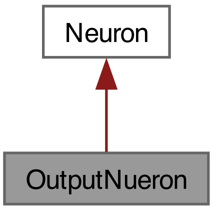
- neuronNetwork.hpp
- neuronNetwork.cpp

6.6 OutputNueron Class Reference

Inheritance diagram for OutputNueron:



Collaboration diagram for OutputNueron:



6.6.1 Detailed Description

Definition at line 15 of file outputNeuron.hpp.

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

- outputNeuron.hpp

6.7 TrainTestSplit< T > Struct Template Reference

A structure to hold the features and targets read from a CSV file. This is for the digit data set.

```
#include <common.hpp>
```

Public Member Functions

- TrainTestSplit (const std::vector< std::vector< T > > &features, const std::vector< std::vector< T > > &targets, float splitRatio)

Public Attributes

- std::vector< std::vector< T > > trainFeatures
- std::vector< std::vector< T > > testFeatures
- std::vector< std::vector< T > > trainTargets
- std::vector< std::vector< T > > testTargets

6.7.1 Detailed Description

template<typename T>
struct TrainTestSplit< T >

A structure to hold the features and targets read from a CSV file. This is for the digit data set.

This structure contains two members:

- trainFeatures: A 2D vector of floats where each inner vector represents a set of features for a single data point.
- targets: A vector of integers where each element represents the target value corresponding to the features.

Definition at line 72 of file common.hpp.

6.7.2 Constructor & Destructor Documentation

6.7.2.1 TrainTestSplit()

```
template<typename T>
TrainTestSplit< T >::TrainTestSplit (
            const std::vector< std::vector< T > > & features,
            const std::vector< std::vector< T > > & targets,
            float splitRatio)  [inline]
```

Definition at line 76 of file common.hpp.

6.7.3 Member Data Documentation

6.7.3.1 testFeatures

```
template<typename T>
std::vector<std::vector<T> > TrainTestSplit< T >::testFeatures
```

Definition at line 88 of file common.hpp.

6.7.3.2 testTargets

```
template<typename T>
std::vector<std::vector<T> > TrainTestSplit< T >::testTargets
```

Definition at line 90 of file common.hpp.

6.7.3.3 trainFeatures

```
template<typename T>
std::vector<std::vector<T> > TrainTestSplit< T >::trainFeatures
```

Definition at line 87 of file common.hpp.

6.7.3.4 trainTargets

```
template<typename T>
std::vector<std::vector<T> > TrainTestSplit< T >::trainTargets
```

Definition at line 89 of file common.hpp.

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

- common.hpp

Chapter 7

File Documentation

7.1 create_dataset.py File Reference

Module for creating and saving the digits dataset.

Functions

- create_dataset.write_to_csv (np.ndarray data, str filename)

  Writes a NumPy array to a CSV file.
- create_dataset.save_digits_dataset ()

  Loads the digits dataset and saves image and target data into CSV files.

7.1.1 Detailed Description

Module for creating and saving the digits dataset.

This module loads the digits dataset from scikit-learn, converts the images and targets to integers, and writes them to CSV files using a helper function.

Definition in file create_dataset.py.

7.1.2 Function Documentation

7.1.2.1 save_digits_dataset()

```
create_dataset.save_digits_dataset ()
```

Loads the digits dataset and saves image and target data into CSV files.

This function loads the digits dataset from scikit-learn, converts the images and targets to integer type, and then writes them to "digits_images.csv" and "digits_targets.csv" files, respectively.

Definition at line 25 of file create_dataset.py.

7.1.2.2 write_to_csv()

```
create_dataset.write_to_csv (
            np.ndarray data,
            str filename)
```

Writes a NumPy array to a CSV file.

Parameters

data	A numpy array containing the data to write.
filename	The name of the output CSV file.

Definition at line 18 of file create_dataset.py.

7.2 create_dataset.py

Go to the documentation of this file.

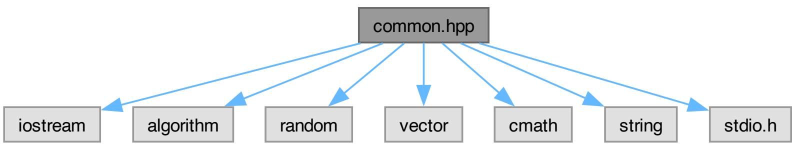
```
00001 #!/usr/bin/env python3
00002
00007
00008 import matplotlib.pyplot as plt
00009 import numpy as np
00010 import csv
00011
00012 # Import datasets, classifiers and performance metrics
00013 from sklearn import datasets, metrics, svm
00014
00015
00018 def write_to_csv(data: np.ndarray, filename: str):
00019     np.savetxt(filename, data, delimiter=",", fmt="%d")
00020
00021
00025 def save_digits_dataset():
00026     # Get the digits dataset
00027     data = datasets.load_digits()
00028     images = data.data
00029     targets = data.target
00030
00031     # Convert the image and target data to int type
00032     images = images.astype(int)
00033     targets = targets.astype(int)
00034
00035     # Save the images and the targets to CSV files
00036     write_to_csv(images, "digits_images.csv")
00037     write_to_csv(targets, "digits_targets.csv")
00038
00039
00040 if __name__ == "__main__":
00041     save_digits_dataset()
```

7.3 common.hpp File Reference

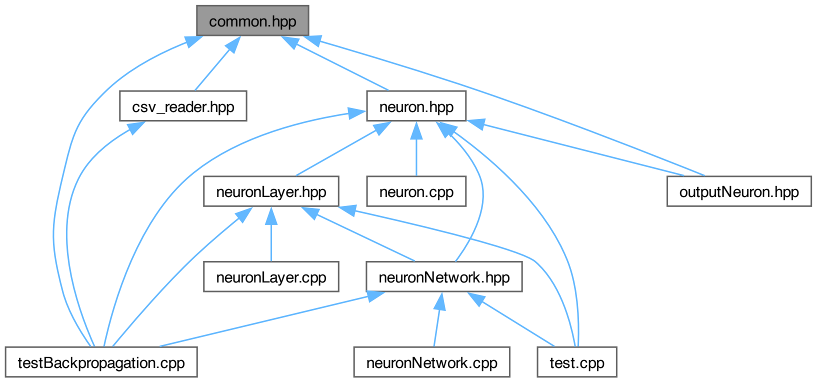
In this file the common utilities are defined.

```
#include <iostream>
#include <algorithm>
#include <random>
#include <vector>
#include <cmath>
#include <string>
#include <stdio.h>
```

Include dependency graph for common.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- struct irisData

    A structure to hold the features and targets read from a CSV file. This is fdor the iris data set.

- struct digitData< T >

    A structure to hold the features and targets read from a CSV file. This is for the digit data set.

- struct TrainTestSplit< T >

    A structure to hold the features and targets read from a CSV file. This is for the digit data set.

Macros

- #define INITIAL_WEIGHT 0.5f
- #define INITIAL_WEIGHT_INPUTN 0.5f
- #define INITIAL_BIAS 0.5f
- #define INITIAL_BIAS_INPUTN 0.5f

Functions

- template<typename T>
  TrainTestSplit< T > createTrainTestSplit (const std::vector< std::vector< T > > &features, const std::vector< std::vector< T > > &targets, float splitRatio)

    Create a Train Test Split object from the features and targets.

- float gradientBetweenNeurons (float &output, float &error)

    This function calculates the gradient between two neurons.

- float deltaGradient (float &learningRate, float &gradient)

    This function calculates the delta gradient for a neuron.

- float deltaBias (float &learningRate, float &deltaGradient)

    This function calculates the delta bias for a neuron.

- template<typename T>
  void printVector (const std::vector< T > &vec, const std::string extra="")

    This function prints the elements of a vector to the console.

- template<typename T>
  void normalizeVector (std::vector< T > &vec)

    This function creates a 2D vector from a 1D vector.

- template<typename T>
  void normalize2DVector (std::vector< std::vector< T > > &vec)

    This function creates a 2D vector from a 1D vector.

7.3.1 Detailed Description

In this file the common utilities are defined.

Author

Stan Merlijn

Version

0.1

Date

2025-02-22

Copyright

Copyright (c) 2025

Definition in file common.hpp.

7.3.2 Macro Definition Documentation

7.3.2.1 INITIAL_BIAS

```
#define INITIAL_BIAS 0.5f
```

Definition at line 23 of file common.hpp.

7.3.2.2 INITIAL_BIAS_INPUTN

```
#define INITIAL_BIAS_INPUTN 0.5f
```

Definition at line 24 of file common.hpp.

7.3.2.3 INITIAL_WEIGHT

```
#define INITIAL_WEIGHT 0.5f
```

Definition at line 21 of file common.hpp.

7.3.2.4 INITIAL_WEIGHT_INPUTN

```
#define INITIAL_WEIGHT_INPUTN 0.5f
```

Definition at line 22 of file common.hpp.

7.3.3 Function Documentation

7.3.3.1 createTrainTestSplit()

```
template<typename T>
TrainTestSplit< T > createTrainTestSplit (
            const std::vector< std::vector< T > > & features,
            const std::vector< std::vector< T > > & targets,
            float splitRatio)
```

Create a Train Test Split object from the features and targets.

Parameters

features	The 2D vector of features to split.
targets	The 2D vector of targets to split.
splitRatio	The ratio to split the data.

Returns

TrainTestSplit<T> The TrainTestSplit object.

Definition at line 219 of file common.hpp.

7.3.3.2 deltaBias()

```
float deltaBias (
            float & learningRate,
            float & deltaGradient)  [inline]
```

This function calculates the delta bias for a neuron.

Parameters

learningRate	The learning rate of the network.
deltaGradient	The gradient of the neuron.

Returns

float The delta bias.

Definition at line 124 of file common.hpp.

