

# NeuraNet

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## Introduction

NeuraNet is a C library providing structures and functions to implement a neural network.

The neural network implemented in NeuraNet consists of a layer of input values, a layer of output values, a layer of hidden values, a set of generic base functions and a set of links. Each base function has 3 parameters (detailed

below) and each link has 3 parameters: the base function index and the indices of input and output values. A NeuraNet is defined by the parameters' values of its generic base functions and links, and the number of input, output and hidden values.

The evaluation of the NeuraNet consists of taking each link, ordered on index of values, and apply the generic base function on the first value and store the result in the second value. If several links has the same second value index, the sum value of all these links is used. However if several links have same input and output values, the outputs of these links are multiplied instead of added (before being eventually added to other links having same output value but different input value).

The generic base functions is a linear function. However by using several links with same input and output values it is possible to simulate any polynomial function. Also, there is no concept of layer inside hidden values, but the input value index is constrained to be lower than the output one. So, the links can be arranged to form layers of subset of hidden values, while still allowing any other type of arrangement inside hidden values. Also, a link can be inactivated by setting its base function index to -1. Finally, the parameters of the base function and the hidden values are constrained to  $[-1.0, 1.0]$ .

NeuraNet provides functions to easily use the library GenAlg to search the values of base functions and links' parameters. An example is given in the unit tests (see below). It also provides functions to save and load the neural network (in JSON format).

NeuraNet has been validated on the Iris data set.

It uses the `PBErr` library.

## 1 Definitions

The generic base function is defined as follow:

$$B(x) = [\tan(1.57079 * b_0)(x + b_1) + b_2] \quad (1)$$

where  $\{b_0, b_1, b_2\} \in [-1.0, 1.0]^3$  are the parameters of the base function and  $x \in \mathbb{R}$  and  $B(x) \in \mathbb{R}$ .

## 2 Interface

```
// ===== NEURANET.H =====

#ifndef NEURANET_H
#define NEURANET_H

// ===== Include =====

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include <stdbool.h>
#include "pberr.h"
#include "pbmath.h"
#include "gset.h"

// ---- NeuraNetBaseFun

// ===== Define =====

#define NN_THETA 1.57079

// ===== Functions declaration =====

// Generic base function for the NeuraNet
// 'param' is an array of NN_NBPARAMBASE float all in [-1,1]
// 'x' is the input value, in [-1,1]
// NNBaseFun(param,x)=
// {tan(param[0]*NN_THETA)*(x+param[1])+param[2]}[-1,1]
// The generic base function returns a value in [-1,1]
#if BUILDMODE != 0
inline
#endif
float NNBaseFun(const float* const param, const float x);

// ---- NeuraNet

// ===== Define =====

#define NN_NBPARAMBASE 3
#define NN_NBPARAMLINK 3

// ===== Data structure =====

typedef struct NeuraNet {
    // Nb of input values
    const int _nbInputVal;
    // Nb of output values
    const int _nbOutputVal;
    // Nb max of hidden values
    const int _nbMaxHidVal;
    // Nb max of base functions
    const int _nbMaxBases;
    // Nb max of links
    const int _nbMaxLinks;
    // VecFloat describing the base functions
    // NN_NBPARAMBASE values per base function
    VecFloat* _bases;
    // VecShort describing the links
```

```

// NN_NBPARAMLINK values per link (base id, input id, output id)
// if (base id equals -1 the link is inactive)
VecShort* _links;
// Hidden values
VecFloat* _hidVal;
// Nb bases used for convolution
const int _nbBasesConv;
// Nb bases per cell used for convolution
const int _nbBasesCellConv;
} NeuraNet;

// ===== Functions declaration =====

// Create a new NeuraNet with 'nbInput' input values, 'nbOutput'
// output values, 'nbMaxHidden' hidden values, 'nbMaxBases' base
// functions, 'nbMaxLinks' links
NeuraNet* NeuraNetCreate(const int nbInput, const int nbOutput,
    const int nbMaxHidden, const int nbMaxBases, const int nbMaxLinks);

// Free the memory used by the NeuraNet 'that'
void NeuraNetFree(NeuraNet** that);

// Create a new NeuraNet with 'nbInput' input values, 'nbOutput'
// output values and a set of hidden layers described by
// 'hiddenLayers' as follow:
// The dimension of 'hiddenLayers' is the number of hidden layers
// and each component of 'hiddenLayers' is the number of hidden value
// in the corresponding hidden layer
// For example, <3,4> means 2 hidden layers, the first one with 3
// hidden values and the second one with 4 hidden values
// If 'hiddenValues' is null it means there is no hidden layers
// Then, links are automatically added between each input values
// toward each hidden values in the first hidden layer, then from each
// hidden values of the first hidden layer to each hidden value of the
// 2nd hidden layer and so on until each values of the output
NeuraNet* NeuraNetCreateFullyConnected(const int nbIn, const int nbOut,
    const VecShort* const hiddenLayers);

// Create a NeuraNet using convolution
// The input's dimension is equal to the dimension of 'dimIn', for
// example if dimIn==<2,3> the input is a 2D array of width 2 and
// height 3, input values are expected ordered by lines
// The NeuraNet has 'nbOutput' outputs
// The dimension of each convolution cells is 'dimCell'
// The maximum number of convolution (in depth) is 'depthConv'
// Each convolution layer has 'thickConv' convolutions in parallel
// The outputs are fully connected to the last layer of convolution cells
// For example, if the input is a 2D array of 4 cols and 3 rows, 2
// outputs, 2x2 convolution cell, convolution depth of 2, and
// convolution thickness of 2:
// index of values from input layer to ouput layer
// 00,01,02,03,
// 04,05,06,07,
// 08,09,10,11
//
// 12,13,14, 18,19,20,
// 15,16,17, 21,22,23,
//
// 24,25 26,27
//
// 28,29
//

```

```

// nbInput: 12
// nbOutput: 2
// nbHidden: 16
// nbMaxBases: 24
// nbMaxLinks: 72
// links:
// 0,0,12, 4,0,18, 1,1,12, 0,1,13, 5,1,18, 4,1,19, 1,2,13, 0,2,14,
// 5,2,19, 4,2,20, 1,3,14, 5,3,20, 2,4,12, 0,4,15, 6,4,18, 4,4,21,
// 3,5,12, 2,5,13, 1,5,15, 0,5,16, 7,5,18, 6,5,19, 5,5,21, 4,5,22,
// 3,6,13, 2,6,14, 1,6,16, 0,6,17, 7,6,19, 6,6,20, 5,6,22, 4,6,23,
// 3,7,14, 1,7,17, 7,7,20, 5,7,23, 2,8,15, 6,8,21, 3,9,15, 2,9,16,
// 7,9,21, 6,9,22, 3,10,16, 2,10,17, 7,10,22, 6,10,23, 3,11,17,
// 7,11,23, 8,12,24, 9,13,24, 8,13,25, 9,14,25, 10,15,24, 11,16,24,
// 10,16,25, 11,17,25, 12,18,26, 13,19,26, 12,19,27, 13,20,27,
// 14,21,26, 15,22,26, 14,22,27, 15,23,27, 16,24,28, 17,24,29,
// 18,25,28, 19,25,29, 20,26,28, 21,26,29, 22,27,28, 23,27,29
NeuraNet* NeuraNetCreateConvolution(const VecShort* const dimIn,
    const int nbOutput, const VecShort* const dimCell,
    const int depthConv, const int thickConv);

// Get the nb of input values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbInput(const NeuraNet* const that);

// Get the nb of output values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbOutput(const NeuraNet* const that);

// Get the nb max of hidden values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxHidden(const NeuraNet* const that);

// Get the nb max of base functions of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxBases(const NeuraNet* const that);

// Get the nb of base functions for convolution of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbBasesConv(const NeuraNet* const that);

// Get the nb of base functions per cell for convolution of
// the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbBasesCellConv(const NeuraNet* const that);

// Get the nb max of links of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxLinks(const NeuraNet* const that);

```

```

// Get the parameters of the base functions of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* NNBases(const NeuraNet* const that);

// Get the links description of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
const VecShort* NNLinks(const NeuraNet* const that);

// Get the hidden values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* NNHiddenValues(const NeuraNet* const that);

// Get the 'iVal'-th hidden value of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
float NNGetHiddenValue(const NeuraNet* const that, const int iVal);

// Set the parameters of the base functions of the NeuraNet 'that' to
// a copy of 'bases'
// 'bases' must be of dimension that->nbMaxBases * NN_NBPARAMBASE
// each base is defined as param[3] in [-1,1]
// tan(param[0]*NN_THETA)*(x+param[1])+param[2]
#if BUILDMODE != 0
inline
#endif
void NNSetBases(NeuraNet* const that, const VecFloat* const bases);

// Set the 'iBase'-th parameter of the base functions of the NeuraNet
// 'that' to 'base'
#if BUILDMODE != 0
inline
#endif
void NNBasesSet(NeuraNet* const that, const int iBase, const float base);

// Set the links description of the NeuraNet 'that' to a copy of 'links'
// Links with a base function equals to -1 are ignored
// If the input id is higher than the output id they are swap
// The links description in the NeuraNet are ordered in increasing
// value of input id and output id, but 'links' doesn't have to be
// sorted
// Each link is defined by (base index, input index, output index)
// If base index equals -1 it means the link is inactive
void NNSetLinks(NeuraNet* const that, VecShort* const links);

// Calculate the output values for the input values 'input' for the
// NeuraNet 'that' and memorize the result in 'output'
// input values in [-1,1] and output values in [-1,1]
// All values of 'output' are set to 0.0 before evaluating
// Links which refer to values out of bounds of 'input' or 'output'
// are ignored
void NNEval(const NeuraNet* const that, const VecFloat* const input, VecFloat* const output);

// Function which return the JSON encoding of 'that'
JSONNode* NNEncodeAsJSON(const NeuraNet* const that);

```

```

// Function which decode from JSON encoding 'json' to 'that'
bool NNDecodeAsJSON(NeuraNet** that, const JSONNode* const json);

// Save the NeuraNet 'that' to the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if the NeuraNet could be saved, false else
bool NNSave(const NeuraNet* const that, FILE* const stream, const bool compact);

// Load the NeuraNet 'that' from the stream 'stream'
// If 'that' is not null the memory is first freed
// Return true if the NeuraNet could be loaded, false else
bool NNLoad(NeuraNet** that, FILE* const stream);

// Print the NeuraNet 'that' to the stream 'stream'
void NNPrintln(const NeuraNet* const that, FILE* const stream);

// ===== Interface with library GenAlg =====
// To use the following functions the user must include the header
// 'genalg.h' before the header 'neuranet.h'

#ifndef GENALG_H

// Get the length of the adn of float values to be used in the GenAlg
// library for the NeuraNet 'that'
static int NNGetGAAdnFloatLength(const NeuraNet* const that)
    __attribute__((unused));
static int NNGetGAAdnFloatLength(const NeuraNet* const that) {
    if (BUILDMODE == 0
        if (that == NULL) {
            NeuraNetErr->_type = PBErrTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'that' is null");
            PBErrCatch(NeuraNetErr);
        }
        return NNGetNbMaxBases(that) * NN_NBPARAMBASE;
    }

// Get the length of the adn of int values to be used in the GenAlg
// library for the NeuraNet 'that'
static int NNGetGAAdnIntLength(const NeuraNet* const that)
    __attribute__((unused));
static int NNGetGAAdnIntLength(const NeuraNet* const that) {
    if (BUILDMODE == 0
        if (that == NULL) {
            NeuraNetErr->_type = PBErrTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'that' is null");
            PBErrCatch(NeuraNetErr);
        }
        return NNGetNbMaxLinks(that) * NN_NBPARAMLINK;
    }

// Set the bounds of the GenAlg 'ga' to be used for bases parameters of
// the NeuraNet 'that'
static void NNSetGABoundsBases(const NeuraNet* const that, GenAlg* const ga)
    __attribute__((unused));
static void NNSetGABoundsBases(const NeuraNet* const that, GenAlg* const ga) {
    if (BUILDMODE == 0
        if (that == NULL) {
            NeuraNetErr->_type = PBErrTypeNullPointer;

```

```

        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErCatch(NeuraNetErr);
    }
    if (ga == NULL) {
        NeuraNetErr->_type = PBErTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'ga' is null");
        PBErCatch(NeuraNetErr);
    }
    if (GAGetLengthAdnFloat(ga) != NNGetGAAdnFloatLength(that)) {
        NeuraNetErr->_type = PBErTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'ga' 's float genes dimension doesn't\
matches 'that' 's max nb of bases (%d==%d)",
        GAGetLengthAdnFloat(ga), NNGetGAAdnFloatLength(that));
        PBErCatch(NeuraNetErr);
    }
}
#endif
// Declare a vector to memorize the bounds
VecFloat2D bounds = VecFloatCreateStatic2D();
// Init the bounds
VecSet(&bounds, 0, -1.0); VecSet(&bounds, 1, 1.0);
// For each gene
for (int iGene = NNGetGAAdnFloatLength(that); iGene--;)
    // Set the bounds
    GASetBoundsAdnFloat(ga, iGene, &bounds);
}

// Set the bounds of the GenAlg 'ga' to be used for links description of
// the NeuraNet 'that'
static void NNSetGABoundsLinks(const NeuraNet* const that, GenAlg* const ga)
    __attribute__((unused));
static void NNSetGABoundsLinks(const NeuraNet* const that, GenAlg* const ga) {
    #if BUILDMODE == 0
        if (that == NULL) {
            NeuraNetErr->_type = PBErTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'that' is null");
            PBErCatch(NeuraNetErr);
        }
        if (ga == NULL) {
            NeuraNetErr->_type = PBErTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'ga' is null");
            PBErCatch(NeuraNetErr);
        }
        if (GAGetLengthAdnInt(ga) != NNGetGAAdnIntLength(that)) {
            NeuraNetErr->_type = PBErTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'ga' 's int genes dimension doesn't\
matches 'that' 's max nb of links (%d==%d)",
            GAGetLengthAdnInt(ga), NNGetGAAdnIntLength(that));
            PBErCatch(NeuraNetErr);
        }
    }
}
#endif
// Declare a vector to memorize the bounds
VecShort2D bounds = VecShortCreateStatic2D();
// For each gene
for (int iGene = 0; iGene < NNGetGAAdnIntLength(that);
    iGene += NN_NBPARAMLINK) {
    // Set the bounds for base id
    VecSet(&bounds, 0, -1);
    VecSet(&bounds, 1, NNGetNbMaxBases(that) - 1);
    GASetBoundsAdnInt(ga, iGene, &bounds);
    // Set the bounds for input value
    VecSet(&bounds, 0, 0);
    VecSet(&bounds, 1, NNGetNbInput(that) + NNGetNbMaxHidden(that) - 1);
}