7.3.3.3 deltaGradient()

```
float deltaGradient (
            float & learningRate,
            float & gradient)  [inline]
```

This function calculates the delta gradient for a neuron.

Parameters

learningRate	The learning rate of the network.
gradient	The gradient of the neuron.

Returns

float The delta gradient.

Definition at line 112 of file common.hpp.

7.3.3.4 gradientBetweenNeurons()

```
float gradientBetweenNeurons (
            float & output,
            float & error)  [inline]
```

This function calculates the gradient between two neurons.

Parameters

output	The output of the neuron.
error	The error of the neuron.

Returns

float The gradient between the neurons.

Definition at line 100 of file common.hpp.

7.3.3.5 normalize2DVector()

```
template<typename T>
void normalize2DVector (
            std::vector< std::vector< T > > & vec)
```

This function creates a 2D vector from a 1D vector.

Parameters

vec	The 1D vector to be converted.
size	The size of the inner vectors.

Returns

std::vector<std::vector<T>> The 2D vector.

Definition at line 182 of file common.hpp.

7.3.3.6 normalizeVector()

```
template<typename T>
void normalizeVector (
            std::vector< T > & vec)
```

This function creates a 2D vector from a 1D vector.

Parameters

vec	The 1D vector to be converted.
size	The size of the inner vectors.

Returns

std::vector<std::vector<T>> The 2D vector.

Definition at line 161 of file common.hpp.

7.3.3.7 printVector()

```
template<typename T>
void printVector (
            const std::vector< T > & vec,
            const std::string extra = "")  [inline]
```

This function prints the elements of a vector to the console.

Parameters

vec	Vector to be printed.

Returns

∗ template<typename T>

Definition at line 137 of file common.hpp.

7.4 common.hpp

Go to the documentation of this file.

```
00001
00011
00012 #pragma once
00013 #include <iostream>
00014 #include <algorithm>
00015 #include <random>
00016 #include <vector>
00017 #include <cmath>
00018 #include <string>
00019 #include <stdio.h>
00020
00021 #define INITIAL_WEIGHT 0.5f
00022 #define INITIAL_WEIGHT_INPUTN 0.5f
00023 #define INITIAL_BIAS 0.5f
00024 #define INITIAL_BIAS_INPUTN 0.5f
00025
00033 struct irisData
00034 {
00035     std::vector<std::vector<float» features;
00036     std::vector<float> targets;
00037 };
00038
00046 template<typename T>
00047 struct digitData
00048 {
00049     std::vector<T> images;
00050     std::vector<T> targets;
00051 };
00052
00053 // Add forward declaration for TrainTestSplit
00054 template<typename T>
00055 struct TrainTestSplit;
00056
00057 // Forward declaration
00058 template<typename T>
00059 TrainTestSplit<T> createTrainTestSplit(
00060     const std::vector<std::vector<T»& features,
00061     const std::vector<std::vector<T»& targets,
00062     float splitRatio);
00063
00071 template<typename T>
00072 struct TrainTestSplit
00073 {
00074     // Constructors
00075     TrainTestSplit() = default;
00076     TrainTestSplit(const std::vector<std::vector<T»& features,
00077         const std::vector<std::vector<T»& targets,
00078         float splitRatio)
00079     {
00080         TrainTestSplit<T> tts = createTrainTestSplit(features, targets, splitRatio);
00081         trainFeatures = tts.trainFeatures;
00082         testFeatures = tts.testFeatures;
00083         trainTargets = tts.trainTargets;
00084         testTargets = tts.testTargets;
00085     }
00086
00087     std::vector<std::vector<T» trainFeatures;
00088     std::vector<std::vector<T» testFeatures;
00089     std::vector<std::vector<T» trainTargets;
00090     std::vector<std::vector<T» testTargets;
00091 };
```

```cpp

inline float gradientBetweenNeurons(float& output, float& error)
{
    return output * error;
}

inline float deltaGradient(float& learningRate, float& gradient)
{
    return learningRate * gradient;
}

inline float deltaBias(float& learningRate, float& deltaGradient)
{
    return learningRate * deltaGradient;
}


template<typename T>
inline void printVector(const std::vector<T> &vec, const std::string extra = "")
{
    if constexpr (std::is_floating_point_v<T>) {
        for (const T &item : vec) {
            printf("%.2f ", item);
        }
    } else if constexpr (std::is_integral_v<T>) {
        for (const T &item : vec) {
            printf("%i ", item);
        }
    }
    if (!extra.empty()) {
        printf("%s", extra.c_str());
    }
}

template<typename T>
void normalizeVector(std::vector<T> &vec)
{
    T maxElement = *std::max_element(vec.begin(), vec.end());
    T minElement = *std::min_element(vec.begin(), vec.end());
    T minMax = maxElement - minElement;

    // https://www.statology.org/normalize-data-between-0-and-1/
    for (std::size_t i = 0; i < vec.size(); i++) {
        T xi = vec[i];
        vec.at(i) = (xi - minElement) / minMax;
    }
}

template<typename T>
void normalize2DVector(std::vector<std::vector<T>> &vec)
{
    // Get the max and min element out of the 2D vector
    T maxElement, minElement = 0;
    T newMaxElement, newMinElement = 0;
    for (std::vector<T> &innerVec : vec) {
        newMaxElement = *std::max_element(innerVec.begin(), innerVec.end());
        newMinElement = *std::min_element(innerVec.begin(), innerVec.end());
        if (newMaxElement > maxElement) {
            maxElement = newMaxElement;
        }
        if (newMinElement < minElement) {
            minElement = newMinElement;
        }
    }

    T minMax = maxElement - minElement;

    // https://www.statology.org/normalize-data-between-0-and-1/
    for (std::vector<T> &innerVec : vec) {
        for (std::size_t i = 0; i < innerVec.size(); i++) {
            T xi = innerVec[i];
            innerVec.at(i) = (xi - minElement) / minMax;
        }
    }

}

template<typename T>
TrainTestSplit<T> createTrainTestSplit(
    const std::vector<std::vector<T>>& features,
    const std::vector<std::vector<T>>& targets,
    float splitRatio)
{
    TrainTestSplit<T> tts;
    // Reserve the memory for the vectors
    tts.trainFeatures.reserve(features.size() * splitRatio);
    tts.testFeatures.reserve(features.size() * (1 - splitRatio));
```

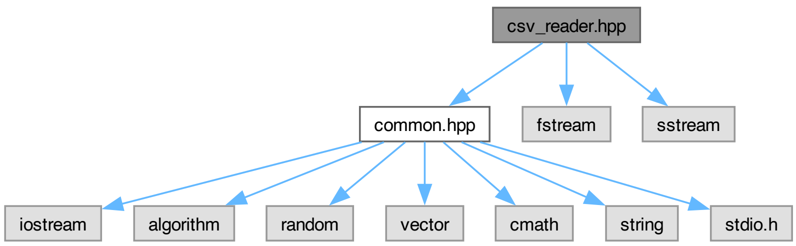
```
    tts.trainTargets.reserve(targets.size() * splitRatio);
    tts.testTargets.reserve(targets.size() * (1 - splitRatio));

    std::random_device rd;
    std::mt19937 gen(rd());
    std::uniform_int_distribution<> dis(0, 1);

    for (std::size_t i = 0; i < features.size(); i++)
    {
        if (i < features.size() * splitRatio) {
            tts.trainFeatures.emplace_back(features[i]);
            tts.trainTargets.emplace_back(targets[i]);
        } else {
            tts.testFeatures.emplace_back(features[i]);
            tts.testTargets.emplace_back(targets[i]);
        }
    }
    return tts;
}
```

7.5 csv_reader.hpp File Reference

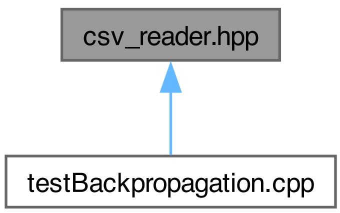
In this class the CSV reader is defined. This is for reading the iris data set.

```
#include "common.hpp"
#include <fstream>
#include <sstream>
```

Include dependency graph for csv_reader.hpp:



This graph shows which files directly or indirectly include this file:



Functions

- std::vector< std::vector< std::string > > readCsv (const std::string &filename, char delimiter=',')
  Reads a CSV file and returns a vector of vectors.
- std::vector< float > getTargets (const std::vector< std::vector< std::string > > &data)
  Extracts the features from the data (column).
- std::vector< std::vector< float > > getFeatures (const std::vector< std::vector< std::string > > &data)
  Extracts the features from the data.
- irisData filterData (const std::vector< std::vector< float > > &features, const std::vector< float > &targets, int target)
  Filters out data points with a specific target value.
- template<typename T>
  T convert (const std::string &str)
  Reads the digit data from a CSV file.
- template<> int convert< int > (const std::string &str)
- template<> float convert< float > (const std::string &str)
- template<typename T>
  std::vector< T > realdCsvFlat (const std::string &filename, char delimiter=',')
  Reads a CSV file and returns a vector of the specified type.
- template<typename T>
  std::vector< std::vector< T > > create2DVector (const std::vector< T > vec, int size)
- template<typename T>
  digitData< T > readDigitData ()
- template<typename T>
  std::vector< T > maskData (std::vector< T > &data, std::vector< T > &mask)

7.5.1 Detailed Description

In this class the CSV reader is defined. This is for reading the iris data set.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Copyright (c) 2025

Definition in file csv_reader.hpp.

7.5.2 Function Documentation

7.5.2.1 convert()

```
template<typename T>
T convert (
            const std::string & str)
```

Reads the digit data from a CSV file.

This function reads the digit data from a CSV file and returns a structure containing the features and target values.

Parameters

filename	The name of the CSV file to read.

Returns

irisData A structure containing the features and target values.

7.5.2.2 convert< float >()

```
template<>
float convert< float > (
            const std::string & str)
```

Definition at line 157 of file csv_reader.hpp.

7.5.2.3 convert< int >()

```
template<>
int convert< int > (
            const std::string & str)
```

Definition at line 152 of file csv_reader.hpp.

7.5.2.4 create2DVector()

```
template<typename T>
std::vector< std::vector< T > > create2DVector (
            const std::vector< T > vec,
            int size)
```

Definition at line 197 of file csv_reader.hpp.

7.5.2.5 filterData()

```
irisData filterData (
            const std::vector< std::vector< float > > & features,
            const std::vector< float > & targets,
            int target)
```

Filters out data points with a specific target value.

This function takes a set of features and corresponding target values, and filters out the data points where the target value matches the specified target. The remaining data points are returned in a new irisData structure.

Parameters

features	A vector of vectors containing the feature data.
targets	A vector containing the target values corresponding to the feature data.
target	The target value to filter out from the data.

Returns

irisData A structure containing the filtered feature data and target values.

Definition at line 119 of file csv_reader.hpp.

7.5.2.6 getFeatures()

```
std::vector< std::vector< float > > getFeatures (
            const std::vector< std::vector< std::string > > & data)
```

Extracts the features from the data.

This function extracts the features from the data and returns a vector of vectors containing the features.

Parameters

data	A vector of vectors representing the rows in the CSV file.

Returns

A vector containing the features.

Definition at line 93 of file csv_reader.hpp.

7.5.2.7 getTargets()

```
std::vector< float > getTargets (
            const std::vector< std::vector< std::string > > & data)
```

Extracts the features from the data (column).

This function extracts the features from the data and returns a vector of vectors containing the features.

Parameters

data	A vector of vectors representing the rows in the CSV file.

Returns

A vector containing the features.

Definition at line 75 of file csv_reader.hpp.

7.5.2.8 maskData()

```
template<typename T>
std::vector< T > maskData (
            std::vector< T > & data,
            std::vector< T > & mask)
```

Definition at line 231 of file csv_reader.hpp.

7.5.2.9 readCsv()

```
std::vector< std::vector< std::string > > readCsv (
            const std::string & filename,
            char delimiter = ',')
```

Reads a CSV file and returns a vector of vectors.

This function reads a CSV file and returns a vector of vectors. Each inner vector represents a row in the CSV file. The function assumes that the CSV file is well-formed and does not contain any missing values.

Parameters

filename	The name of the CSV file to read.
delimiter	The delimiter used in the CSV file.

Returns

A vector of vectors representing the rows in the CSV file.

Definition at line 32 of file csv_reader.hpp.

7.5.2.10 readDigitData()

```
template<typename T>
digitData< T > readDigitData ()
```

Definition at line 213 of file csv_reader.hpp.

7.5.2.11 realdCsvFlat()

```
template<typename T>
std::vector< T > realdCsvFlat (
            const std::string & filename,
            char delimiter = ',')
```

Reads a CSV file and returns a vector of the specified type.

This templatized function reads a CSV file, splits each line by the given delimiter, converts the tokens to type T, and returns them.

Template Parameters

T	The type to convert the CSV tokens into.

Parameters

filename	The name of the CSV file to read.
delimiter	The delimiter used in the CSV file.

Returns

A vector of all the tokens in the CSV file converted to type T.

Definition at line 173 of file csv_reader.hpp.

7.6 csv_reader.hpp

Go to the documentation of this file.

```
#pragma once
#include "common.hpp"
#include <fstream>
#include <sstream>


// ===================================================================================================
// Section: reading iris data
// ===================================================================================================

std::vector<std::vector<std::string» readCsv(const std::string& filename, char delimiter=',')
{
    // Create a vector to store the rows
    std::vector<std::vector<std::string» rows;
    std::ifstream file(filename);

    // Check if the file is open
    if (!file.is_open()) {
        std::cerr « "Error: Could not open file " « filename « std::endl;
        return rows;
    }

    // Read the file line by line
    std::string line;
    while (std::getline(file, line)) {
        std::stringstream ss(line);
        std::vector<std::string> cols;
        std::string col;

        while (std::getline(ss, col, delimiter)) {
            cols.push_back(col);
        }

        // Add the columns to the rows
        rows.push_back(cols);
    }

    // Close the file
    file.close();

    return rows;
}


std::vector<float> getTargets(const std::vector<std::vector<std::string»& data)
{
    std::vector<float> targets;
    for (const auto& row : data) {
        targets.push_back(std::stof(row.back()));
    }
    return targets;
}

std::vector<std::vector<float» getFeatures(const std::vector<std::vector<std::string»& data)
{
    std::vector<std::vector<float» features;
    for (const auto& row : data) {
        std::vector<float> feature_row;
        // Skip the last column which contains the target
        for (int i = 0; i < row.size() - 1; i++) {
            feature_row.push_back(std::stof(row[i]));
        }
        features.push_back(feature_row);
    }
    return features;
}

irisData filterData(const std::vector<std::vector<float»& features, const std::vector<float>& targets,
    int target)
{
    std::vector<std::vector<float» filtered_features;
    std::vector<float> filtered_targets;
    for (int i = 0; i < features.size(); i++) {
        if (targets[i] != target) {
            filtered_features.push_back(features[i]);
            filtered_targets.push_back(targets[i]);
        }
    }
    return irisData{filtered_features, filtered_targets};
}

```

```

// =================================================================================================
// Section: reading digits data
// =================================================================================================


// Helper conversion function template with specializations.
template<typename T>
T convert(const std::string& str);

template<>
int convert<int>(const std::string& str) {
    return std::stoi(str);
}

template<>
float convert<float>(const std::string& str) {
    return std::stof(str);
}

template<typename T>
std::vector<T> realdCsvFlat(const std::string& filename, char delimiter = ',')
{
    std::vector<T> data;
    std::ifstream file(filename);

    if (!file.is_open()) {
        std::cerr « "Error: Could not open file " « filename « std::endl;
        return data;
    }

    std::string line;
    while (std::getline(file, line)) {
        std::stringstream ss(line);
        std::string token;

        while (std::getline(ss, token, delimiter)) {
            data.push_back(convert<T>(token));
        }
    }
    file.close();
    return data;
}

template<typename T>
std::vector<std::vector<T» create2DVector(const std::vector<T> vec, int size)
{
    std::vector<std::vector<T» data;
    data.reserve(vec.size() / size);
    for (int i = 0; i < vec.size(); i += size) {
        std::vector<T> row;
        for (int j = 0; j < size; j++) {
            row.push_back(vec[i + j]);
        }
        data.push_back(row);
    }

    return data;
}

template<typename T>
digitData<T> readDigitData()
{
    // Not the best way to do this, but it works for now
    // presumes that the data is in the data folder in the root of the project
    const std::string filenameImages = "../../data/digits_images.csv";
    const std::string filenameTargets = "../../data/digits_targets.csv";

    // Load the data
    digitData<T> data;
    std::vector<T> images = realdCsvFlat<T>(filenameImages);
    normalizeVector(images);
    data.images = images;
    data.targets = realdCsvFlat<T>(filenameTargets);

    return data;
}

template<typename T>
std::vector<T> maskData(std::vector<T>& data, std::vector<T>& mask)
{
    T off, on;
    if constexpr (std::is_floating_point_v<T>) {
        off = 0.0f;
        on  = 1.0f;
    } else if constexpr (std::is_integral_v<T>) {
        off = 0;
```

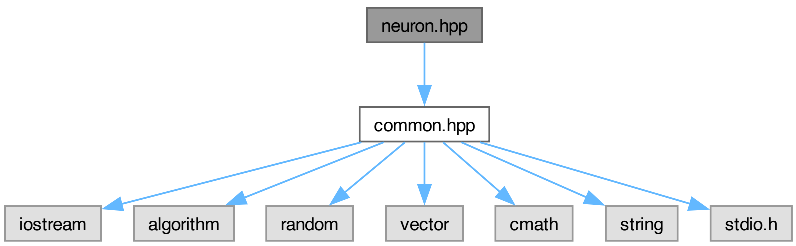
```
        on  = 1;
    } else {
        throw std::runtime_error("Data type not supported");
    }

    std::vector<T> maskedData;
    maskedData.reserve(data.size() * mask.size());
    for (std::size_t i = 0; i < data.size(); i++)
    {
        for (std::size_t j = 0; j < mask.size();j++)
        {
            if (data.at(i) == mask.at(j)) {
                maskedData.emplace_back(on);
            } else {
                maskedData.emplace_back(off);
            }
        }
    }
    return maskedData;
}
```

7.7 neuron.hpp File Reference

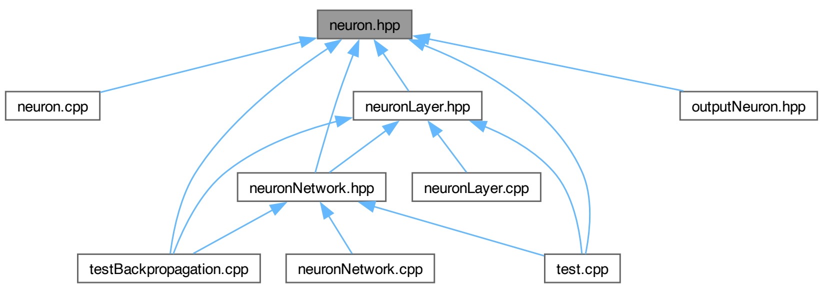
In this file the Neuron class is declared. This class represents a single neuron in a neural network.

```
#include "common.hpp"
```

Include dependency graph for neuron.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class Neuron

  Represents a single neuron in a neural network.

7.7.1 Detailed Description

In this file the Neuron class is declared. This class represents a single neuron in a neural network.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Definition in file neuron.hpp.