```



```

        GASetBoundsAdnInt(ga, iGene + 1, &bounds);
        // Set the bounds for input value
        VecSet(&bounds, 0, NNGetNbInput(that));
        VecSet(&bounds, 1, NNGetNbInput(that) + NNGetNbMaxHidden(that) +
            NNGetNbOutput(that) - 1);
        GASetBoundsAdnInt(ga, iGene + 2, &bounds);
    }
}

#endif

// ====== Inliner ======

#if BUILDMODE != 0
#include "neuranet-inline.c"
#endif

#endif

```

## 3 Code

### 3.1 pbmath.c

```

// ====== NEURANET.C ======

// ====== Include ======

#include "neuranet.h"
#if BUILDMODE == 0
#include "neuranet-inline.c"
#endif

// ----- NeuraNet

// ====== Functions implementation ======

// Create a new NeuraNet with 'nbInput' input values, 'nbOutput'
// output values, 'nbMaxHidden' hidden values, 'nbMaxBases' base
// functions, 'nbMaxLinks' links
NeuraNet* NeuraNetCreate(const int nbInput, const int nbOutput,
    const int nbMaxHidden, const int nbMaxBases, const int nbMaxLinks) {
    #if BUILDMODE == 0
        if (nbInput <= 0) {
            NeuraNetErr->_type = PBErrTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'nbInput' is invalid (0<=%d)", nbInput);
            PBErrCatch(NeuraNetErr);
        }
        if (nbOutput <= 0) {
            NeuraNetErr->_type = PBErrTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'nbOutput' is invalid (0<=%d)", nbOutput);
            PBErrCatch(NeuraNetErr);
        }
        if (nbMaxHidden < 0) {
            NeuraNetErr->_type = PBErrTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'nbMaxHidden' is invalid (0<=%d)",
                nbMaxHidden);
            PBErrCatch(NeuraNetErr);
        }
    #endif
}

```

```

}
if (nbMaxBases <= 0) {
    NeuraNetErr->_type = PBErrTypeInvalidArg;
    sprintf(NeuraNetErr->_msg, "'nbMaxBases' is invalid (0<%d)",
        nbMaxBases);
    PBErrCatch(NeuraNetErr);
}
if (nbMaxLinks <= 0) {
    NeuraNetErr->_type = PBErrTypeInvalidArg;
    sprintf(NeuraNetErr->_msg, "'nbMaxLinks' is invalid (0<%d)",
        nbMaxLinks);
    PBErrCatch(NeuraNetErr);
}
#endif
// Declare the new NeuraNet
NeuraNet* that = PBErrMalloc(NeuraNetErr, sizeof(NeuraNet));
// Set properties
*(int*)&(that->_nbInputVal) = nbInput;
*(int*)&(that->_nbOutputVal) = nbOutput;
*(int*)&(that->_nbMaxHidVal) = nbMaxHidden;
*(int*)&(that->_nbMaxBases) = nbMaxBases;
*(int*)&(that->_nbMaxLinks) = nbMaxLinks;
*(int*)&(that->_nbBasesConv) = 0;
*(int*)&(that->_nbBasesCellConv) = 0;
that->_bases = VecFloatCreate(nbMaxBases * NN_NBPARAMBASE);
that->_links = VecShortCreate(nbMaxLinks * NN_NBPARAMLINK);
if (nbMaxHidden > 0)
    that->_hidVal = VecFloatCreate(nbMaxHidden);
else
    that->_hidVal = NULL;
// Return the new NeuraNet
return that;
}

// Free the memory used by the NeuraNet 'that'
void NeuraNetFree(NeuraNet** that) {
    // Check argument
    if (that == NULL || *that == NULL)
        // Nothing to do
        return;
    // Free memory
    VecFree(&((*that)->_bases));
    VecFree(&((*that)->_links));
    VecFree(&((*that)->_hidVal));
    free(*that);
    *that = NULL;
}

// Create a new NeuraNet with 'nbIn' innput values, 'nbOut'
// output values and a set of hidden layers described by
// 'hiddenLayers' as follow:
// The dimension of 'hiddenLayers' is the number of hidden layers
// and each component of 'hiddenLayers' is the number of hidden value
// in the corresponding hidden layer
// For example, <3,4> means 2 hidden layers, the first one with 3
// hidden values and the second one with 4 hidden values
// If 'hiddenValues' is null it means there is no hidden layers
// Then, links are automatically added between each input values
// toward each hidden values in the first hidden layer, then from each
// hidden values of the first hidden layer to each hidden value of the
// 2nd hidden layer and so on until each values of the output
NeuraNet* NeuraNetCreateFullyConnected(const int nbIn, const int nbOut,

```

```

    const VecShort* const hiddenLayers) {
#ifdef BUILDMODE == 0
    if (nbIn <= 0) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'nbInput' is invalid (0<%d)", nbIn);
        PBErrCatch(NeuraNetErr);
    }
    if (nbOut <= 0) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'nbOutput' is invalid (0<%d)", nbOut);
        PBErrCatch(NeuraNetErr);
    }
#endif
    // Declare variable to memorize the number of links, bases
    // and hidden values
    int nbHiddenVal = 0;
    int nbBases = 0;
    int nbLinks = 0;
    int nbHiddenLayer = 0;
    // If there are hidden layers
    if (hiddenLayers != NULL) {
        // Get the number of hidden layers
        nbHiddenLayer = VecGetDim(hiddenLayers);
        // Declare two variables for computation
        int nIn = nbIn;
        int nOut = 0;
        // Calculate the nb of links and hidden values
        for (int iLayer = 0; iLayer < nbHiddenLayer; ++iLayer) {
            nOut = VecGet(hiddenLayers, iLayer);
            nbHiddenVal += nOut;
            nbLinks += nIn * nOut;
            nIn = nOut;
        }
        nbLinks += nIn * nbOut;
    }
    // Else, there is no hidden layers
    } else {
        // Set the number of links
        nbLinks = nbIn * nbOut;
    }
    // There is one base function per link
    nbBases = nbLinks;
    // Create the NeuraNet
    NeuraNet* nn =
        NeuraNetCreate(nbIn, nbOut, nbHiddenVal, nbBases, nbLinks);
    // Declare a variable to memorize the index of the link
    int iLink = 0;
    // Declare variables for computation
    int shiftIn = 0;
    int shiftOut = nbIn;
    int nIn = nbIn;
    int nOut = 0;
    // Loop on hidden layers
    for (int iLayer = 0; iLayer <= nbHiddenLayer; ++iLayer) {
        // Init the links
        if (iLayer < nbHiddenLayer)
            nOut = VecGet(hiddenLayers, iLayer);
        else
            nOut = nbOut;
        for (int iIn = 0; iIn < nIn; ++iIn) {
            for (int iOut = 0; iOut < nOut; ++iOut) {
                int jLink = NN_NBPARAMLINK * iLink;
                VecSet(nn->_links, jLink, iLink);
            }
        }
    }
}

```

```

        VecSet(nn->_links, jLink + 1, iIn + shiftIn);
        VecSet(nn->_links, jLink + 2, iOut + shiftOut);
        ++iLink;
    }
}
shiftIn = shiftOut;
shiftOut += nOut;
nIn = nOut;
}
// Return the new NeuraNet
return nn;
}

// Create a NeuraNet using convolution
// The input's dimension is equal to the dimension of 'dimIn', for
// example if dimIn==<2,3> the input is a 2D array of width 2 and
// height 3, input values are expected ordered by lines
// The NeuraNet has 'nbOutput' outputs
// The dimension of each convolution cells is 'dimCell'
// The maximum number of convolution (in depth) is 'depthConv'
// Each convolution layer has 'thickConv' convolutions in parallel
// The outputs are fully connected to the last layer of convolution cells
// For example, if the input is a 2D array of 4 cols and 3 rows, 2
// outputs, 2x2 convolution cell, convolution depth of 2, and
// convolution thickness of 2:
// index of values from input layer to ouput layer
// 00,01,02,03,
// 04,05,06,07,
// 08,09,10,11
//
// 12,13,14, 18,19,20,
// 15,16,17, 21,22,23,
//
// 24,25 26,27
//
// 28,29
//
// nbInput: 12
// nbOutput: 2
// nbHidden: 16
// nbMaxBases: 24
// nbMaxLinks: 72
// links:
// 0,0,12, 4,0,18, 1,1,12, 0,1,13, 5,1,18, 4,1,19, 1,2,13, 0,2,14,
// 5,2,19, 4,2,20, 1,3,14, 5,3,20, 2,4,12, 0,4,15, 6,4,18, 4,4,21,
// 3,5,12, 2,5,13, 1,5,15, 0,5,16, 7,5,18, 6,5,19, 5,5,21, 4,5,22,
// 3,6,13, 2,6,14, 1,6,16, 0,6,17, 7,6,19, 6,6,20, 5,6,22, 4,6,23,
// 3,7,14, 1,7,17, 7,7,20, 5,7,23, 2,8,15, 6,8,21, 3,9,15, 2,9,16,
// 7,9,21, 6,9,22, 3,10,16, 2,10,17, 7,10,22, 6,10,23, 3,11,17,
// 7,11,23, 8,12,24, 9,13,24, 8,13,25, 9,14,25, 10,15,24, 11,16,24,
// 10,16,25, 11,17,25, 12,18,26, 13,19,26, 12,19,27, 13,20,27,
// 14,21,26, 15,22,26, 14,22,27, 15,23,27, 16,24,28, 17,24,29,
// 18,25,28, 19,25,29, 20,26,28, 21,26,29, 22,27,28, 23,27,29
NeuraNet* NeuraNetCreateConvolution(const VecShort* const dimIn,
    const int nbOutput, const VecShort* const dimCell,
    const int depthConv, const int thickConv) {
#if BUILDMODE == 0
    if (dimIn == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'dimIn' is null");
        PBErrCatch(NeuraNetErr);
    }
}

```

```

for (int iDim = VecGetDim(dimIn); iDim--;)
    if (VecGet(dimIn, iDim) <= 0) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'dimIn' %dth dim is invalid (%d>0)",
            iDim, VecGet(dimIn, iDim));
        PBErrCatch(NeuraNetErr);
    }
if (nbOutput <= 0) {
    NeuraNetErr->_type = PBErrTypeInvalidArg;
    sprintf(NeuraNetErr->_msg, "'nbOutput' is invalid (0<=%d)", nbOutput);
    PBErrCatch(NeuraNetErr);
}
if (dimCell == NULL) {
    NeuraNetErr->_type = PBErrTypeNullPointer;
    sprintf(NeuraNetErr->_msg, "'dimCell' is null");
    PBErrCatch(NeuraNetErr);
}
if (VecGetDim(dimCell) != VecGetDim(dimIn)) {
    NeuraNetErr->_type = PBErrTypeNullPointer;
    sprintf(NeuraNetErr->_msg, "'dimCell' 's dim is invalid (%d==%d)",
        VecGetDim(dimCell), VecGetDim(dimIn));
    PBErrCatch(NeuraNetErr);
}
for (int iDim = VecGetDim(dimCell); iDim--;)
    if (VecGet(dimCell, iDim) <= 0) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'dimCell' %dth dim is invalid (%d>0)",
            iDim, VecGet(dimCell, iDim));
        PBErrCatch(NeuraNetErr);
    }
if (depthConv < 0) {
    NeuraNetErr->_type = PBErrTypeInvalidArg;
    sprintf(NeuraNetErr->_msg, "'depthConv' is invalid (0<=%d)",
        depthConv);
    PBErrCatch(NeuraNetErr);
}
#endif
// Declare a variable to memorize the nb of input, hidden values,
// bases and links
int nbIn = 0;
int nbHiddenVal = 0;
int nbBases = 0;
int nbLinks = 0;
// Calculate the number of inputs
nbIn = 1;
for (int iDim = VecGetDim(dimIn); iDim--;)
    nbIn *= VecGet(dimIn, iDim);
// Calculate the number of bases, links and hidden values
// Declare a variable to memorize the number of links per cell
int nbLinkPerCell = 1;
for (int iDim = VecGetDim(dimCell); iDim--;)
    nbLinkPerCell *= VecGet(dimCell, iDim);
// Declare a variable to memorize the position of the convolution
// cell in the current convolution layer
VecShort* pos = VecShortCreate(VecGetDim(dimIn));
// Declare a variable to memorize the position in the convolution cell
VecShort* posCell = VecShortCreate(VecGetDim(dimIn));
// Declare variables to memorize the dimension and size of the input
// layer at current convolution level
VecShort* curDimIn = VecClone(dimIn);
int sizeLayerIn = 1;
for (int iDim = VecGetDim(curDimIn); iDim--;) {

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```

    sizeLayerIn *= VecGet(curDimIn, iDim);
}
// Declare variables to memorize the dimension and size of the
// output layer at current convolution level
VecShort* curDimOut = VecClone(curDimIn);
int sizeLayerOut = 1;
for (int iDim = VecGetDim(curDimOut); iDim--;) {
    VecSetAdd(curDimOut, iDim, -1 * VecGet(dimCell, iDim) + 1);
    sizeLayerOut *= VecGet(curDimOut, iDim);
}
// Loop on convolution levels
for (int iConv = 0; iConv < depthConv; ++iConv) {
    // Update the number of bases
    nbBases += nbLinkPerCell;
    // Update the number of hidden values
    nbHiddenVal += sizeLayerOut;
    // Update the number of links
    nbLinks += sizeLayerOut * nbLinkPerCell;
    // If we are not a the last convolution level
    if (iConv < depthConv - 1) {
        // Update input and output dimensions at next convolution level
        VecCopy(curDimIn, curDimOut);
        sizeLayerIn = sizeLayerOut;
        sizeLayerOut = 1;
        for (int iDim = VecGetDim(curDimOut); iDim--;) {
            VecSetAdd(curDimOut, iDim, -1 * VecGet(dimCell, iDim) + 1);
            sizeLayerOut *= VecGet(curDimOut, iDim);
        }
    }
}
// Multiply by the number of convolution in parallel
nbHiddenVal *= thickConv;
nbBases *= thickConv;
nbLinks *= thickConv;
int nbBasesConv = nbBases;
// Add the links and bases for the fully connected layer toward output
nbBases += sizeLayerOut * thickConv * nbOutput;
nbLinks += sizeLayerOut * thickConv * nbOutput;
// Create the NeuraNet
NeuraNet* nn =
    NeuraNetCreate(nbIn, nbOutput, nbHiddenVal, nbBases, nbLinks);
*(int*)&(nn->_nbBasesConv) = nbBasesConv;
*(int*)&(nn->_nbBasesCellConv) = nbLinkPerCell;
// Declare variables to create the links
VecShort* links = VecShortCreate(nbLinks * NN_NBPARAMLINK);
// Declare a variable to memorize the index of the currentlty
// created link
int iLink = 0;
// Reset the dimension and size of the input layer at current
// convolution level
VecCopy(curDimIn, dimIn);
sizeLayerIn = 1;
for (int iDim = VecGetDim(curDimIn); iDim--;) {
    sizeLayerIn *= VecGet(curDimIn, iDim);
}
// Reset the dimension and size of the output layer at current
// convolution level
VecCopy(curDimOut, dimIn);
sizeLayerOut = 1;
for (int iDim = VecGetDim(curDimOut); iDim--;) {
    VecSetAdd(curDimOut, iDim, -1 * VecGet(dimCell, iDim) + 1);
    sizeLayerOut *= VecGet(curDimOut, iDim);
}