7.8 neuron.hpp

Go to the documentation of this file.

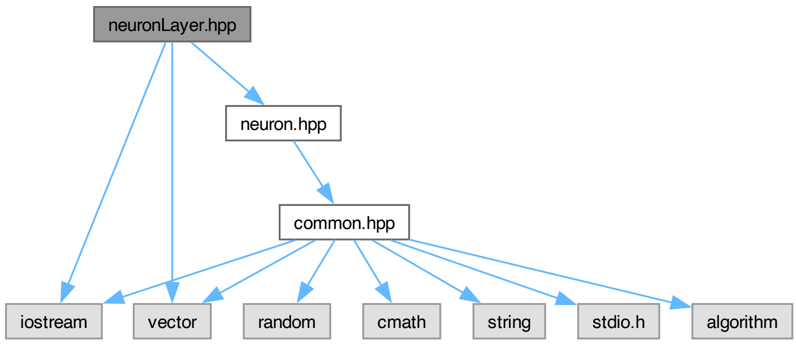
```
#pragma once
#include "common.hpp"
class Neuron {
private:
    std::vector<float> _weights;
    std::vector<float> _lastInput;
    float _bias;
    float _learningRate;
    float _lastOutput;
    float _delta;

public:
    Neuron(int nSizeWeights, float initialWeight, float initialBias);

    Neuron(const std::vector<float>& weights, float bias, float learningRate = 0.1);

    float sigmoid(float x);

    float activate(const std::vector<float>& inputs);

    float predict(const std::vector<float>& inputs);

    void deltaError(const std::vector<float>& inputs, const std::vector<Neuron>& neuronsNextLayer, float target, bool isOutputNeuron);

    void update();

    float computeHiddenDelta(const std::vector<float>& inputs, float sum);

    float sigmoidDerivative(float output);

    float computeOutputDelta(float target);

    const std::vector<float>& getWeights() const { return _weights; }

    float getBias() const { return _bias; }

    float getError() const { return _delta; }

    void __str__() const;



};
```

7.9 neuronLayer.hpp File Reference

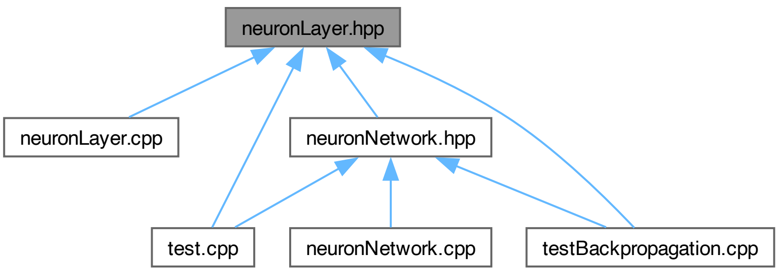
In this file the NeuronLayer class is declared. This class represents a layer of neurons in a neural network.

```
#include <iostream>
#include <vector>
#include "neuron.hpp"
```

Include dependency graph for neuronLayer.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class NeuronLayer

    Represents a layer of neurons in a neural network.

7.9.1 Detailed Description

In this file the NeuronLayer class is declared. This class represents a layer of neurons in a neural network.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Copyright (c) 2025

Definition in file neuronLayer.hpp.

7.10 neuronLayer.hpp

Go to the documentation of this file.

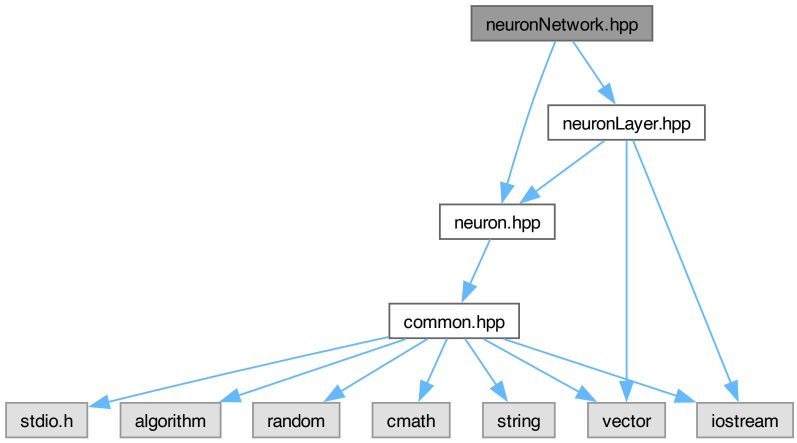
```
#pragma once
#include <iostream>
#include <vector>
#include "neuron.hpp"

class NeuronLayer {
private:
    std::vector<Neuron> _neurons;
    std::vector<float> _output;

public:
    NeuronLayer(std::vector<Neuron> neurons);

    NeuronLayer(int nNeurons, int nSizeWeights);

    std::vector<float>& feedForward(const std::vector<float>& inputs);

    void computeOutputErros(const std::vector<float>& targets);

    void computeHiddenErrors(const std::vector<float>& inputs, const std::vector<Neuron>&
neuronsNextLayer);

    void update();

    const std::vector<Neuron>& getNeurons() { return _neurons; }

    const std::vector<float>& getOutput() const { return _output; }

    void __str__() const;
};
```

7.11 neuronNetwork.hpp File Reference

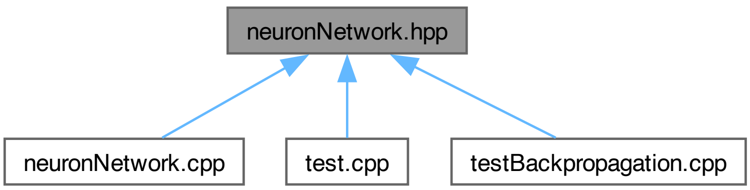
In this file the NeuronNetwork class is declared. This class represents a neural network with multiple layers of neurons.

```
#include "neuron.hpp"
#include "neuronLayer.hpp"
```

Include dependency graph for neuronNetwork.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class NeuronNetwork

    Represents a neural network with multiple layers of neurons.

7.11.1 Detailed Description

In this file the NeuronNetwork class is declared. This class represents a neural network with multiple layers of neurons.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

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Definition in file neuronNetwork.hpp.

7.12 neuronNetwork.hpp

Go to the documentation of this file.

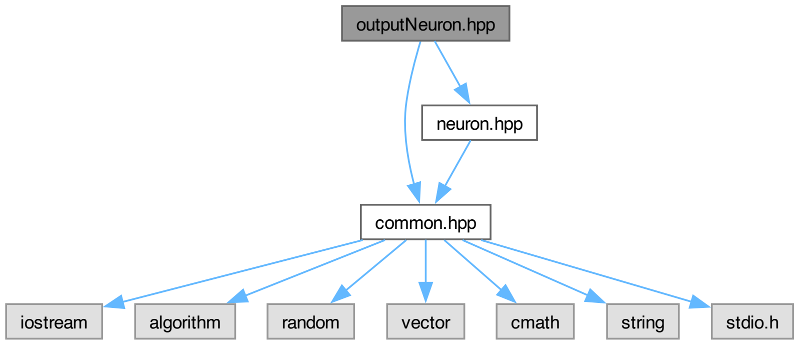
```
#pragma once
#include "neuron.hpp"
#include "neuronLayer.hpp"

class NeuronNetwork {
private:
    std::vector<NeuronLayer> _layers;
    std::vector<float> _currentTargets;

    std::vector<float> _inputVec;
    std::vector<float> _currentLayerOutput;
    std::vector<float> _tempOutputBuffer;

    std::vector<float> _outputMask;
public:
    NeuronNetwork(std::vector<NeuronLayer> layers);

    NeuronNetwork(std::vector<int> layers);


    const std::vector<float>& feedForward(const std::vector<float>& inputs);

    std::vector<float> predict(const std::vector<float>& input);

    void backPropagation(const std::vector<float>& targets);

    void maskTarget(float target);
    void update();
    void trainInputs2D(const std::vector<std::vector<float»& inputs, const std::vector<std::vector<float»& targets, int epochs);

    std::vector<NeuronLayer> getLayers() const { return _layers; }

    void setTarget(std::vector<float>& targets) {_currentTargets = targets;}

    void __str__() const;


};
```

7.13 outputNeuron.hpp File Reference

In this file the OutputNeuron class is declared. This class represents a single output neuron in a neural network.

```
#include "common.hpp"
#include "neuron.hpp"
```

Include dependency graph for outputNeuron.hpp:



Classes

- class OutputNueron

7.13.1 Detailed Description

In this file the OutputNeuron class is declared. This class represents a single output neuron in a neural network.

Author

Stan Merlijn

Version

0.1

Date

2025-02-24

Copyright

Copyright (c) 2025

Definition in file outputNeuron.hpp.

7.14 outputNeuron.hpp

Go to the documentation of this file.

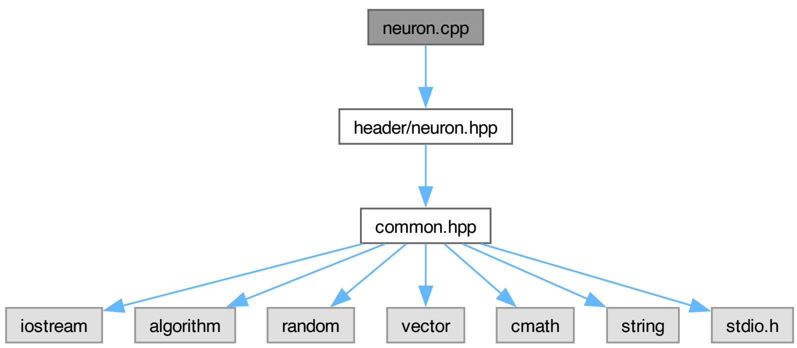
```
#include "common.hpp"
#include "neuron.hpp"

class OutputNueron : Neuron
{
public:

private:

};
```

7.15 neuron.cpp File Reference

In this file the Neuron class is implemented.

`#include "header/neuron.hpp"`

Include dependency graph for neuron.cpp:



7.15.1 Detailed Description

In this file the Neuron class is implemented.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Copyright (c) 2025

Definition in file neuron.cpp.

7.16 neuron.cpp

Go to the documentation of this file.

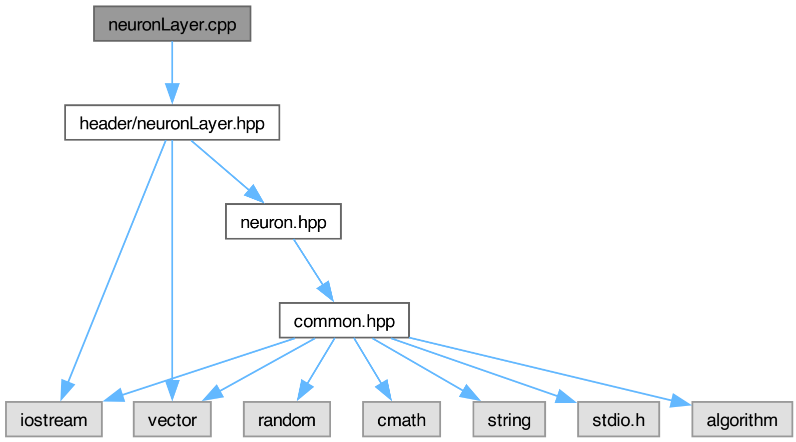
```cpp

#include "header/neuron.hpp"

Neuron::Neuron(int nSizeWeights, float initialWeight, float initialBias)
{
    // Initialize the weights and bias
    _weights = std::vector<float>(nSizeWeights, initialWeight);
    _lastInput.reserve(nSizeWeights);

    // Initialize the delta and learning rate
    _delta = 0.0f;
    _bias = initialBias;
    _learningRate = 0.5f;
    _lastOutput = 0.0f;
}

Neuron::Neuron(const std::vector<float>& weights, float bias, float learningRate)
    : _weights(weights), _bias(bias), _learningRate(learningRate) {}

float Neuron::sigmoid(float x)
{
    // Sigmoid activation function
    return 1 / (1 + exp(-x));
}

float Neuron::activate(const std::vector<float>& inputs)
{
    // Calculate the weighted sum of the inputs
    _lastInput = inputs;
    float weightedSum = _bias;

    // Dot product of the weights and inputs
    for (std::size_t i = 0; i < _weights.size(); i++)
    {
        weightedSum += _weights[i] * inputs[i];
    }

    // Return the result of the sigmoid function
    _lastOutput = sigmoid(weightedSum);
    return _lastOutput;
}

float Neuron::predict(const std::vector<float>& inputs)
{
    // Return 1 if the result is greater than 0.5, otherwise return 0(threshold)
    return (activate(inputs) > 0.5) ? 1 : 0;
}

void Neuron::update()
{
    // Update the weights and bias
    for (std::size_t i = 0; i < _weights.size(); i++)
    {
        _weights[i] -= _learningRate * _lastInput[i] * _delta;
    }
    // Update the bias
    _bias -= _learningRate * _delta;
}

float Neuron::computeHiddenDelta(const std::vector<float>& inputs, float sum)
{
    _delta = sigmoidDerivative(_lastOutput) * sum;;
    return _delta;
}

float Neuron::computeOutputDelta(float target)
{
    _delta = sigmoidDerivative(_lastOutput) * -(target - _lastOutput);
    return _delta;
}

float Neuron::sigmoidDerivative(float output)
{
    return output * (1 - output);
}

void Neuron::__str__() const
{
    // Print the neuron details
    printf("\nNeurons with %zu weights: ", _weights.size());
    printVector(_weights);
    printf("| Bias = %f | Learning rate = %f", _bias, _learningRate);
```

```
00092 }
```

7.17 neuronLayer.cpp File Reference

In this file the NeuronLayer class is implemented.

`#include "header/neuronLayer.hpp"`
Include dependency graph for neuronLayer.cpp:



7.17.1 Detailed Description

In this file the NeuronLayer class is implemented.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Copyright (c) 2025

Definition in file neuronLayer.cpp.

7.18 neuronLayer.cpp

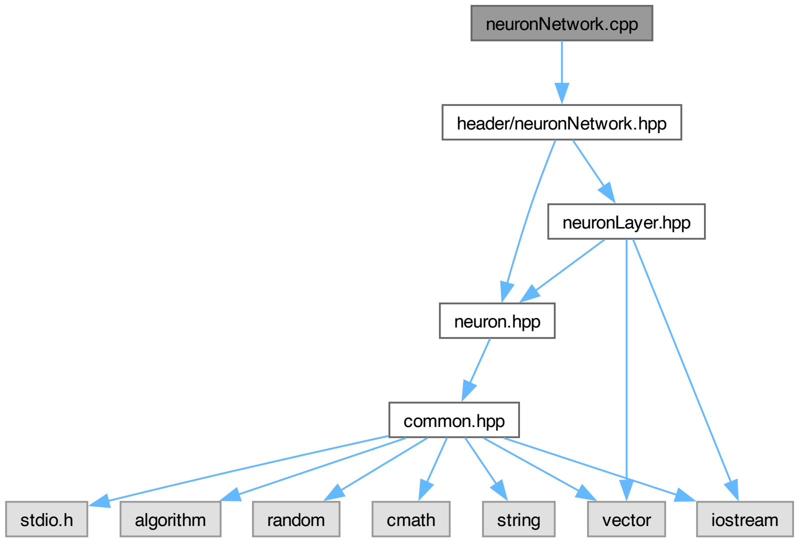
Go to the documentation of this file.

```cpp

#include "header/neuronLayer.hpp"

NeuronLayer::NeuronLayer(std::vector<Neuron> neurons)
    : _neurons(neurons) {}

NeuronLayer::NeuronLayer(int nNeurons, int nSizeWeights)
{
    _output.resize(nNeurons);
    // nNeurons check
    if (nNeurons == 0) {
        printf("nNeuron must be atleast 1 is %d", nNeurons) ;
        return;
    }

    std::random_device rd;
    std::mt19937 gen(rd());
    std::uniform_real_distribution<> dis(0.1f, 1.0f);

    _neurons.reserve(nNeurons);
    for (std::size_t i = 0; i < nNeurons; i++)
    {
        _neurons.emplace_back(nSizeWeights, dis(gen), dis(gen));
    }
}

std::vector<float>& NeuronLayer::feedForward(const std::vector<float>& inputs)
{
    // Feed forward through each neuron in the layer
    for (std::size_t i = 0; i < _neurons.size(); i++)
    {
        // For now using the activate instead of predict.
        // The predict function is used for binary classification i think.
        _output[i] = _neurons[i].activate(inputs);
    }
    return _output;
}

void NeuronLayer::computeOutputErros(const std::vector<float> &targets)
{
    // Will only run for the output neurons
    for (std::size_t i = 0; i < targets.size(); i++) {
        _neurons[i].computeOutputDelta(targets[i]);
    }
}

void NeuronLayer::computeHiddenErrors(const std::vector<float>& inputs, const std::vector<Neuron>& neuronsNextLayer)
{
    // // Simply get the first neurons weight size
    for (std::size_t i = 0; i < _neurons.size(); i++) {

        float sum = 0.0f;

        // Loop over neurons in next layer
        for (std::size_t j = 0; j < neuronsNextLayer.size(); j++)
        {
            sum += neuronsNextLayer[j].getWeights()[i] * neuronsNextLayer[j].getError();
        }

        _neurons[i].computeHiddenDelta(inputs, sum);
    }
}

void NeuronLayer::update()
{
    for (Neuron& n : _neurons)
    {
        n.update();
    }
}

void NeuronLayer::__str__() const
{
    // Print the layer details
    printf("\nNeuronLayer with %zu neurons", _neurons.size());
    for (std::size_t i = 0; i < _neurons.size(); i++)
    {
        _neurons[i].__str__();
    }
    printf("\n");
}
```

7.19 neuronNetwork.cpp File Reference

In this file the NeuronNetwork class is implemented.

`#include "header/neuronNetwork.hpp"`
Include dependency graph for neuronNetwork.cpp:



7.19.1 Detailed Description

In this file the NeuronNetwork class is implemented.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

Copyright (c) 2025

Definition in file neuronNetwork.cpp.