```

```

}
// Declare variables to memorize the index of the beginning of the
// input and output layer and base functions at current convolution
// level
int* iStartBase = PBErrMalloc(NeuraNetErr, sizeof(int) * thickConv);
int* iStartLayerIn = PBErrMalloc(NeuraNetErr, sizeof(int) * thickConv);
int* iStartLayerOut = PBErrMalloc(NeuraNetErr,
    sizeof(int) * thickConv);
for (int iThick = 0; iThick < thickConv; ++iThick) {
    iStartLayerIn[iThick] = 0;
    iStartLayerOut[iThick] = sizeLayerIn + iThick * sizeLayerOut;
    iStartBase[iThick] = iThick * nbLinkPerCell;
}
// Loop on convolution levels
for (int iConv = 0; iConv < depthConv; ++iConv) {
    // Reset the position of the convolution cell in the input layer
    VecSetNull(pos);
    // Loop on position of the convolution cell at the current
    // convolution levels
    do {
        do {
            // Loop on convolution in parallel
            for (int iThick = 0; iThick < thickConv; ++iThick) {
                // Declare a variable to memorize the index of the input of the
                // current link
                int iInput = 0;
                for (int iDim = VecGetDim(curDimIn); iDim--;) {
                    iInput += VecGet(curDimIn, iDim);
                    iInput += VecGet(posCell, iDim) + VecGet(pos, iDim);
                }
                iInput += iStartLayerIn[iThick];
                // Declare a variable to memorize the index of the output of
                // the current link
                int iOutput = 0;
                for (int iDim = VecGetDim(curDimOut); iDim--;) {
                    iOutput += VecGet(curDimOut, iDim);
                    iOutput += VecGet(pos, iDim);
                }
                iOutput += iStartLayerOut[iThick];
                // Declare a variable to memorize the index of the base of the
                // current link
                int iBase = 0;
                for (int iDim = VecGetDim(posCell); iDim--;) {
                    iBase += VecGet(dimCell, iDim);
                    iBase += VecGet(posCell, iDim);
                }
                iBase += iStartBase[iThick];
                // Set the current link's parameters
                VecSet(links, iLink * NN_NBPARAMLINK, iBase);
                VecSet(links, iLink * NN_NBPARAMLINK + 1, iInput);
                VecSet(links, iLink * NN_NBPARAMLINK + 2, iOutput);
                // Increment the index of the current link
                ++iLink;
            }
        } while (VecPStep(posCell, dimCell));
    } while (VecPStep(pos, curDimOut));
    // If we are not at the last convolution level
    if (iConv < depthConv - 1) {
        // Update input and output dimensions at next convolution level
        VecCopy(curDimIn, curDimOut);
        sizeLayerIn = sizeLayerOut;
        sizeLayerOut = 1;
    }
}

```

```

    for (int iDim = VecGetDim(curDimOut); iDim--;) {
        VecSetAdd(curDimOut, iDim, -1 * VecGet(dimCell, iDim) + 1);
        sizeLayerOut *= VecGet(curDimOut, iDim);
    }
}
// Update the start index of input and output layers and bases
// for each convolution in parallel
for (int iThick = 0; iThick < thickConv; ++iThick) {
    iStartLayerIn[iThick] = iStartLayerOut[iThick];
    iStartLayerOut[iThick] = iStartLayerIn[0] +
        thickConv * sizeLayerIn + iThick * sizeLayerOut;
    iStartBase[iThick] =
        ((iConv + 1) * thickConv + iThick) * nbLinkPerCell;
}
}
// Set the links of the last fully connected layer between last
// convolution and NeuraNet output
// Declare a variable to remember the index of the base
int iBase = iStartBase[0];
// Loop on the last output of convolution layer
for (int iLayerOut = 0; iLayerOut < sizeLayerOut; ++iLayerOut) {
    // Loop on parallel convolution
    for (int iThick = 0; iThick < thickConv; ++iThick) {
        // Loop on output of the NeuraNet
        for (int iOut = 0; iOut < nbOutput; ++iOut) {
            // Declare a variable to memorize the index of the input of
            // the link
            int iInput = iStartLayerIn[0] +
                iLayerOut * thickConv + iThick;
            // Declare a variable to memorize the index of the output of
            // the link
            int iOutput = iOut + nbIn + nbHiddenVal;
            // Set the link's parameters
            VecSet(links, iLink * NN_NBPARAMLINK, iBase);
            VecSet(links, iLink * NN_NBPARAMLINK + 1, iInput);
            VecSet(links, iLink * NN_NBPARAMLINK + 2, iOutput);
            // Increment the link index
            ++iLink;
            // Increment the base function
            ++iBase;
        }
    }
}
// Set up the links
NNSetLinks(nn, links);
// Free memory
VecFree(&links);
VecFree(&pos);
VecFree(&posCell);
VecFree(&curDimIn);
VecFree(&curDimOut);
free(iStartBase);
free(iStartLayerIn);
free(iStartLayerOut);
// Return the new NeuraNet
return nn;
}

// Calculate the output values for the input values 'input' for the
// NeuraNet 'that' and memorize the result in 'output'
// input values in [-1,1] and output values in [-1,1]
// All values of 'output' are set to 0.0 before evaluating

```



```

// Links which refer to values out of bounds of 'input' or 'output'
// are ignored
void NNEval(const NeuraNet* const that, const VecFloat* const input, VecFloat* const output) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (input == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'input' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (output == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'output' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (VecGetDim(input) != that->_nbInputVal) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg,
            "'input' 's dimension is invalid (%d!=%d)",
            VecGetDim(input), that->_nbInputVal);
        PBErrCatch(NeuraNetErr);
    }
    if (VecGetDim(output) != that->_nbOutputVal) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg,
            "'output' 's dimension is invalid (%d!=%d)",
            VecGetDim(output), that->_nbOutputVal);
        PBErrCatch(NeuraNetErr);
    }
}
#endif
// Reset the hidden values and output
if (NNGetNbMaxHidden(that) > 0)
    VecSetNull(that->_hidVal);
VecSetNull(output);
// If there are links in the network
if (VecGet(that->_links, 0) != -1) {
    // Declare two variables to memorize the starting index of hidden
    // values and output values in the link definition
    int startHid = NNGetNbInput(that);
    int startOut = NNGetNbMaxHidden(that) + NNGetNbInput(that);
    // Declare a variable to memorize the previous link
    int prevLink[2] = {-1, -1};
    // Declare a variable to memorize the previous output value
    float prevOut = 1.0;
    // Loop on links
    int iLink = 0;
    while (iLink < NNGetNbMaxLinks(that) &&
        VecGet(that->_links, NN_NBPARAMLINK * iLink) != -1) {
        // Declare a variable for optimization
        int jLink = NN_NBPARAMLINK * iLink;
        // If this link has different input or output than previous link
        // and we are not on the first link
        if (iLink != 0 &&
            (VecGet(that->_links, jLink + 1) != prevLink[0] ||
             VecGet(that->_links, jLink + 2) != prevLink[1])) {
            // Add the previous output value to the output of the previous
            // link
            if (prevLink[1] < startOut) {

```

```

        int iVal = prevLink[1] - startHid;
        float nVal = MIN(1.0, MAX(-1.0, VecGet(that->_hidVal, iVal) + prevOut));
        VecSet(that->_hidVal, iVal, nVal);
    } else {
        int iVal = prevLink[1] - startOut;
        float nVal = VecGet(output, iVal) + prevOut;
        VecSet(output, iVal, nVal);
    }
    // Reset the previous output
    prevOut = 1.0;
}
// Update the previous link
prevLink[0] = VecGet(that->_links, jLink + 1);
prevLink[1] = VecGet(that->_links, jLink + 2);
// Multiply the previous output by the evaluation of the current
// link with the base function of the link and the normalised
// input value
float* param = that->_bases->_val +
    VecGet(that->_links, jLink) * NN_NBPARAMBASE;
float x = 0.0;
if (prevLink[0] < startHid)
    x = VecGet(input, prevLink[0]);
else
    x = NNGetHiddenValue(that, prevLink[0] - startHid);
prevOut *= NNBaseFun(param, x);
// Move to the next link
++iLink;
}
// Update the output of the last link
if (prevLink[1] < startOut) {
    int iVal = prevLink[1] - startHid;
    float nVal = MIN(1.0, MAX(-1.0, VecGet(that->_hidVal, iVal) + prevOut));
    VecSet(that->_hidVal, iVal, nVal);
} else {
    int iVal = prevLink[1] - startOut;
    float nVal = VecGet(output, iVal) + prevOut;
    VecSet(output, iVal, nVal);
}
}
}

// Function which return the JSON encoding of 'that'
JSONNode* NNEncodeAsJSON(const NeuraNet* const that) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        PBMathErr->_type = PBErrTypeNullPointer;
        sprintf(PBMathErr->_msg, "'that' is null");
        PBErrCatch(PBMathErr);
    }
#endif
    // Create the JSON structure
    JSONNode* json = JSONCreate();
    // Declare a buffer to convert value into string
    char val[100];
    // Encode the nbInputVal
    sprintf(val, "%d", that->_nbInputVal);
    JSONAddProp(json, "_nbInputVal", val);
    // Encode the nbOutputVal
    sprintf(val, "%d", that->_nbOutputVal);
    JSONAddProp(json, "_nbOutputVal", val);
    // Encode the nbMaxHidVal
    sprintf(val, "%d", that->_nbMaxHidVal);

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```

JSONAddProp(json, "_nbMaxHidVal", val);
// Encode the nbMaxBases
sprintf(val, "%d", that->_nbMaxBases);
JSONAddProp(json, "_nbMaxBases", val);
// Encode the nbMaxLinks
sprintf(val, "%d", that->_nbMaxLinks);
JSONAddProp(json, "_nbMaxLinks", val);
// Encode the bases
JSONAddProp(json, "_bases", VecEncodeAsJSON(that->_bases));
// Encode the links
JSONAddProp(json, "_links", VecEncodeAsJSON(that->_links));
// Return the created JSON
return json;
}

// Function which decode from JSON encoding 'json' to 'that'
bool NNDecodeAsJSON(NeuraNet** that, const JSONNode* const json) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        PBMathErr->_type = PBErrTypeNullPointer;
        sprintf(PBMathErr->_msg, "'that' is null");
        PBErrCatch(PBMathErr);
    }
    if (json == NULL) {
        PBMathErr->_type = PBErrTypeNullPointer;
        sprintf(PBMathErr->_msg, "'json' is null");
        PBErrCatch(PBMathErr);
    }
#endif
    // If 'that' is already allocated
    if (*that != NULL)
        // Free memory
        NeuraNetFree(that);
    // Decode the nbInputVal
    JSONNode* prop = JSONProperty(json, "_nbInputVal");
    if (prop == NULL) {
        return false;
    }
    int nbInputVal = atoi(JSONLabel(JSONValue(prop, 0)));
    // Decode the nbOutputVal
    prop = JSONProperty(json, "_nbOutputVal");
    if (prop == NULL) {
        return false;
    }
    int nbOutputVal = atoi(JSONLabel(JSONValue(prop, 0)));
    // Decode the nbMaxHidVal
    prop = JSONProperty(json, "_nbMaxHidVal");
    if (prop == NULL) {
        return false;
    }
    int nbMaxHidVal = atoi(JSONLabel(JSONValue(prop, 0)));
    // Decode the nbMaxBases
    prop = JSONProperty(json, "_nbMaxBases");
    if (prop == NULL) {
        return false;
    }
    int nbMaxBases = atoi(JSONLabel(JSONValue(prop, 0)));
    // Decode the nbMaxLinks
    prop = JSONProperty(json, "_nbMaxLinks");
    if (prop == NULL) {
        return false;
    }
}