7.20 neuronNetwork.cpp

Go to the documentation of this file.

```
#include "header/neuronNetwork.hpp"

NeuronNetwork::NeuronNetwork(std::vector<NeuronLayer> layers)
    : _layers(layers) {}

NeuronNetwork::NeuronNetwork(std::vector<int> layerSizes)
{
    // Reserve the input vector and the current targets
    _inputVec.resize(layerSizes.front());
    _currentTargets.resize(layerSizes.back());

    // Reserve because there is no default constructor for NeuronLayer
    _layers.reserve(layerSizes.size());

    // Reserve the temp output buffer and the current layer output
    _tempOutputBuffer.resize(*std::max_element(layerSizes.begin(), layerSizes.end()));
    _currentLayerOutput.resize(*std::max_element(layerSizes.begin(), layerSizes.end()));
    // Create the layers
    for (std::size_t i = 1; i < layerSizes.size(); i++) {
        // If its the first layer then the input size is the first element in the layerSizes
        if (i == 1) {
            _layers.emplace_back(layerSizes[i], layerSizes.front());
        } else {
            _layers.emplace_back(layerSizes[i], layerSizes[i-1]);
        }
    }
}

const std::vector<float>& NeuronNetwork::feedForward(const std::vector<float>& inputs)
{
    // Set the input vector and the current layer output
    _inputVec = inputs;
    _currentLayerOutput = inputs;

    // Feed forward through each layer in the network
    for (std::size_t i = 0; i < _layers.size(); i++) {
        _currentLayerOutput = _layers[i].feedForward(_currentLayerOutput);
    }
    return _currentLayerOutput;
}

std::vector<float> NeuronNetwork::predict(const std::vector<float>& input)
{
    return feedForward(input);
}

void NeuronNetwork::backPropagation(const std::vector<float>& targets)
{
    // Compute the output errors
    int last = _layers.size() -1;
    _layers[last].computeOutputErros(targets);

    // Reverse loop For hidden layers
    for (int i = last-1; i > -1; i--) {
        // If is output neuron compute the output error
        if (i == 0) { // If i == 0 then its the input layer
            _layers[i].computeHiddenErrors(_inputVec, _layers[i + 1].getNeurons());
        } else { // Else compute the hidden error
            _layers[i].computeHiddenErrors(_layers[i-1].getOutput(), _layers[i + 1].getNeurons());
        }
    }
}

void NeuronNetwork::update()
{
    for (NeuronLayer& nL : _layers) {
        nL.update();
    }
}

void NeuronNetwork::trainInputs2D(const std::vector<std::vector<float»& inputs, const
std::vector<std::vector<float»& targets, int epochs)
{
    // Check if the flat input is the same as the targets
    if (!((inputs.size()) == targets.size())) {
        throw std::runtime_error("Input and target size are not the same");
    }

    // Loop over the epochs
    for (int x = 0; x < epochs; x++) {
        // Loop over each input and target
```

```
        for (std::size_t i = 0; i < targets.size(); i++) {
            feedForward(inputs[i]);                    // Feed forward
            backPropagation(targets[i]);               // Back propagate
            update();                                  // Update the weights
        }
    }
}

// void NeuronNetwork::trainInputs(const std::vector<std::vector<float»& inputs, const std::vector<std::vector<float»& targets,
//      int inputSize, int targetSize, int epochs)
// {
//      // Check if the flat input is the same as the targets
//      // if (!((inputs.size() / inputSize) == targets.size() / targetSize)) {
//      //      throw std::runtime_error("Input and target size are not the same");
//      // }

//      std::vector<float> input(inputSize);
//      // std::vector<float> target(targetSize);

//      // Loop over the epochs
//      for (int x = 0; x < epochs; x++) {
//          // Loop over each input and target
//          for (std::size_t i = 0; i < targets.size(); i++) {
//              // Set the input for the network
//              std::size_t startIndexInput = i * inputSize;

//              // for (std::size_t j = 0; j < inputSize; j++) {
//              //      input[j] = inputs[startIndexInput + j];
//              // }

//              // Set the target for the network
//              // std::size_t startIndexTarget =  i * targetSize;
//              // for (std::size_t j = 0; j < targetSize; j++) {
//              //      _target[j] = targets[startIndexTarget + j];
//              // }

//              // maskTarget(targets[i]); // Set the target for the network
//              feedForward(inputs[i]);     // Feed forward
//              backPropagation(targets[i]);      // Back propagate
//              update();                // Update the weights
//          }
//      }
// }

void NeuronNetwork::maskTarget(float target)
{
    // if (_outputMask.size() != _currentTargets.size()) {
    //     throw std::runtime_error("OutputMask and current targets are not the same size");
    //     exit(1);
    // }


    // Set the target to the current target
    for (std::size_t i = 0; i < _outputMask.size(); i++) {
        if (_outputMask[i] == target) {
            _currentTargets[i] = 1.0f;
        } else {
            _currentTargets[i] = 0.0f;
        }
    }
}

void NeuronNetwork::__str__() const
{
    // Print the network details
    printf("\nNeuronNetwork with %zu layers\n", _layers.size());
    for (std::size_t i = 0; i < _layers.size(); i++)
    {
        _layers[i].__str__();
    }
}
```

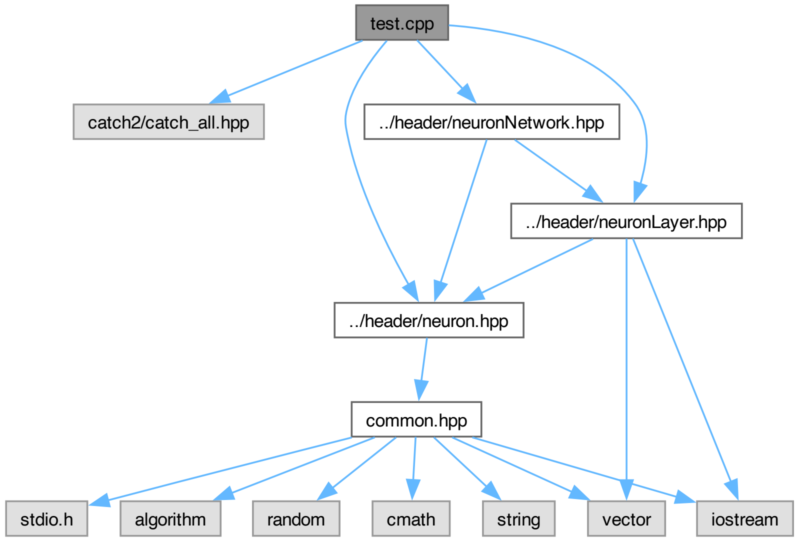
7.21 test.cpp File Reference

In this file the tests for the Neuron, NeuronLayer and NeuronNetwork classes are implemented.

```
#include <catch2/catch_all.hpp>
#include "../header/neuron.hpp"
```

```
#include "../header/neuronLayer.hpp"
#include "../header/neuronNetwork.hpp"
```

Include dependency graph for test.cpp:



Functions

- TEST_CASE ("Neuron AND gate", "[neuron]")

  In this test case we test the ability of a single neuron to learn the AND gate.
- TEST_CASE ("Neuron OR gate", "[neuron]")

  In this test case we test the ability of a single neuron to learn the OR gate.
- TEST_CASE ("Neuron NOT gate", "[neuron]")

  In this test case we test the ability of a single neuron to learn the NOT gate.
- TEST_CASE ("Neuron NOR gate (NOT OR)", "[neuron]")

  In this test case we test the ability of a single neuron to learn the NOR gate.
- TEST_CASE ("Half Adder using Two-Layer Neuron Network", "[half-adder]")

  In this test case we test the ability of a two-layer neural network to learn the XOR gate.

7.21.1 Detailed Description

In this file the tests for the Neuron, NeuronLayer and NeuronNetwork classes are implemented.

Unit tests for the Neuron, NeuronLayer and NeuronNetwork classes.

Author

Stan Merlijn

Version

0.1

Date

2025-02-14

Copyright

This file contains a series of test cases to verify the functionality of the Neuron and NeuronLayer classes. The tests include training and prediction for various logic gates.

Test Cases:

- Neuron for AND Gate: Tests the Neuron's ability to learn the AND gate.
- Neuron for OR Gate: Tests the Neuron's ability to learn the OR gate.
- Neuron for NOT Gate: Tests the Neuron's ability to learn the NOT gate.
- Neuron for NOR Gate (3 inputs): Tests the Neuron's ability to learn the NOR gate with 3 inputs.
- NeuronNetwork for the XOR gate with 2 inputs.

Note

The tests use the Catch2 framework for unit testing.

Definition in file test.cpp.

7.21.2 Macro Definition Documentation

7.21.2.1 CATCH_CONFIG_MAIN

```
#define CATCH_CONFIG_MAIN
```

Definition at line 11 of file test.cpp.

7.21.3 Function Documentation

7.21.3.1 TEST_CASE() [1/5]

```
TEST_CASE (
            "Half Adder using Two-Layer Neuron Network" ,
            "" [half-adder])
```

In this test case we test the ability of a two-layer neural network to learn the XOR gate.

The XOR gate is a binary operation that returns true if the inputs are different, and false otherwise. The network consists of two layers: a hidden layer with an OR and an AND neuron, and an output layer with a *XOR* and a carry neuron.

The XOR in this case is not a traditional XOR gate, but a neuron that computes the XOR operation. It works because it can only take 3 inputs which is linearly separable. The inputs are the output of the OR and AND neurons. The are as follows:

x1	x2	OR	AND
0	0	0	0
0	1	1	0
1	0	1	0
1	1	1	1

So the only inputs for the XOR neuron are (0,0), (1,0) and (0,0).

XOR = OR - AND; neuron with weights {1, -1} and bias -0.5

- $x1 = 0, x2 = 0 : 1 * 0 + -1 * 0 - 0.5 = -0.5$
- $x1 = 1, x2 = 0 : 1 * 1 + -1 * 0 - 0.5 = 0.5$
- $x1 = 1, x2 = 1 : 1 * 1 + -1 * 1 - 0.5 = -0.5$

Definition at line 137 of file test.cpp.

7.21.3.2 TEST_CASE() [2/5]

```
TEST_CASE (
            "Neuron AND gate" ,
            "" [neuron])
```

In this test case we test the ability of a single neuron to learn the AND gate.

The AND gate is a binary operation that returns true if both inputs are true, and false otherwise. With a bias of -1.5 the dot product will only be greater than 0 if both inputs are 1

- $x1 = 0, x2 = 0 : 1 * 0 + 1 * 0 - 1.5 = -1.5$
- $x1 = 0, x2 = 1 : 1 * 0 + 1 * 1 - 1.5 = -0.5$
- $x1 = 1, x2 = 0 : 1 * 1 + 1 * 0 - 1.5 = -0.5$
- $x1 = 1, x2 = 1 : 1 * 1 + 1 * 1 - 1.5 = 0.5$

Definition at line 45 of file test.cpp.

7.21.3.3 TEST_CASE() [3/5]

```
TEST_CASE (
            "Neuron NOR gate (NOT OR)" ,
            "" [neuron])
```

In this test case we test the ability of a single neuron to learn the NOR gate.

The NOR gate is a binary operation that returns true if both inputs are false, and false otherwise. With a bias of 0.5 the dot product will be greater than 0 if both inputs are 0

- $x1 = 0, x2 = 0 : -1 * 0 + -1 * 0 + 0.5 = 0.5$
- $x1 = 0, x2 = 1 : -1 * 0 + -1 * 1 + 0.5 = -0.5$
- $x1 = 1, x2 = 0 : -1 * 1 + -1 * 0 + 0.5 = -0.5$
- $x1 = 1, x2 = 1 : -1 * 1 + -1 * 1 + 0.5 = -1.5$

Definition at line 103 of file test.cpp.

7.21.3.4 TEST_CASE() [4/5]

```
TEST_CASE (
            "Neuron NOT gate" ,
            "" [neuron])
```

In this test case we test the ability of a single neuron to learn the NOT gate.

The NOT gate is a unary operation that returns true if the input is false, and false otherwise. With a bias of 1 the dot product will be greater than 0 if the first input is 0

- $x1 = 1 : -2 * 1 + 0 * 1 + 1 = -1$
- $x1 = 0 : -2 * 0 + 0 * 0 + 1 = 1$

Definition at line 83 of file test.cpp.

7.21.3.5 TEST_CASE() [5/5]

```
TEST_CASE (
            "Neuron OR gate" ,
            "" [neuron])
```

In this test case we test the ability of a single neuron to learn the OR gate.

The OR gate is a binary operation that returns true if at least one of the inputs is true, and false otherwise. With a bias of -0.5 the dot product will be greater than 0 if any of the inputs are 1

- $x1 = 0, x2 = 0 : 1 * 0 + 1 * 0 - 0.5 = -0.5$
- $x1 = 0, x2 = 1 : 1 * 0 + 1 * 1 - 0.5 = 0.5$
- $x1 = 1, x2 = 0 : 1 * 1 + 1 * 0 - 0.5 = 0.5$
- $x1 = 1, x2 = 1 : 1 * 1 + 1 * 1 - 0.5 = 1.5$

Definition at line 65 of file test.cpp.

7.22 test.cpp

Go to the documentation of this file.

```
00001
00011 #define CATCH_CONFIG_MAIN
00012 #include <catch2/catch_all.hpp>
00013
00014 #include "../header/neuron.hpp"
00015 #include "../header/neuronLayer.hpp"
00016 #include "../header/neuronNetwork.hpp"
00017
00034
00045 TEST_CASE("Neuron AND gate", "[neuron]") {
00046     // Create a neuron with weights 1, 1 and bias -1.5
00047
00048     Neuron n({1, 1}, -1.5);
00049     REQUIRE(n.predict({0, 0}) == 0);
```

```cpp
    REQUIRE(n.predict({0, 1}) == 0);
    REQUIRE(n.predict({1, 0}) == 0);
    REQUIRE(n.predict({1, 1}) == 1);
}

TEST_CASE("Neuron OR gate", "[neuron]") {
    // Create a neuron with weights 1, 1 and bias -0.5

    Neuron n({1, 1}, -0.5);
    REQUIRE(n.predict({0, 0}) == 0);
    REQUIRE(n.predict({0, 1}) == 1);
    REQUIRE(n.predict({1, 0}) == 1);
    REQUIRE(n.predict({1, 1}) == 1);
}

TEST_CASE("Neuron NOT gate", "[neuron]") {
    // Create a neuron with weights -2 and 0 and bias 1

    Neuron n({-2, 0}, 1);
    REQUIRE(n.predict({0, 0}) == 1);
    REQUIRE(n.predict({0, 0}) == 1);
    REQUIRE(n.predict({1, 0}) == 0);
    REQUIRE(n.predict({1, 0}) == 0);
}

TEST_CASE("Neuron NOR gate (NOT OR)", "[neuron]") {
    // Create a neuron with weights -1, -1 and bias 0.5

    Neuron n({-1, -1}, 0.5);
    REQUIRE(n.predict({0, 0}) == 1);
    REQUIRE(n.predict({0, 1}) == 0);
    REQUIRE(n.predict({1, 0}) == 0);
    REQUIRE(n.predict({1, 1}) == 0);
}

TEST_CASE("Half Adder using Two-Layer Neuron Network", "[half-adder]") {
    // Hidden layer: compute OR and AND
    Neuron n_or({1, 1}, -0.5);   // OR gate
    Neuron n_and({1, 1}, -1.5);  // AND gate
    NeuronLayer hiddenLayer({n_or, n_and});

    // Output layer: compute XOR (for sum) and carry
    Neuron n_xor({1, -1}, -0.5);

    // Carry = AND; neuron with weights {1, 1} and bias -1.5
    Neuron n_carry({1, 1}, -1.5);
    NeuronLayer outputLayer({n_xor, n_carry});

    // Two-layer network for half adder
    NeuronNetwork halfAdder({hiddenLayer, outputLayer});

    // Test cases for half adder: {Sum, Carry}
    REQUIRE(halfAdder.feedForward({0, 0}) == std::vector<float>{0, 0});
    REQUIRE(halfAdder.feedForward({0, 1}) == std::vector<float>{1, 0});
    REQUIRE(halfAdder.feedForward({1, 0}) == std::vector<float>{1, 0});
    REQUIRE(halfAdder.feedForward({1, 1}) == std::vector<float>{0, 1});
}
```