```

```

    int nbMaxLinks = atoi(JSONLabel(JSONValue(prop, 0)));
    // Allocate memory
    *that = NeuraNetCreate(nbInputVal, nbOutputVal, nbMaxHidVal,
        nbMaxBases, nbMaxLinks);
    // Decode the bases
    prop = JSONProperty(json, "_bases");
    if (prop == NULL) {
        return false;
    }
    if (!VecDecodeAsJSON(&((*that)->_bases), prop)) {
        return false;
    }
    // Decode the links
    prop = JSONProperty(json, "_links");
    if (prop == NULL) {
        return false;
    }
    if (!VecDecodeAsJSON(&((*that)->_links), prop)) {
        return false;
    }
    // Return the success code
    return true;
}

// Save the NeuraNet 'that' to the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if the NeuraNet could be saved, false else
bool NNSave(const NeuraNet* const that, FILE* const stream, const bool compact) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (stream == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'stream' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    // Get the JSON encoding
    JSONNode* json = NNEncodeAsJSON(that);
    // Save the JSON
    if (!JSONSave(json, stream, compact)) {
        return false;
    }
    // Free memory
    JSONFree(&jjson);
    // Return success code
    return true;
}

// Load the NeuraNet 'that' from the stream 'stream'
// If 'that' is not null the memory is first freed
// Return true if the NeuraNet could be loaded, false else
bool NNLoad(NeuraNet** that, FILE* const stream) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }

```

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    }
    if (stream == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'stream' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    // Declare a json to load the encoded data
    JSONNode* json = JSONCreate();
    // Load the whole encoded data
    if (!JSONLoad(json, stream)) {
        return false;
    }
    // Decode the data from the JSON
    if (!NNDecodeAsJSON(that, json)) {
        return false;
    }
    // Free the memory used by the JSON
    JSONFree(&json);
    // Return the success code
    return true;
}

// Print the NeuraNet 'that' to the stream 'stream'
void NNPrintLn(const NeuraNet* const that, FILE* const stream) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (stream == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'stream' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    fprintf(stream, "nbInput: %d\n", that->_nbInputVal);
    fprintf(stream, "nbOutput: %d\n", that->_nbOutputVal);
    fprintf(stream, "nbHidden: %d\n", that->_nbMaxHidVal);
    fprintf(stream, "nbMaxBases: %d\n", that->_nbMaxBases);
    fprintf(stream, "nbMaxLinks: %d\n", that->_nbMaxLinks);
    fprintf(stream, "bases: ");
    VecPrint(that->_bases, stream);
    fprintf(stream, "\n");
    fprintf(stream, "links: ");
    VecPrint(that->_links, stream);
    fprintf(stream, "\n");
    fprintf(stream, "hidden values: ");
    VecPrint(that->_hidVal, stream);
    fprintf(stream, "\n");
}

// Set the links description of the NeuraNet 'that' to a copy of 'links'
// Links with a base function equals to -1 are ignored
// If the input id is higher than the output id they are swap
// The links description in the NeuraNet are ordered in increasing
// value of input id and output id, but 'links' doesn't have to be
// sorted
// Each link is defined by (base index, input index, output index)
// If base index equals -1 it means the link is inactive
void NNSetLinks(NeuraNet* const that, VecShort* const links) {

```

```

#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (links == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'links' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (VecGetDim(links) != that->_nbMaxLinks * NN_NBPARAMLINK) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg,
            "'links' 's dimension is invalid (%d!=%d)",
            VecGetDim(links), that->_nbMaxLinks);
        PBErrCatch(NeuraNetErr);
    }
#endif
    // Declare a GSet to sort the links
    GSet set = GSetCreateStatic();
    // Declare a variable to memorize the maximum id
    int maxId = NNGetNbInput(that) + NNGetNbMaxHidden(that) +
        NNGetNbOutput(that);
    // Loop on links
    for (int iLink = 0; iLink < NNGetNbMaxLinks(that) * NN_NBPARAMLINK;
        iLink += NN_NBPARAMLINK) {
        // If this link is active
        if (VecGet(links, iLink) != -1) {
            // Declare two variable to memorize the effective input and output
            int in = VecGet(links, iLink + 1);
            int out = VecGet(links, iLink + 2);
            // If the input is greater than the output
            if (in > out) {
                // Swap the input and output
                int tmp = in;
                in = out;
                out = tmp;
            }
            // Add the link to the set, sorting on input and ouput
            float sortVal = (float)(in * maxId + out);
            GSetAddSort(&set, links->_val + iLink, sortVal);
        }
    }
    // Declare a variable to memorize the number of active links
    int nbLink = GSetNbElem(&set);
    // If there are active links
    if (nbLink > 0) {
        // loop on active sorted links
        GSetIterForward iter = GSetIterForwardCreateStatic(&set);
        int iLink = 0;
        do {
            short *link = GSetIterGet(&iter);
            VecSet(that->_links, iLink * NN_NBPARAMLINK, link[0]);
            if (link[1] <= link[2]) {
                VecSet(that->_links, iLink * NN_NBPARAMLINK + 1, link[1]);
                VecSet(that->_links, iLink * NN_NBPARAMLINK + 2, link[2]);
            } else {
                VecSet(that->_links, iLink * NN_NBPARAMLINK + 1, link[2]);
                VecSet(that->_links, iLink * NN_NBPARAMLINK + 2, link[1]);
            }
        }
        ++iLink;
    }

```

```

    } while (GSetIterStep(&iter));
}
// Reset the inactive links
for (int iLink = nbLink; iLink < NNGetNbMaxLinks(that); ++iLink)
    VecSet(that->_links, iLink * NN_NPARAMLINK, -1);
// Free the memory
GSetFlush(&set);
}

```

## 3.2 pbmath-inline.c

```

// ===== NEURANET-INLINE.C =====

// ----- NeuraNetBaseFun

// ===== Functions implementation =====

// Generic base function for the NeuraNet
// 'param' is an array of 3 float all in [-1,1]
// 'x' is the input value
// NNBaseFun(param,x)=
// {tan(param[0]*NN_THETA)*(x+param[1])+param[2]}[-1,1]
// The generic base function returns a value in [-1,1]
#if BUILDMODE != 0
inline
#endif
float NNBaseFun(const float* const param, const float x) {
#if BUILDMODE == 0
    if (param == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'param' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    //return MIN(1.0, MAX(-1.0,
    // tan(param[0] * NN_THETA) * (x + param[1]) + param[2]));
    return tan(param[0] * NN_THETA) * (x + param[1]) + param[2];
}

// ----- NeuraNet

// ===== Functions implementation =====

// Get the nb of input values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbInput(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbInputVal;
}

```

```

// Get the nb of output values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbOutput(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbOutputVal;
}

// Get the nb max of hidden values of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxHidden(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbMaxHidVal;
}

// Get the nb max of base functions of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxBases(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbMaxBases;
}

// Get the nb of base functions for convolution of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbBasesConv(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbBasesConv;
}

// Get the nb of base functions per cell for convolution of
// the NeuraNet 'that'

```



```

#if BUILDMODE != 0
inline
#endif
int NNGetNbBasesCellConv(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbBasesCellConv;
}

// Get the nb max of links of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
int NNGetNbMaxLinks(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbMaxLinks;
}

// Get the parameters of the base functions of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* NNBases(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_bases;
}

// Get the links description of the NeuraNet 'that'
#if BUILDMODE != 0
inline
#endif
const VecShort* NNLinks(const NeuraNet* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_links;
}

// Get the hidden values of the NeuraNet 'that'
#if BUILDMODE != 0
inline

```

```

#endif
const VecFloat* NNHiddenValues(const NeuraNet* const that) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
#endif
    return that->_hidVal;
}

// Get the 'iVal'-th hidden value of the NeuraNet 'that'
#ifdef BUILDMODE != 0
inline
#endif
float NNGetHiddenValue(const NeuraNet* const that, const int iVal) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (iVal < 0 || iVal >= that->_nbMaxHidVal) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg, "'iVal' is invalid (0<=%d<=%d)",
            iVal, that->_nbMaxHidVal);
        PBErrCatch(NeuraNetErr);
    }
#endif
    return VecGet(that->_hidVal, iVal);
}

// Set the parameters of the base functions of the NeuraNet 'that' to
// a copy of 'bases'
// 'bases' must be of dimension that->nbMaxBases * NN_NBPARAMBASE
// each base is defined as param[3] in [-1,1]
// tan(param[0]*NN_THETA)*(x+param[1])+param[2]
#ifdef BUILDMODE != 0
inline
#endif
void NNSetBases(NeuraNet* const that, const VecFloat* const bases) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (bases == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'bases' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (VecGetDim(bases) != that->_nbMaxBases * NN_NBPARAMBASE) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg,
            "'bases' 's dimension is invalid (%d!=%d)",
            VecGetDim(bases), that->_nbMaxBases * NN_NBPARAMBASE);
        PBErrCatch(NeuraNetErr);
    }
#endif
    VecCopy(that->_bases, bases);
}

```

```

}
// Set the 'iBase'-th parameter of the base functions of the NeuraNet
// 'that' to 'base'
#if BUILDMODE != 0
inline
#endif
void NNBasesSet(NeuraNet* const that, const int iBase, const float base) {
#if BUILDMODE == 0
    if (that == NULL) {
        NeuraNetErr->_type = PBErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PBErrCatch(NeuraNetErr);
    }
    if (iBase < 0 || iBase >= that->_nbMaxBases * NN_NBPARAMBASE) {
        NeuraNetErr->_type = PBErrTypeInvalidArg;
        sprintf(NeuraNetErr->_msg,
            "'iBase' is invalid (0<=%d<%d)",
            iBase, that->_nbMaxBases * NN_NBPARAMBASE);
        PBErrCatch(NeuraNetErr);
    }
}
#endif
VecSet(that->_bases, iBase, base);
}

```

## 4 Makefile

```

# Build mode
# 0: development (max safety, no optimisation)
# 1: release (min safety, optimisation)
# 2: fast and furious (no safety, optimisation)
BUILD_MODE?=1

all: main

# Makefile definitions
MAKEFILE_INC=../PMake/Makefile.inc
include $(MAKEFILE_INC)

# Rules to make the executable
repo=neuranet
$(repo)_EXENAME: \
$(repo)_EXENAME.o \
$(repo)_EXE_DEP \
$(repo)_DEP
$(COMPILER) 'echo "$(repo)_EXE_DEP" "$(repo)_EXENAME.o" | tr ' ' '\n' | sort -u' $(LINK_ARG) $(repo)_LINK_ARG

$(repo)_EXENAME.o: \
$(repo)_DIR/$(repo)_EXENAME.c \
$(repo)_INC_H_EXE \
$(repo)_EXE_DEP
$(COMPILER) $(BUILD_ARG) $(repo)_BUILD_ARG 'echo "$(repo)_INC_DIR" | tr ' ' '\n' | sort -u' -c $(repo)_DIR/

```

## 5 Unit tests

```
#include <stdlib.h>
#include <stdio.h>
#include <time.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/time.h>
#include "pberr.h"
#include "genalg.h"
#include "neuranet.h"

#define RANDOMSEED 4

void UnitTestNNBaseFun() {
    srandom(RANDOMSEED);
    float param[4];
    float x = 0.0;
    float check[100] = {
        -4.664967,-3.920526,-3.176085,-2.431644,-1.687203,-0.942763,
        -0.198322,0.546119,1.290560,2.035000,-0.153181,-0.403978,
        -0.654776,-0.905573,-1.156371,-1.407168,-1.657966,-1.908763,
        -2.159561,-2.410358,0.586943,0.301165,0.015387,-0.270391,
        -0.556169,-0.841946,-1.127724,-1.413502,-1.699280,-1.985057,
        2.760699,2.805863,2.851027,2.896191,2.941355,2.986519,
        3.031683,3.076847,3.122011,3.167175,0.774302,0.903425,
        1.032548,1.161672,1.290795,1.419918,1.549042,1.678165,
        1.807288,1.936412,2.321817,2.100005,1.878192,1.656379,
        1.434567,1.212754,0.990941,0.769129,0.547316,0.325503,
        -1.349660,-1.452492,-1.555323,-1.658154,-1.760985,-1.863817,
        -1.966648,-2.069479,-2.172311,-2.275142,2.030713,1.867117,
        1.703522,1.539926,1.376330,1.212735,1.049139,0.885544,0.721949,
        0.558353,-1.439830,-1.174441,-0.909051,-0.643662,-0.378272,
        -0.112883,0.152507,0.417896,0.683286,0.948675,0.819425,0.765620,
        0.711816,0.658011,0.604206,0.550401,0.496596,0.442791,0.388987,
        0.335182
    };
};

for (int iTest = 0; iTest < 10; ++iTest) {
    param[0] = 2.0 * (rnd() - 0.5);
    param[1] = 2.0 * rnd();
    param[2] = 2.0 * (rnd() - 0.5) * PBMATH_PI;
    param[3] = 2.0 * (rnd() - 0.5);
    for (int ix = 0; ix < 10; ++ix) {
        x = -1.0 + 2.0 * 0.1 * (float)ix;
        float y = NNBaseFun(param, x);
        if (ISEQUALF(y, check[iTest * 10 + ix]) == false) {
            NeuraNetErr->_type = PBErrTypeUnitTestFailed;
            sprintf(NeuraNetErr->_msg, "NNBaseFun failed");
            PBErrCatch(NeuraNetErr);
        }
    }
}

printf("UnitTestNNBaseFun OK\n");
}

void UnitTestNeuraNetCreateFree() {
    int nbIn = 1;
    int nbOut = 2;
    int nbHid = 3;
    int nbBase = 4;
```