7.23 testBackpropagation.cpp

```cpp

#define CATCH_CONFIG_MAIN
#include <catch2/catch_all.hpp>

#include "../header/common.hpp"
#include "../header/csv_reader.hpp"
#include "../header/neuron.hpp"
#include "../header/neuronLayer.hpp"
#include "../header/neuronNetwork.hpp"

#include <random>
#include <chrono>



// Function to check new operator
static int s_Allocations = 0;

void* operator new(size_t size)
{
    s_Allocations++;
    return malloc(size);
}
```

```

// Macro version for when you want to time a block of code in-place.
#define MEASURE_BLOCK(message, code_block)                   \
    {                                                        \
        auto start = std::chrono::high_resolution_clock::now(); \
        code_block;                                          \
        auto end = std::chrono::high_resolution_clock::now();   \
        auto duration = std::chrono::duration<double, std::milli>(end - start).count();   \
        std::cout « message « " took " « duration « " ms" « std::endl; \
    }


using namespace Catch::Matchers;

TEST_CASE("Loading digit data", "[backpropagation]") {
    // Load the digit data
    digitData _digitData = readDigitData<int>();

    // Check the size of the data
    REQUIRE(_digitData.images.size() == 1797 * 64);
    REQUIRE(_digitData.targets.size() == 1797);

    // Exit program if the data is not loaded
    if (_digitData.images.size() == 0 || _digitData.targets.size() == 0) {
        FAIL("Could not load digit dataset");
        exit(1);
    }

    SUCCEED("Successfully loaded digit dataset");
}

TEST_CASE("Testing initialization of the NeuronLayer", "[NeuronLayer]")
{
    // create a neuronLayer with 10 neurons
    int nNeurons = 10;
    NeuronLayer nL(nNeurons, 4);

    REQUIRE(nL.getNeurons().size() == nNeurons);
    nL.__str__();
    SUCCEED("Successfully initialized NeuronLayer");
}

TEST_CASE("Testing initialization of the NeuronNetwork", "[NeuronNetwork]")
{
    return;
    // Initialize layers sizes
    int sizeInput  = 4;
    int hidden1    = 2;
    int hidden2    = 6;
    int sizeOutput = 3;

    // Initialize the Neural Network
    std::vector<int> layers = {sizeInput, hidden1, hidden2, sizeOutput};
    std::vector<float> outputMask = {0.0f, 1.0f, 2.0f};

    BENCHMARK("Initializing Neural Network"){
        NeuronNetwork nn(layers);
    };

    NeuronNetwork nn(layers);

    // Get the neurons
    std::vector<NeuronLayer> neuronLayers = nn.getLayers();
    // nn.__str__();

    // Check the input weigths
    for(int i = 0; i < neuronLayers.size(); i++) {
        NeuronLayer nL = neuronLayers.at(i);
        std::vector<Neuron> neurons = nL.getNeurons();

        for (Neuron& n : neurons) {
            std::vector<float> weights = n.getWeights();

            // Get the weight from 1 neuron since all should be same for a initialized layer
            float weight = weights[0];
            float bias = n.getBias();

            // Using require that and withinRel too check floating point numbers.
            if (i == 0) {
                SECTION("Input Neurons") {
                    REQUIRE(weights.size() == 1);
                }
            } else {
                SECTION("Hidden and output Neurons") {
                    REQUIRE(weights.size() == layers[i - 1]);
                }
            }
```

```
        }
    }
}

TEST_CASE("AND neural Network", "[NeuronNetwork][AND]")
{
    NeuronNetwork nn({2, 1});
    int inputSize = 2;
    int targetSize = 1;

    std::vector<std::vector<float» inputs = {
        {0.0f, 0.0f},
        {0.0f, 1.0f},
        {1.0f, 0.0f},
        {1.0f, 1.0f}
    };
    std::vector<std::vector<float» targets = {
        {0.0f},
        {0.0f},
        {0.0f},
        {1.0f}
    };

    MEASURE_BLOCK("Training the network AND", {
        nn.trainInputs2D(inputs, targets, 10000);
    });

    // Check if the network can predict the correct output
    for (int i = 0; i < targets.size(); i++)
    {

        std::vector<float> prediction = nn.predict(inputs[i]);

        printf("For input ");
        printVector(inputs[i], " Prediction ");
        printVector(prediction, "\n");

        if (i == 3) { // Checks for 1 1
            CHECK_THAT(prediction[0], WithinAbs(1.0f, 0.05f));
        } else { // Checks for 0 0, 0 1, 1 0
            CHECK_THAT(prediction[0], WithinAbs(0.0f, 0.05f));
        }
    }
}

TEST_CASE("XOR Neural Network", "[NeuronNetwork][XOR]")
{
    NeuronNetwork nn({2, 2, 1});
    int inputSize = 2;
    int targetSize = 1;

    std::vector<std::vector<float» inputs = {
        {0.0f, 0.0f},
        {0.0f, 1.0f},
        {1.0f, 0.0f},
        {1.0f, 1.0f}
    };
    std::vector<std::vector<float» targets = {
        {0.0f},
        {1.0f},
        {1.0f},
        {0.0f}
    };

    MEASURE_BLOCK("Training the network XOR", {
        nn.trainInputs2D(inputs, targets, 10000);
    });

    for (int i = 0; i < targets.size(); i++)
    {
        std::vector<float> prediction = nn.predict(inputs[i]);

        printf("For input ");
        printVector(inputs[i], " Prediction ");
        printVector(prediction, "\n");

        // Check if the network can predict the correct output
        if (i == 1 || i == 2) { // Checks for 0 1, 1 0
            CHECK_THAT(prediction[0], WithinAbs(1.0f, 0.05f));
        } else { // Checks for 0 0, 1 1
            CHECK_THAT(prediction[0], WithinAbs(0.0f, 0.05f));
        }
    }
}

TEST_CASE("Half adder Neuron Network", "[NeuronNetwork][HalfAdder]")
{
```

```
    NeuronNetwork nn({2, 3, 2});
    int inputSize = 2;
    int targetSize = 2;

    std::vector<std::vector<float» inputs = {
        {0.0f, 0.0f},
        {1.0f, 0.0f},
        {0.0f, 1.0f},
        {1.0f, 1.0f}
    };
    std::vector<std::vector<float» targets = {
        {0.0f, 0.0f},
        {1.0f, 0.0f},
        {1.0f, 0.0f},
        {0.0f, 1.0f}
    };

    MEASURE_BLOCK("Training the network Half Adder", {
        nn.trainInputs2D(inputs, targets, 10000);
    });

    for (int i = 0; i < targets.size(); i++)
    {
        std::vector<float> prediction = nn.predict(inputs[i]);

        printf("For input ");
        printVector(inputs[i], " Prediction ");
        printVector(prediction, "\n");

        // Check if the network can predict the correct output
        if (i == 1 || i == 2) { // Checks for 0 1, 1 0
            CHECK_THAT(prediction[0], WithinAbs(1.0f, 0.05f));
        } else { // Checks for 0 0, 1 1
            CHECK_THAT(prediction[0], WithinAbs(0.0f, 0.05f));
        }
    }
}

TEST_CASE("NeuronNetwork Learning Iris dataset", "[backpropagation][Iris]") {
    //
================================================================================================
    // Load the iris dataset
    //
================================================================================================

    // Read the iris data set
    std::vector<std::vector<std::string» data = readCsv("../../data/iris.csv");

    // Extract the features and targets
    std::vector<std::vector<float» features = getFeatures(data);
    std::vector<float>              targets  = getTargets(data);

    // We expect 150 examples where each image consists of 4 integer values.
    int inputSize = 4;
    int outputSize = 3;
    // len of features and targets should be the same

    // Define a network architecture: an input layer of 4 neurons,
    // one hidden layer of 16 neurons, and an output layer of 3 neurons.
    std::vector<int> layers = { inputSize, 4, outputSize };
    std::vector<float> outputMask = {0.0f, 1.0f, 2.0f};

    // Mask the targets
    std::vector<float> maskedData = maskData(targets, outputMask);
    std::vector<std::vector<float» targetMaskedData = create2DVector(maskedData, outputSize);

    // Create training and test split
    normalize2DVector(features);

    // Train and test split
    TrainTestSplit tts(features, targetMaskedData, 0.90);

    //
================================================================================================
    // Train the network
    //
================================================================================================

    NeuronNetwork nn(layers);

    printf("vector size %zu\n", tts.trainFeatures.size());

    MEASURE_BLOCK("Training the network", {
        nn.trainInputs2D(tts.trainFeatures, tts.trainTargets, 2000);
    });

    nn.trainInputs2D(tts.trainFeatures, tts.trainTargets,  5000);
```

```

    // Print the output mask for the network
    printf("\nOutputMask \t ");
    printVector(outputMask, "\n");

    SECTION("Testing test set") {
        for (std::size_t i = 0; i < tts.testFeatures.size(); i++) {
            std::vector<float> input = tts.testFeatures[i];
            std::vector<float> target = tts.testTargets[i];
            std::vector<float> prediction = nn.feedForward(input);
            printVector(input, " | ");
            printVector(prediction, "\n");
            for (std::size_t j = 0; j < prediction.size(); j++) {
                if (target[j] > 0.95f) { // Check if the target is 1
                    CHECK_THAT(prediction[j], WithinAbs(1.0f, 0.1f));
                } else {
                    CHECK_THAT(prediction[j], WithinAbs(0.0f, 0.1f));
                }
            }
        }
    }

    SECTION("Testing Random predictions") {
        // Randomly select nToCheck images and check if the network can classify them
        int nToCheck = 20;
        std::random_device rd;
        std::mt19937 gen(rd());
        int min = 0, max = tts.testTargets.size() -1;
        std::uniform_int_distribution<> dist(min, max);


        for (int i = 0; i < nToCheck; i++) {
            int randomIndex = dist(gen);
            std::vector<float> input = tts.trainFeatures[randomIndex];
            std::vector<float> target = tts.trainTargets[randomIndex];
            std::vector<float> prediction = nn.feedForward(input);

            printVector(target, "| ");
            printVector(prediction, "\n");

            for (std::size_t j = 0; j < prediction.size(); j++) {
                if (target[j] > 0.95f) { // Check if the target is 1
                    CHECK_THAT(1.0f, WithinAbs(prediction[j], 0.1f));
                } else {
                    CHECK_THAT(0.0f, WithinAbs(prediction[j], 0.1f));
                }
            }
        }
    }
}

TEST_CASE("NeuronNetwork Learning digit data", "[backpropagation]") {
    //
================================================================================================
    // Load the digit dataset
    //
================================================================================================

    // Load the digit dataset
    digitData digits = readDigitData<float>();

    // We expect 1797 examples where each image consists of 64 integer values.
    int numData = digits.targets.size();
    int inputSize = 64;
    int outputSize = 10;

    // Define a network architecture: an input layer of 64 neurons,
    // one hidden layer of 16 neurons, and an output layer of 10 neurons.
    std::vector<int> layers = { inputSize, 16, outputSize };
    std::vector<float> outputMask = {0.0f, 1.0f, 2.0f, 3.0f, 4.0f, 5.0f, 6.0f, 7.0f, 8.0f, 9.0f};

    // Mask the targets
    std::vector<float> maskedData = maskData(digits.targets, outputMask);

    // Create 2D vectors for the target and input data
    std::vector<std::vector<float» targetMaskedData = create2DVector(maskedData, outputSize);
    std::vector<std::vector<float» imagesMaskedData = create2DVector(digits.images, inputSize);
    normalize2DVector(imagesMaskedData);

    // Train and test split
    TrainTestSplit tts(imagesMaskedData, targetMaskedData, 0.90);

    //
================================================================================================
    // Train the network
    //
================================================================================================
```

```
    NeuronNetwork nn(layers);

    printf("vector size for test features %zu\n", tts.testFeatures.size());

    MEASURE_BLOCK("Training the network", {
        nn.trainInputs2D(tts.trainFeatures, tts.trainTargets, 2000);
    });

    nn.trainInputs2D(tts.trainFeatures, tts.trainTargets,  5000);

    // Number of features to check
    SECTION("Testing test set") {
        printf("Testing the test split for digit dataset\n");
        for (std::size_t i = 0; i < tts.testFeatures.size(); i++) {
            std::vector<float> input = tts.testFeatures[i];
            std::vector<float> target = tts.testTargets[i];
            std::vector<float> prediction = nn.feedForward(input);
            printVector(target, " | ");
            printVector(prediction, "\n");

            for (std::size_t j = 0; j < prediction.size(); j++) {
                if (target[j] > 0.95f) { // Check if the target is 1
                    CHECK_THAT(prediction[j], WithinAbs(1.0f, 0.1f));
                } else {
                    CHECK_THAT(prediction[j], WithinAbs(0.0f, 0.1f));
                }
            }
        }
    }

    SECTION("Testing random predictions") {
        printf("Testing random predictions for digit dataset\n");
        // Randomly select nToCheck images and check if the network can classify them
        int nToCheck = 20;
        std::random_device rd;
        std::mt19937 gen(rd());
        int min = 0, max = tts.testTargets.size() -1;
        std::uniform_int_distribution<> dist(min, max);

        // Print the output mask for the network
        printf("\nOutputMask \t\t     ");
        printVector(outputMask, "\n");

        for (int i = 0; i < nToCheck; i++) {
            int randomIndex = dist(gen);

            std::vector<float> input = tts.trainFeatures[randomIndex];
            std::vector<float> target = tts.trainTargets[randomIndex];
            float targetValue = digits.targets[randomIndex];

            // Predict the output
            std::vector<float> prediction = nn.feedForward(input);

            // Print the predictions
            printf("Prediction for target %.2f | ", targetValue);
            printVector(prediction, "\n");

            // Find the target in the target mask
            int targetIndex = static_cast<int>(targetValue);

            // NOTE: The prediction is a probability, it can be false.
            CHECK_THAT(1.0f, WithinRel(prediction[targetIndex], 0.1f));
        }
    }
}
```