```

int nbLink = 5;
NeuraNet* nn = NeuraNetCreate(nbIn, nbOut, nbHid, nbBase, nbLink);
if (nn == NULL ||
    nn->_nbInputVal != nbIn ||
    nn->_nbOutputVal != nbOut ||
    nn->_nbMaxHidVal != nbHid ||
    nn->_nbMaxBases != nbBase ||
    nn->_nbBasesConv != 0 ||
    nn->_nbMaxLinks != nbLink ||
    nn->_bases == NULL ||
    nn->_links == NULL ||
    nn->_hidVal == NULL) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NeuraNetFree failed");
    PBErrCatch(NeuraNetErr);
}
NeuraNetFree(&nn);
if (nn != NULL) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NeuraNetFree failed");
    PBErrCatch(NeuraNetErr);
}
printf("UnitTestNeuraNetCreateFree OK\n");
}

void UnitTestNeuraNetCreateFullyConnected() {
    int nbIn = 2;
    int nbOut = 3;
    VecShort* hiddenLayers = NULL;
    NeuraNet* nn = NeuraNetCreateFullyConnected(nbIn, nbOut, hiddenLayers);
    if (nn == NULL ||
        nn->_nbInputVal != nbIn ||
        nn->_nbOutputVal != nbOut ||
        nn->_nbMaxHidVal != 0 ||
        nn->_nbMaxBases != 6 ||
        nn->_nbMaxLinks != 6 ||
        nn->_bases == NULL ||
        nn->_links == NULL ||
        nn->_hidVal != NULL) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NeuraNetCreateFullyConnected failed");
        PBErrCatch(NeuraNetErr);
    }
    int checka[18] = {
        0,0,2, 1,0,3, 2,0,4,
        3,1,2, 4,1,3, 5,1,4
    };
    for (int i = 18; i--;)
        if (VecGet(nn->_links, i) != checka[i]) {
            NeuraNetErr->_type = PBErrTypeUnitTestFailed;
            sprintf(NeuraNetErr->_msg, "NeuraNetCreateFullyConnected failed");
            PBErrCatch(NeuraNetErr);
        }
    NeuraNetFree(&nn);
    nbIn = 5;
    nbOut = 2;
    hiddenLayers = VecShortCreate(2);
    VecSet(hiddenLayers, 0, 4);
    VecSet(hiddenLayers, 1, 3);
    nn = NeuraNetCreateFullyConnected(nbIn, nbOut, hiddenLayers);
    if (nn == NULL ||
        nn->_nbInputVal != nbIn ||

```

```

    nn->_nbOutputVal != nbOut ||
    nn->_nbMaxHidVal != 7 ||
    nn->_nbMaxBases != 38 ||
    nn->_nbMaxLinks != 38 ||
    nn->_bases == NULL ||
    nn->_links == NULL ||
    nn->_hidVal == NULL) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NeuraNetCreateFullyConnected failed");
    PBErrCatch(NeuraNetErr);
}
int checkb[114] = {
    0,0,5, 1,0,6, 2,0,7, 3,0,8,
    4,1,5, 5,1,6, 6,1,7, 7,1,8,
    8,2,5, 9,2,6, 10,2,7, 11,2,8,
    12,3,5, 13,3,6, 14,3,7, 15,3,8,
    16,4,5, 17,4,6, 18,4,7, 19,4,8,
    20,5,9, 21,5,10, 22,5,11,
    23,6,9, 24,6,10, 25,6,11,
    26,7,9, 27,7,10, 28,7,11,
    29,8,9, 30,8,10, 31,8,11,
    32,9,12, 33,9,13,
    34,10,12, 35,10,13,
    36,11,12, 37,11,13
};
for (int i = 114; i--;)
    if (VecGet(nn->_links, i) != checkb[i]) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NeuraNetCreateFullyConnected failed");
        PBErrCatch(NeuraNetErr);
    }
NeuraNetFree(&nn);
VecFree(&hiddenLayers);
printf("UnitTestNeuraNetCreateFullyConnected OK\n");
}

void UnitTestNeuraNetCreateConvolution() {
    int nbOut = 2;
    int thickConv = 2;
    int depthConv = 2;
    VecShort* dimIn = VecShortCreate(2);
    VecSet(dimIn, 0, 4);
    VecSet(dimIn, 1, 3);
    VecShort* dimCell = VecShortCreate(2);
    VecSet(dimCell, 0, 2);
    VecSet(dimCell, 1, 2);
    NeuraNet* nn = NeuraNetCreateConvolution(dimIn, nbOut, dimCell,
        depthConv, thickConv);
    NNPrintln(nn, stdout);
    if (nn == NULL ||
        nn->_nbInputVal != 12 ||
        nn->_nbOutputVal != 2 ||
        nn->_nbMaxHidVal != 16 ||
        nn->_nbMaxBases != 24 ||
        nn->_nbMaxLinks != 72 ||
        nn->_bases == NULL ||
        nn->_links == NULL ||
        nn->_hidVal == NULL) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NeuraNetCreateConvolution failed");
        PBErrCatch(NeuraNetErr);
    }
}

```

```

int check[216] = {
    0,0,12, 4,0,18, 1,1,12, 0,1,13, 5,1,18, 4,1,19, 1,2,13, 0,2,14,
    5,2,19, 4,2,20, 1,3,14, 5,3,20, 2,4,12, 0,4,15, 6,4,18, 4,4,21,
    3,5,12, 2,5,13, 1,5,15, 0,5,16, 7,5,18, 6,5,19, 5,5,21, 4,5,22,
    3,6,13, 2,6,14, 1,6,16, 0,6,17, 7,6,19, 6,6,20, 5,6,22, 4,6,23,
    3,7,14, 1,7,17, 7,7,20, 5,7,23, 2,8,15, 6,8,21, 3,9,15, 2,9,16,
    7,9,21, 6,9,22, 3,10,16, 2,10,17, 7,10,22, 6,10,23, 3,11,17,
    7,11,23, 8,12,24, 9,13,24, 8,13,25, 9,14,25, 10,15,24, 11,16,24,
    10,16,25, 11,17,25, 12,18,26, 13,19,26, 12,19,27, 13,20,27,
    14,21,26, 15,22,26, 14,22,27, 15,23,27, 16,24,28, 17,24,29,
    18,25,28, 19,25,29, 20,26,28, 21,26,29, 22,27,28, 23,27,29
};
for (int iCheck = 216; iCheck--;) {
    if (VecGet(nn->_links, iCheck) != check[iCheck]) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NeuraNetCreateConvolution failed");
        PBErrCatch(NeuraNetErr);
    }
}
NeuraNetFree(&nn);
VecFree(&dimIn);
VecFree(&dimCell);
printf("UnitTestNeuraNetCreateConvolution OK\n");
}

void UnitTestNeuraNetGetSet() {
    int nbIn = 10;
    int nbOut = 20;
    int nbHid = 30;
    int nbBase = 4;
    int nbLink = 5;
    NeuraNet* nn = NeuraNetCreate(nbIn, nbOut, nbHid, nbBase, nbLink);
    if (NNGetNbInput(nn) != nbIn) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbInput failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNGetNbMaxBases(nn) != nbBase) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbMaxBases failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNGetNbBasesConv(nn) != 0) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbBasesConv failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNGetNbBasesCellConv(nn) != 0) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbBasesCellConv failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNGetNbMaxHidden(nn) != nbHid) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbMaxHidden failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNGetNbMaxLinks(nn) != nbLink) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbMaxLinks failed");
        PBErrCatch(NeuraNetErr);
    }
}

```

```

if (NNGetNbOutput(nn) != nbOut) {
    NetErr->_type = PErrTypeUnitTestFailed;
    sprintf(NetErr->_msg, "NNGetNbOutput failed");
    PErrCatch(NetErr);
}
if (NNBases(nn) != nn->_bases) {
    NetErr->_type = PErrTypeUnitTestFailed;
    sprintf(NetErr->_msg, "NNBases failed");
    PErrCatch(NetErr);
}
if (NNLinks(nn) != nn->_links) {
    NetErr->_type = PErrTypeUnitTestFailed;
    sprintf(NetErr->_msg, "NNLinks failed");
    PErrCatch(NetErr);
}
if (NNHiddenValues(nn) != nn->_hidVal) {
    NetErr->_type = PErrTypeUnitTestFailed;
    sprintf(NetErr->_msg, "NNHiddenValues failed");
    PErrCatch(NetErr);
}
VecFloat* bases = VecFloatCreate(nbBase * NN_NBPARAMBASE);
for (int i = nbBase * NN_NBPARAMBASE; i--;)
    VecSet(bases, i, 0.01 * (float)i);
NNSetBases(nn, bases);
for (int i = nbBase * NN_NBPARAMBASE; i--;)
    if (ISEQUALF(VecGet(NNBases(nn), i), 0.01 * (float)i) == false) {
        NetErr->_type = PErrTypeUnitTestFailed;
        sprintf(NetErr->_msg, "NNSetBases failed");
        PErrCatch(NetErr);
    }
VecFree(&bases);
VecShort* links = VecShortCreate(15);
short data[15] = {2,2,35, 1,1,12, -1,0,0, 2,15,20, 3,20,15};
for (int i = 15; i--;)
    VecSet(links, i, data[i]);
NNSetLinks(nn, links);
short check[15] = {1,1,12,2,2,35,2,15,20,3,15,20,-1,0,0};
for (int i = 15; i--;)
    if (VecGet(NNLinks(nn), i) != check[i]) {
        NetErr->_type = PErrTypeUnitTestFailed;
        sprintf(NetErr->_msg, "NNSetLinks failed");
        PErrCatch(NetErr);
    }
VecFree(&links);
NetFree(&nn);
printf("UnitTestNeuraNetGetSet OK\n");
}

void UnitTestNeuraNetSaveLoad() {
    int nbIn = 10;
    int nbOut = 20;
    int nbHid = 30;
    int nbBase = 4;
    int nbLink = 5;
    Net* nn = NetCreate(nbIn, nbOut, nbHid, nbBase, nbLink);
    VecFloat* bases = VecFloatCreate(nbBase * NN_NBPARAMBASE);
    for (int i = nbBase * NN_NBPARAMBASE; i--;)
        VecSet(bases, i, 0.01 * (float)i);
    NNSetBases(nn, bases);
    VecFree(&bases);
    VecShort* links = VecShortCreate(15);
    short data[15] = {2,2,35, 1,1,12, -1,0,0, 2,15,20, 3,20,15};

```



```

for (int i = 15; i--;)
    VecSet(links, i, data[i]);
NNSetLinks(nn, links);
VecFree(&links);
FILE* fd = fopen("./neuranet.txt", "w");
if (NNSave(nn, fd, false) == false) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NNSave failed");
    PBErrCatch(NeuraNetErr);
}
fclose(fd);
fd = fopen("./neuranet.txt", "r");
NeuraNet* loaded = NeuraNetCreate(1, 1, 1, 1, 1);
if (NNLoad(&loaded, fd) == false) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NNLoad failed");
    PBErrCatch(NeuraNetErr);
}
if (NNGetNbInput(loaded) != nbIn ||
    NNGetNbMaxBases(loaded) != nbBase ||
    NNGetNbMaxHidden(loaded) != nbHid ||
    NNGetNbMaxLinks(loaded) != nbLink ||
    NNGetNbOutput(loaded) != nbOut) {
    NeuraNetErr->_type = PBErrTypeUnitTestFailed;
    sprintf(NeuraNetErr->_msg, "NNLoad failed");
    PBErrCatch(NeuraNetErr);
}
for (int i = nbBase * NN_NBPARAMBASE; i--;)
    if (ISEQUALF(VecGet(NNBases(loaded), i), 0.01 * (float)i) == false) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNLoad failed");
        PBErrCatch(NeuraNetErr);
    }
short check[15] = {1,1,12,2,2,35,2,15,20,3,15,20,-1,0,0};
for (int i = 15; i--;)
    if (VecGet(NNLinks(loaded), i) != check[i]) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNLoad failed");
        PBErrCatch(NeuraNetErr);
    }
fclose(fd);
NeuraNetFree(&loaded);
NeuraNetFree(&nn);
printf("UnitTestNeuraNetSaveLoad OK\n");
}

void UnitTestNeuraNetEvalPrint() {
    int nbIn = 3;
    int nbOut = 3;
    int nbHid = 3;
    int nbBase = 3;
    int nbLink = 7;
    NeuraNet* nn = NeuraNetCreate(nbIn, nbOut, nbHid, nbBase, nbLink);
    // hidden[0] = tan(0.5*NN_THETA)*tan(-0.5*NN_THETA)*input[0]^2
    // hidden[1] = tan(0.5*NN_THETA)*input[1]
    // hidden[2] = 0
    // output[0] = tan(0.5*NN_THETA)*hidden[0]+tan(0.5*NN_THETA)*hidden[1]
    // output[1] = tan(0.5*NN_THETA)*hidden[1]
    // output[2] = 0
    NNbasesSet(nn, 0, 0.5);
    NNbasesSet(nn, 3, -0.5);
    NNbasesSet(nn, 8, -0.5);
}

```

```

short data[21] = {0,0,3, 1,0,3, 0,1,4, 0,3,6, 0,4,6, 0,4,7, -1,0,0};
VecShort *links = VecShortCreate(21);
for (int i = 21; i--;)
    VecSet(links, i, data[i]);
NNSetLinks(nn, links);
VecFree(&links);
VecFloat3D input = VecFloatCreateStatic3D();
VecFloat3D output = VecFloatCreateStatic3D();
VecFloat3D check = VecFloatCreateStatic3D();
VecFloat3D checkhidden = VecFloatCreateStatic3D();
NNPrintln(nn, stdout);
for (int i = -10; i <= 10; ++i) {
    for (int j = -10; j <= 10; ++j) {
        for (int k = -10; k <= 10; ++k) {
            VecSet(&input, 0, 0.1 * (float)i);
            VecSet(&input, 1, 0.1 * (float)j);
            VecSet(&input, 2, 0.1 * (float)k);
            NNEval(nn, (VecFloat*)&input, (VecFloat*)&output);
            VecSet(&checkhidden, 0, tan(0.5 * NN_THETA) * tan(-0.5 * NN_THETA) * fsquare(VecGet(&input, 0)));
            VecSet(&checkhidden, 1, tan(0.5 * NN_THETA) * VecGet(&input, 1));
            VecSet(&check, 0,
                tan(0.5 * NN_THETA) * (VecGet(&checkhidden, 0) + VecGet(&checkhidden, 1)));
            VecSet(&check, 1, tan(0.5 * NN_THETA) * VecGet(&checkhidden, 1));
            if (VecIsEqual(&output, &check) == false ||
                VecIsEqual(NNHiddenValues(nn), &checkhidden) == false) {
                NeuraNetErr->_type = PBErrTypeUnitTestFailed;
                sprintf(NeuraNetErr->_msg, "NNEval failed");
                PBErrCatch(NeuraNetErr);
            }
        }
    }
}
NeuraNetFree(&nn);
printf("UnitTestNeuraNetEvalPrint OK\n");
}

#ifdef GENALG_H
float evaluate(const NeuraNet* const nn) {
    VecFloat3D input = VecFloatCreateStatic3D();
    VecFloat3D output = VecFloatCreateStatic3D();
    VecFloat3D check = VecFloatCreateStatic3D();
    float val = 0.0;
    int nb = 0;
    for (int i = -5; i <= 5; ++i) {
        for (int j = -5; j <= 5; ++j) {
            for (int k = -5; k <= 5; ++k) {
                VecSet(&input, 0, 0.2 * (float)i);
                VecSet(&input, 1, 0.2 * (float)j);
                VecSet(&input, 2, 0.2 * (float)k);
                NNEval(nn, (VecFloat*)&input, (VecFloat*)&output);
                VecSet(&check, 0,
                    0.5 * (VecGet(&input, 1) - fsquare(VecGet(&input, 0))));
                VecSet(&check, 1, VecGet(&input, 1));
                val += VecDist(&output, &check);
                ++nb;
            }
        }
    }
    return -1.0 * val / (float)nb;
}

void UnitTestNeuraNetGA() {

```

```

//srandom(RANDOMSEED);
srandom(time(NULL));
int nbIn = 3;
int nbOut = 3;
int nbHid = 3;
int nbBase = 7;
int nbLink = 7;
NeuraNet* nn = NeuraNetCreate(nbIn, nbOut, nbHid, nbBase, nbLink);
GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    NNGetGAAdnFloatLength(nn), NNGetGAAdnIntLength(nn));
NNSetGABoundsBases(nn, ga);
NNSetGABoundsLinks(nn, ga);
// Must be declared as a GenAlg applied to a NeuraNet or links will
// get corrupted
GASetTypeNeuraNet(ga, nbIn, nbHid, nbOut);
GAInit(ga);
float best = -1000000.0;
float ev = 0.0;
do {
    for (int iEnt = GAGetNbAdns(ga); iEnt--;) {
        if (GAAdnIsNew(GAAdn(ga, iEnt))) {
            NNSetBases(nn, GAAdnAdnF(GAAdn(ga, iEnt)));
            NNSetLinks(nn, GAAdnAdnI(GAAdn(ga, iEnt)));
            float value = evaluate(nn);
            GASetAdnValue(ga, GAAdn(ga, iEnt), value);
        }
    }
    GASTep(ga);
    NNSetBases(nn, GABestAdnF(ga));
    NNSetLinks(nn, GABestAdnI(ga));
    ev = evaluate(nn);
    if (ev > best + PBMath_EPSILON) {
        best = ev;
        printf("%lu %f\n", GAGetCurEpoch(ga), best);
        fflush(stdout);
    }
} while (GAGetCurEpoch(ga) < 30000 && fabs(ev) > 0.001);
//} while (GAGetCurEpoch(ga) < 100 && fabs(ev) > 0.001);
printf("best after %lu epochs: %f \n", GAGetCurEpoch(ga), best);
NNPrintln(nn, stdout);
FILE* fd = fopen("./bestnn.txt", "w");
NNSave(nn, fd, false);
fclose(fd);
NeuraNetFree(&nn);
GenAlgFree(&ga);
printf("UnitTestNeuraNetGA OK\n");
}
#endif

void UnitTestNeuraNet() {
    UnitTestNeuraNetCreateFree();
    UnitTestNeuraNetCreateFullyConnected();
    UnitTestNeuraNetCreateConvolution();
    UnitTestNeuraNetGetSet();
    UnitTestNeuraNetSaveLoad();
    UnitTestNeuraNetEvalPrint();
#ifdef GENALG_H
    UnitTestNeuraNetGA();
#endif

    printf("UnitTestNeuraNet OK\n");
}

```

```

void UnitTestAll() {
    UnitTestNNBaseFun();
    UnitTestNeuraNet();
    printf("UnitTestAll OK\n");
}

int main() {
    UnitTestAll();
    // Return success code
    return 0;
}

```

## 6 Unit tests output

```

UnitTestNNBaseFun OK
UnitTestNeuraNetCreateFree OK
UnitTestNeuraNetCreateFullyConnected OK
nbInput: 12
nbOutput: 2
nbHidden: 16
nbMaxBases: 24
nbMaxLinks: 72
bases: <0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
links: <0,0,12,4,0,18,1,1,12,0,1,13,5,1,18,4,1,19,1,2,13,0,2,14,5,2,19,4,2,20,1,3,14,5,3,20,2,4,12,0,4,15,6,4,18,4,4
hidden values: <0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000>
UnitTestNeuraNetCreateConvolution OK
UnitTestNeuraNetGetSet OK
UnitTestNeuraNetSaveLoad OK
nbInput: 3
nbOutput: 3
nbHidden: 3
nbMaxBases: 3
nbMaxLinks: 7
bases: <0.500,0.000,0.000,-0.500,0.000,0.000,0.000,0.000,0.000,-0.500>
links: <0,0,3,1,0,3,0,1,4,0,3,6,0,4,6,0,4,7,-1,0,0>
hidden values: <0.000,0.000,0.000>
UnitTestNeuraNetEvalPrint OK
1 -1.296268
2 -0.793269
3 -0.593373
5 -0.576006
6 -0.549867
7 -0.494886
8 -0.486314
9 -0.298343
13 -0.204136
35 -0.192649
54 -0.190462
55 -0.163913
59 -0.162536
79 -0.117823
117 -0.094827
119 -0.088946
150 -0.088918
727 -0.084724
1526 -0.082081
1559 -0.077222

```

```

1560 -0.073862
2132 -0.067213
2816 -0.066514
2983 -0.057736
3232 -0.057176
3377 -0.053370
6599 -0.041052
6603 -0.039224
8746 -0.037679
10625 -0.037287
14662 -0.035465
16077 -0.020611
18778 -0.013657
best after 30000 epochs: -0.013657
nbInput: 3
nbOutput: 3
nbHidden: 3
nbMaxBases: 7
nbMaxLinks: 7
bases: <0.301,-0.859,-0.052,0.145,-0.448,-0.042,0.070,0.892,0.016,-0.852,-0.805,0.844,-0.056,0.313,0.369,0.502,0.706
links: <2,0,6,3,0,6,0,1,6,5,1,7,6,2,5,4,4,4,-1,2,5>
hidden values: <0.000,0.342,-1.000>
UnitTestNeuraNetGA OK
UnitTestNeuraNet OK
UnitTestAll OK

```

neuranet.txt:

```

{
  "_nbInputVal": "10",
  "_nbOutputVal": "20",
  "_nbMaxHidVal": "30",
  "_nbMaxBases": "4",
  "_nbMaxLinks": "5",
  "_bases": {
    "_dim": "12",
    "_val": ["0.000000", "0.010000", "0.020000", "0.030000", "0.040000", "0.050000", "0.060000", "0.070000", "0.080000", "0.090000", "0.100000", "0.110000"]
  },
  "_links": {
    "_dim": "15",
    "_val": ["1", "1", "12", "2", "2", "35", "2", "15", "20", "3", "15", "20", "-1", "0", "0"]
  }
}

```

bestnn.txt:

```

{
  "_nbInputVal": "3",
  "_nbOutputVal": "3",
  "_nbMaxHidVal": "3",
  "_nbMaxBases": "7",
  "_nbMaxLinks": "7",
  "_bases": {
    "_dim": "21",
    "_val": ["0.300810", "-0.858828", "-0.051753", "0.145469", "-0.448091", "-0.041673", "0.070493", "0.892269", "0.015508", "0.020000", "0.030000", "0.040000", "0.050000", "0.060000", "0.070000", "0.080000", "0.090000", "0.100000", "0.110000"]
  },
  "_links": {
    "_dim": "21",
    "_val": ["2", "0", "6", "3", "0", "6", "0", "1", "6", "5", "1", "7", "6", "2", "5", "4", "4", "4", "-1", "2", "5"]
  }
}

```

## 7 Validation

### 7.1 Iris data set

Source: <https://archive.ics.uci.edu/ml/datasets/iris>

main.c:

```
#include <stdlib.h>
#include <stdio.h>
#include <time.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/time.h>
#include "pberr.h"
#include "genalg.h"
#include "neuranet.h"

// https://archive.ics.uci.edu/ml/datasets/iris

// Nb of step between each save of the GenAlg
// Saving it allows to restart a stop learning process but is
// very time consuming if there are many input/hidden/output
// If 0 never save
#define SAVE_GA_EVERY 0
// Nb input and output of the NeuraNet
#define NB_INPUT 4
#define NB_OUTPUT 3
// Nb max of hidden values, links and base functions
#define NB_MAXHIDDEN 20
#define NB_MAXLINK 20
#define NB_MAXBASE NB_MAXLINK
// Size of the gene pool and elite pool
#define ADN_SIZE_POOL 100
#define ADN_SIZE_ELITE 20
// Initial best value during learning, must be lower than any
// possible value returned by Evaluate()
#define INIT_BEST_VAL 0.0
// Value of the NeuraNet above which the learning process stops
#define STOP_LEARNING_AT_VAL 0.999
// Number of epoch above which the learning process stops
#define STOP_LEARNING_AT_EPOCH 2000
// Save NeuraNet in compact format
#define COMPACT true

// Categories of data sets

typedef enum DataSetCat {
    unknownDataSet,
    datalearn,
    datatest,
    dataall
} DataSetCat;
#define NB_DATASET 4
const char* dataSetNames[NB_DATASET] = {
    "unknownDataSet", "datalearn", "datatest", "dataall"
};
```

```

// Structure for the data set
typedef enum IrisCat {
    setosa, versicolor, virginica
} IrisCat;
const char* irisCatNames[3] = {
    "setosa", "versicolor", "virginica"
};

typedef struct Iris {
    float _props[4];
    IrisCat _cat;
} Iris;

typedef struct DataSet {
    // Category of the data set
    DataSetCat _cat;
    // Number of sample
    int _nbSample;
    // Samples
    Iris* _samples;
} DataSet;

// Get the DataSetCat from its 'name'
DataSetCat GetCategoryFromName(const char* const name) {
    // Declare a variable to memorize the DataSetCat
    DataSetCat cat = unknownDataSet;
    // Search the dataset
    for (int iSet = NB_DATASET; iSet--;)
        if (strcmp(name, dataSetNames[iSet]) == 0)
            cat = iSet;
    // Return the category
    return cat;
}

// Load the data set of category 'cat' in the DataSet 'that'
// Return true on success, else false
bool DataSetLoad(DataSet* const that, const DataSetCat cat) {
    // Set the category
    that->_cat = cat;

    // Load the data according to 'cat'
    FILE* f = fopen("./bezdekIris.data", "r");
    if (f == NULL) {
        printf("Couldn't open the data set file\n");
        return false;
    }
    char buffer[500];
    int ret = 0;
    if (cat == datalearn) {
        that->_nbSample = 75;
        that->_samples =
            PBErrMalloc(NeuraNetErr, sizeof(Iris) * that->_nbSample);
        for (int iCat = 0; iCat < 3; ++iCat) {
            for (int iSample = 0; iSample < 25; ++iSample) {
                ret = fscanf(f, "%f,%f,%f,%f,%s",
                    that->_samples[25 * iCat + iSample]._props,
                    that->_samples[25 * iCat + iSample]._props + 1,
                    that->_samples[25 * iCat + iSample]._props + 2,
                    that->_samples[25 * iCat + iSample]._props + 3,
                    buffer);
                if (ret == EOF) {
                    printf("Couldn't read the dataset\n");
                }
            }
        }
    }
}

```

```

        fclose(f);
        return false;
    }
    that->_samples[25 * iCat + iSample]->_cat = (IrisCat)iCat;
}
for (int iSample = 0; iSample < 25; ++iSample) {
    ret = fscanf(f, "%s\n", buffer);
    if (ret == EOF) {
        printf("Couldn't read the dataset\n");
        fclose(f);
        return false;
    }
}
}
} else if (cat == datatest) {
    that->_nbSample = 75;
    that->_samples =
        PBErrMalloc(NeuraNetErr, sizeof(Iris) * that->_nbSample);
    for (int iCat = 0; iCat < 3; ++iCat) {
        for (int iSample = 0; iSample < 25; ++iSample) {
            ret = fscanf(f, "%s\n", buffer);
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
    }
    for (int iSample = 0; iSample < 25; ++iSample) {
        ret = fscanf(f, "%f,%f,%f,%f,%s",
            that->_samples[25 * iCat + iSample]->_props,
            that->_samples[25 * iCat + iSample]->_props + 1,
            that->_samples[25 * iCat + iSample]->_props + 2,
            that->_samples[25 * iCat + iSample]->_props + 3,
            buffer);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
        that->_samples[25 * iCat + iSample]->_cat = (IrisCat)iCat;
    }
}
} else if (cat == dataall) {
    that->_nbSample = 150;
    that->_samples =
        PBErrMalloc(NeuraNetErr, sizeof(Iris) * that->_nbSample);
    for (int iCat = 0; iCat < 3; ++iCat) {
        for (int iSample = 0; iSample < 50; ++iSample) {
            ret = fscanf(f, "%f,%f,%f,%f,%s",
                that->_samples[50 * iCat + iSample]->_props,
                that->_samples[50 * iCat + iSample]->_props + 1,
                that->_samples[50 * iCat + iSample]->_props + 2,
                that->_samples[50 * iCat + iSample]->_props + 3,
                buffer);
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
        that->_samples[50 * iCat + iSample]->_cat = (IrisCat)iCat;
    }
}
}

```



```

    } else {
        printf("Invalid dataset\n");
        fclose(f);
        return false;
    }
    fclose(f);

    // Return success code
    return true;
}

// Free memory for the DataSet 'that'
void DataSetFree(DataSet** that) {
    if (*that == NULL) return;
    // Free the memory
    free((*that)->_samples);
    free(*that);
    *that = NULL;
}

// Evaluation function for the NeuraNet 'that' on the DataSet 'dataset'
// Return the value of the NeuraNet, the bigger the better
float Evaluate(const NeuraNet* const that,
               const DataSet* const dataset) {
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Declare a variable to memorize the value
    float val = 0.0;

    // Evaluate

    for (int iSample = dataset->_nbSample; iSample--;) {
        for (int iInp = 0; iInp < NNGetNbInput(that); ++iInp) {
            VecSet(input, iInp,
                  dataset->_samples[iSample]._props[iInp]);
        }
        NNEval(that, input, output);
        int pred = VecGetIMaxVal(output);
        if (dataset->_cat == datatest) {
            printf("#%d pred%d real%d ", iSample, pred,
                  dataset->_samples[iSample]._cat);
            VecPrint(output, stdout);
        }
        if ((IrisCat)pred == dataset->_samples[iSample]._cat) {
            if (dataset->_cat == datatest)
                printf(" OK\n");
            val += 1.0;
        } else {
            if (dataset->_cat == datatest)
                printf(" NG\n");
        }
    }

    val /= (float)(dataset->_nbSample);

    // Free memory
    VecFree(&input);
    VecFree(&output);
    // Return the result of the evaluation
    return val;
}

```

```

// Create the NeuraNet
NeuraNet* createNN(void) {
    // Create the NeuraNet
    int nbIn = NB_INPUT;
    int nbOut = NB_OUTPUT;
    int nbMaxHid = NB_MAXHIDDEN;
    int nbMaxLink = NB_MAXLINK;
    int nbMaxBase = NB_MAXBASE;
    NeuraNet* nn =
        NeuraNetCreate(nbIn, nbOut, nbMaxHid, nbMaxBase, nbMaxLink);

    // Return the NeuraNet
    return nn;
}

// Learn based on the SataSetCat 'cat'
void Learn(DataSetCat cat) {
    // Init the random generator
    srand(time(NULL));
    // Declare variables to measure time
    struct timespec start, stop;
    // Start measuring time
    clock_gettime(CLOCK_REALTIME, &start);
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Create the NeuraNet
    NeuraNet* nn = createNN();
    // Declare a variable to memorize the best value
    float bestVal = INIT_BEST_VAL;
    // Declare a variable to memorize the limit in term of epoch
    unsigned long int limitEpoch = STOP_LEARNING_AT_EPOCH;
    // Create the GenAlg used for learning
    // If previous weights are available in "./bestga.txt" reload them
    GenAlg* ga = NULL;
    FILE* fd = fopen("./bestga.txt", "r");
    if (fd) {
        printf("Reloading previous GenAlg...\n");
        if (!GALoad(&ga, fd)) {
            printf("Failed to reload the GenAlg.\n");
            NeuraNetFree(&nn);
            DataSetFree(&dataset);
            return;
        } else {
            printf("Previous GenAlg reloaded.\n");
            if (GABestAdnF(ga) != NULL)
                NNSetBases(nn, GABestAdnF(ga));
            if (GABestAdnI(ga) != NULL)
                NNSetLinks(nn, GABestAdnI(ga));
            bestVal = Evaluate(nn, dataset);
            printf("Starting with best at %f.\n", bestVal);
            limitEpoch += GAGetCurEpoch(ga);
        }
        fclose(fd);
    } else {
        ga = GenAlgCreate(ADN_SIZE_POOL, ADN_SIZE_ELITE,
            NNGetGAAdnFloatLength(nn), NNGetGAAdnIntLength(nn));
    }
}

```

```

NNSetGABoundsBases(nn, ga);
NNSetGABoundsLinks(nn, ga);
// Must be declared as a GenAlg applied to a NeuraNet or links will
// get corrupted
GASetTypeNeuraNet(ga, NB_INPUT, NB_MAXHIDDEN, NB_OUTPUT);
GAInit(ga);
}
// If there is a NeuraNet available, reload it into the GenAlg
fd = fopen("./bestnn.txt", "r");
if (fd) {
    printf("Reloading previous NeuraNet...\n");
    if (!NNLoad(&nn, fd)) {
        printf("Failed to reload the NeuraNet.\n");
        NeuraNetFree(&nn);
        DataSetFree(&dataset);
        return;
    } else {
        printf("Previous NeuraNet reloaded.\n");
        bestVal = Evaluate(nn, dataset);
        printf("Starting with best at %f.\n", bestVal);
        GenAlgAdn* adn = GAAdn(ga, 0);
        VecCopy(adn->_adnF, nn->_bases);
        VecCopy(adn->_adnI, nn->_links);
    }
    fclose(fd);
}
// Start learning process
printf("Learning...\n");
printf("Will stop when curEpoch >= %lu or bestVal >= %f\n",
    limitEpoch, STOP_LEARNING_AT_VAL);
printf("Will save the best NeuraNet in ./bestnn.txt at each improvement\n");
fflush(stdout);
// Declare a variable to memorize the best value in the current epoch
float curBest = 0.0;
float curWorst = 0.0;
// Declare a variable to manage the save of GenAlg
int delaySave = 0;
// Learning loop
while (bestVal < STOP_LEARNING_AT_VAL &&
    GAGetCurEpoch(ga) < limitEpoch) {
    curWorst = curBest;
    curBest = INIT_BEST_VAL;
    int curBestI = 0;
    unsigned long int ageBest = 0;
    // For each adn in the GenAlg
    //for (int iEnt = GAGetNbAdns(ga); iEnt--;) {
    for (int iEnt = 0; iEnt < GAGetNbAdns(ga); ++iEnt) {
        // Get the adn
        GenAlgAdn* adn = GAAdn(ga, iEnt);
        // Set the links and base functions of the NeuraNet according
        // to this adn
        if (GABestAdnF(ga) != NULL)
            NNSetBases(nn, GAAdnAdnF(adn));
        if (GABestAdnI(ga) != NULL)
            NNSetLinks(nn, GAAdnAdnI(adn));
        // Evaluate the NeuraNet
        float value = Evaluate(nn, dataset);
        // Update the value of this adn
        GASetAdnValue(ga, adn, value);
        // Update the best value in the current epoch
        if (value > curBest) {
            curBest = value;

```

```

        curBestI = iEnt;
        ageBest = GAAdnGetAge(adn);
    }
    if (value < curWorst)
        curWorst = value;
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
// If there has been improvement during this epoch
if (curBest > bestVal) {
    bestVal = curBest;
    // Display info about the improvment
    printf("Improvement at epoch %05lu: %f(%03d) (in %02d:%02d:%02d:%02ds) \n",
        GAGetCurEpoch(ga), bestVal, curBestI, day, hour, min, sec);
    fflush(stdout);
    // Set the links and base functions of the NeuraNet according
    // to the best adn
    GenAlgAdn* bestAdn = GAAdn(ga, curBestI);
    if (GAAdnAdnF(bestAdn) != NULL)
        NNSetBases(nn, GAAdnAdnF(bestAdn));
    if (GAAdnAdnI(bestAdn) != NULL)
        NNSetLinks(nn, GAAdnAdnI(bestAdn));
    // Save the best NeuraNet
    fd = fopen("./bestnn.txt", "w");
    if (!NNSave(nn, fd, COMPACT)) {
        printf("Couldn't save the NeuraNet\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
} else {
    fprintf(stderr,
        "Epoch %05lu: v%f a%03lu(%03d) kt%03lu ",
        GAGetCurEpoch(ga), curBest, ageBest, curBestI,
        GAGetNbKTEvent(ga));
    fprintf(stderr, "(in %02d:%02d:%02d:%02ds) \r",
        day, hour, min, sec);
    fflush(stderr);
}
}
++delaySave;
if (SAVE_GA EVERY != 0 && delaySave >= SAVE_GA EVERY) {
    delaySave = 0;
    // Save the adns of the GenAlg, use a temporary file to avoid
    // loosing the previous one if something goes wrong during
    // writing, then replace the previous file with the temporary one
    fd = fopen("./bestga.tmp", "w");
    if (!GASave(ga, fd, COMPACT)) {
        printf("Couldn't save the GenAlg\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
}

```

```

    }
    fclose(fd);
    int ret = system("mv ./bestga.tmp ./bestga.txt");
    (void)ret;
}
// Step the GenAlg
GAStep(ga);
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
printf("\nLearning complete (in %d:%d:%d:ds)\n",
    day, hour, min, sec);
// Free memory
NeuraNetFree(&nn);
GenAlgFree(&ga);
DataSetFree(&dataset);
}

// Check the NeuraNet 'that' on the DataSetCat 'cat'
void Validate(const NeuraNet* const that, const DataSetCat cat) {
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Evaluate the NeuraNet
    float value = Evaluate(that, dataset);
    // Display the result
    printf("Value: %.6f\n", value);
    // Free memory
    DataSetFree(&dataset);
}

// Predict using the NeuraNet 'that' on 'inputs' (given as an array of
// 'nbInp' char*)
void Predict(const NeuraNet* const that, const int nbInp,
    char** const inputs) {
    // Start measuring time
    clock_t clockStart = clock();
    // Check the number of inputs
    if (nbInp != NNGetNbInput(that)) {
        printf("Wrong number of inputs, there should %d, there was %d\n",
            NNGetNbInput(that), nbInp);
        return;
    }
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Set the input
    for (int iInp = 0; iInp < nbInp; ++iInp) {
        float v = 0.0;
        sscanf(inputs[iInp], "%f", &v);
    }
}

```

```

    VecSet(input, iInp, v);
}
// Predict
NNEval(that, input, output);
int pred = -1;
if (VecGet(output, 0) > VecGet(output, 1) &&
    VecGet(output, 0) > VecGet(output, 2))
    pred = 0;
else if (VecGet(output, 1) > VecGet(output, 0) &&
    VecGet(output, 1) > VecGet(output, 2))
    pred = 1;
else if (VecGet(output, 2) > VecGet(output, 1) &&
    VecGet(output, 2) > VecGet(output, 0))
    pred = 2;
// End measuring time
clock_t clockEnd = clock();
double timeUsed =
    ((double)(clockEnd - clockStart)) / (CLOCKS_PER_SEC * 0.001);
// If the clock has been reset meanwhile
if (timeUsed < 0.0)
    timeUsed = 0.0;
printf("Prediction: %s (in %fms)\n", irisCatNames[pred], timeUsed);

// Free memory
VecFree(&input);
VecFree(&output);
}

int main(int argc, char** argv) {
    // Declare a variable to memorize the mode (learning/checking)
    int mode = -1;
    // Declare a variable to memorize the dataset used
    DataSetCat cat = unknownDataSet;
    // Decode mode from arguments
    if (argc >= 3) {
        if (strcmp(argv[1], "-learn") == 0) {
            mode = 0;
            cat = GetCategoryFromName(argv[2]);
        } else if (strcmp(argv[1], "-check") == 0) {
            mode = 1;
            cat = GetCategoryFromName(argv[2]);
        } else if (strcmp(argv[1], "-predict") == 0) {
            mode = 2;
        }
    }
    // If the mode is invalid print some help
    if (mode == -1) {
        printf("Select a mode from:\n");
        printf("-learn <dataset name>\n");
        printf("-check <dataset name>\n");
        printf("-predict <input values>\n");
        return 0;
    }
    if (mode == 0) {
        Learn(cat);
    } else if (mode == 1) {
        NeuraNet* nn = NULL;
        FILE* fd = fopen("./bestnn.txt", "r");
        if (!NNLoad(&nn, fd)) {
            printf("Couldn't load the best NeuraNet\n");
            return 0;
        }
    }
}

```

```

    fclose(fd);
    Validate(nn, cat);
    NeuraNetFree(&nn);
} else if (mode == 2) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Predict(nn, argc - 2, argv + 2);
    NeuraNetFree(&nn);
}
// Return success code
return 0;
}

```

## 7.2 Abalone data set

Source: <http://www.cs.toronto.edu/~delve/data/abalone/desc.html>

main.c:

```

#include <stdlib.h>
#include <stdio.h>
#include <time.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/time.h>
#include "pberr.h"
#include "genalg.h"
#include "neuranet.h"

// http://www.cs.toronto.edu/~delve/data/abalone/desc.html

// Nb of step between each save of the GenAlg
// Saving it allows to restart a stop learning process but is
// very time consuming if there are many input/hidden/output
// If 0 never save
#define SAVE_GA_EVERY 0
// Nb input and output of the NeuraNet
#define NB_INPUT 10
#define NB_OUTPUT 1
// Nb max of hidden values, links and base functions
#define NB_MAXHIDDEN 50
#define NB_MAXLINK 100
#define NB_MAXBASE NB_MAXLINK
// Size of the gene pool and elite pool
#define ADN_SIZE_POOL 500
#define ADN_SIZE_ELITE 20
// Initial best value during learning, must be lower than any
// possible value returned by Evaluate()
#define INIT_BEST_VAL -10000.0
// Value of the NeuraNet above which the learning process stops
#define STOP_LEARNING_AT_VAL -0.01
// Number of epoch above which the learning process stops

```

```

#define STOP_LEARNING_AT_EPOCH 5000
// Save NeuraNet in compact format
#define COMPACT true

// Categories of data sets

typedef enum DataSetCat {
    unknownDataSet,
    datalearn,
    datatest,
    dataall
} DataSetCat;
#define NB_DATASET 4
const char* dataSetNames[NB_DATASET] = {
    "unknownDataSet", "datalearn", "datatest", "dataall"
};

// Structure for the data set

typedef struct Abalone {
    float _props[10];
    float _age;
} Abalone;

typedef struct DataSet {
    // Category of the data set
    DataSetCat _cat;
    // Number of sample
    int _nbSample;
    // Samples
    Abalone* _samples;
    float _weights[29];
} DataSet;

// Get the DataSetCat from its 'name'
DataSetCat GetCategoryFromName(const char* const name) {
    // Declare a variable to memorize the DataSetCat
    DataSetCat cat = unknownDataSet;
    // Search the dataset
    for (int iSet = NB_DATASET; iSet--;)
        if (strcmp(name, dataSetNames[iSet]) == 0)
            cat = iSet;
    // Return the category
    return cat;
}

// Load the data set of category 'cat' in the DataSet 'that'
// Return true on success, else false
bool DataSetLoad(DataSet* const that, const DataSetCat cat) {
    // Set the category
    that->_cat = cat;

    // Load the data according to 'cat'
    FILE* f = fopen("./Prototask.data", "r");
    if (f == NULL) {
        printf("Couldn't open the data set file\n");
        return false;
    }
    char sex;
    int age;
    int ret = 0;
    if (cat == datalearn) {

```



```

that->_nbSample = 3000;
that->_samples =
    PBErrMalloc(NeuraNetErr, sizeof(Abalone) * that->_nbSample);
for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
    ret = fscanf(f, "%c %f %f %f %f %f %f %f %d\n",
        &sex,
        that->_samples[iSample]._props + 3,
        that->_samples[iSample]._props + 4,
        that->_samples[iSample]._props + 5,
        that->_samples[iSample]._props + 6,
        that->_samples[iSample]._props + 7,
        that->_samples[iSample]._props + 8,
        that->_samples[iSample]._props + 9,
        &age);
    if (ret == EOF) {
        printf("Couldn't read the dataset\n");
        fclose(f);
        return false;
    }
    that->_samples[iSample]._age = (float)age;
    if (sex == 'M') {
        that->_samples[iSample]._props[0] = 1.0;
        that->_samples[iSample]._props[1] = -1.0;
        that->_samples[iSample]._props[2] = -1.0;
    } else if (sex == 'F') {
        that->_samples[iSample]._props[0] = -1.0;
        that->_samples[iSample]._props[1] = 1.0;
        that->_samples[iSample]._props[2] = -1.0;
    } else if (sex == 'I') {
        that->_samples[iSample]._props[0] = -1.0;
        that->_samples[iSample]._props[1] = -1.0;
        that->_samples[iSample]._props[2] = 1.0;
    }
}
} else if (cat == datatest) {
    for (int iSample = 0; iSample < 3000; ++iSample) {
        float dummy;
        ret = fscanf(f, "%c %f %f %f %f %f %f %f %d\n",
            &sex,
            &dummy,
            &dummy,
            &dummy,
            &dummy,
            &dummy,
            &dummy,
            &dummy,
            &age);
        (void)dummy;
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
}
that->_nbSample = 1177;
that->_samples =
    PBErrMalloc(NeuraNetErr, sizeof(Abalone) * that->_nbSample);
for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
    ret = fscanf(f, "%c %f %f %f %f %f %f %f %d\n",
        &sex,
        that->_samples[iSample]._props + 3,
        that->_samples[iSample]._props + 4,

```



```

        printf("Invalid dataset\n");
        fclose(f);
        return false;
    }
    fclose(f);

    for (int iCat = 29; iCat--;)
        that->_weights[iCat] = 0.0;
    for (int iSample = that->_nbSample; iSample--;) {
        int cat = (int)round(that->_samples[iSample]._age) - 1;
        if (cat < 0 || cat >= 29) {
            printf("Invalid age #%d %f\n", iSample,
                that->_samples[iSample]._age);
            return false;
        }
        that->_weights[cat] += 1.0;
    }
    for (int iCat = 29; iCat--;)
        that->_weights[iCat] =
            ((float)(that->_nbSample) - that->_weights[iCat]) /
            (float)(that->_nbSample);

    // Return success code
    return true;
}

// Free memory for the DataSet 'that'
void DataSetFree(DataSet** that) {
    if (*that == NULL) return;
    // Free the memory
    free((*that)->_samples);
    free(*that);
    *that = NULL;
}

// Evaluation function for the NeuraNet 'that' on the DataSet 'dataset'
// Return the value of the NeuraNet, the bigger the better
float Evaluate(const NeuraNet* const that,
    const DataSet* const dataset) {
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Declare a variable to memorize the value
    float val = 0.0;

    // Evaluate

    int count[29] = {0};
    for (int iSample = dataset->_nbSample; iSample--;) {
        for (int iInp = 0; iInp < NNGetNbInput(that); ++iInp) {
            VecSet(input, iInp,
                dataset->_samples[iSample]._props[iInp]);
        }
        NNEval(that, input, output);

        float pred = VecGet(output, 0);
        float age = dataset->_samples[iSample]._age + 0.5;
        float v = fabs(pred - age);
        val -= v;
        if (dataset->_cat != datalearn) {
            int iErr = (int)round(v);
            ++(count[iErr]);
        }
    }
}

```

```

    }

}

val /= (float)(dataset->_nbSample);
if (dataset->_cat != datalearn) {
    float perc = 0.0;
    printf("age_err count cumul_perc\n");
    for (int iErr = 0; iErr < 29; ++ iErr) {
        perc += (float)(count[iErr]) / (float)(dataset->_nbSample);
        printf("%2d %4d %f\n", iErr, count[iErr], perc);
    }
}

// Free memory
VecFree(&input);
VecFree(&output);
// Return the result of the evaluation
return val;
}

// Create the NeuraNet
NeuraNet* createNN(void) {
    // Create the NeuraNet
    int nbIn = NB_INPUT;
    int nbOut = NB_OUTPUT;
    int nbMaxHid = NB_MAXHIDDEN;
    int nbMaxLink = NB_MAXLINK;
    int nbMaxBase = NB_MAXBASE;
    NeuraNet* nn =
        NeuraNetCreate(nbIn, nbOut, nbMaxHid, nbMaxBase, nbMaxLink);

    // Return the NeuraNet
    return nn;
}

// Learn based on the SataSetCat 'cat'
void Learn(DataSetCat cat) {
    // Init the random generator
    srand(time(NULL));
    // Declare variables to measure time
    struct timespec start, stop;
    // Start measuring time
    clock_gettime(CLOCK_REALTIME, &start);
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Create the NeuraNet
    NeuraNet* nn = createNN();
    // Declare a variable to memorize the best value
    float bestVal = INIT_BEST_VAL;
    // Declare a variable to memorize the limit in term of epoch
    unsigned long int limitEpoch = STOP_LEARNING_AT_EPOCH;
    // Create the GenAlg used for learning
    // If previous weights are available in "./bestga.txt" reload them
    GenAlg* ga = NULL;
    FILE* fd = fopen("./bestga.txt", "r");
    if (fd) {
        printf("Reloading previous GenAlg...\n");
    }

```

```

if (!GALoad(&ga, fd)) {
    printf("Failed to reload the GenAlg.\n");
    NeuraNetFree(&nn);
    DataSetFree(&dataset);
    return;
} else {
    printf("Previous GenAlg reloaded.\n");
    if (GABestAdnF(ga) != NULL)
        NNSetBases(nn, GABestAdnF(ga));
    if (GABestAdnI(ga) != NULL)
        NNSetLinks(nn, GABestAdnI(ga));
    bestVal = Evaluate(nn, dataset);
    printf("Starting with best at %f.\n", bestVal);
    limitEpoch += GAGetCurEpoch(ga);
}
fclose(fd);
} else {
    ga = GenAlgCreate(ADN_SIZE_POOL, ADN_SIZE_ELITE,
        NNGetGAAdnFloatLength(nn), NNGetGAAdnIntLength(nn));
    NNSetGABoundsBases(nn, ga);
    NNSetGABoundsLinks(nn, ga);
    // Must be declared as a GenAlg applied to a NeuraNet or links will
    // get corrupted
    GASetTypeNeuraNet(ga, NB_INPUT, NB_MAXHIDDEN, NB_OUTPUT);
    GAINit(ga);
}
// If there is a NeuraNet available, reload it into the GenAlg
fd = fopen("./bestnn.txt", "r");
if (fd) {
    printf("Reloading previous NeuraNet...\n");
    if (!NNLoad(&nn, fd)) {
        printf("Failed to reload the NeuraNet.\n");
        NeuraNetFree(&nn);
        DataSetFree(&dataset);
        return;
    } else {
        printf("Previous NeuraNet reloaded.\n");
        bestVal = Evaluate(nn, dataset);
        printf("Starting with best at %f.\n", bestVal);
        GenAlgAdn* adn = GAAdn(ga, 0);
        VecCopy(adn->_adnF, nn->_bases);
        VecCopy(adn->_adnI, nn->_links);
    }
    fclose(fd);
}
// Start learning process
printf("Learning...\n");
printf("Will stop when curEpoch >= %lu or bestVal >= %f\n",
    limitEpoch, STOP_LEARNING_AT_VAL);
printf("Will save the best NeuraNet in ./bestnn.txt at each improvement\n");
fflush(stdout);
// Declare a variable to memorize the best value in the current epoch
float curBest = 0.0;
float curWorst = 0.0;
// Declare a variable to manage the save of GenAlg
int delaySave = 0;
// Learning loop
while (bestVal < STOP_LEARNING_AT_VAL &&
    GAGetCurEpoch(ga) < limitEpoch) {
    curWorst = curBest;
    curBest = INIT_BEST_VAL;
    int curBestI = 0;

```

```

unsigned long int ageBest = 0;
// For each adn in the GenAlg
//for (int iEnt = GAGetNbAdns(ga); iEnt--;) {
for (int iEnt = 0; iEnt < GAGetNbAdns(ga); ++iEnt) {
    // Get the adn
    GenAlgAdn* adn = GAAdn(ga, iEnt);
    // Set the links and base functions of the NeuraNet according
    // to this adn
    if (GABestAdnF(ga) != NULL)
        NNSetBases(nn, GAAdnAdnF(adn));
    if (GABestAdnI(ga) != NULL)
        NNSetLinks(nn, GAAdnAdnI(adn));
    // Evaluate the NeuraNet
    float value = Evaluate(nn, dataset);
    // Update the value of this adn
    GASetAdnValue(ga, adn, value);
    // Update the best value in the current epoch
    if (value > curBest) {
        curBest = value;
        curBestI = iEnt;
        ageBest = GAAdnGetAge(adn);
    }
    if (value < curWorst)
        curWorst = value;
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
// If there has been improvement during this epoch
if (curBest > bestVal) {
    bestVal = curBest;
    // Display info about the improvment
    printf("Improvement at epoch %05lu: %f(%03d) (in %02d:%02d:%02d:%02ds) \n",
        GAGetCurEpoch(ga), bestVal, curBestI, day, hour, min, sec);
    fflush(stdout);
    // Set the links and base functions of the NeuraNet according
    // to the best adn
    GenAlgAdn* bestAdn = GAAdn(ga, curBestI);
    if (GAAdnAdnF(bestAdn) != NULL)
        NNSetBases(nn, GAAdnAdnF(bestAdn));
    if (GAAdnAdnI(bestAdn) != NULL)
        NNSetLinks(nn, GAAdnAdnI(bestAdn));
    // Save the best NeuraNet
    fd = fopen("./bestnn.txt", "w");
    if (!NNSave(nn, fd, COMPACT)) {
        printf("Couldn't save the NeuraNet\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
} else {
    fprintf(stderr,
        "Epoch %05lu: v%f a%03lu(%03d) kt%03lu ",

```

```

        GAGetCurEpoch(ga), curBest, ageBest, curBestI,
        GAGetNbKTEvent(ga));
    fprintf(stderr, "(in %02d:%02d:%02ds) \r",
        day, hour, min, sec);
    fflush(stderr);
}
++delaySave;
if (SAVE_GA_EVERY != 0 && delaySave >= SAVE_GA_EVERY) {
    delaySave = 0;
    // Save the adns of the GenAlg, use a temporary file to avoid
    // loosing the previous one if something goes wrong during
    // writing, then replace the previous file with the temporary one
    fd = fopen("./bestga.tmp", "w");
    if (!GASave(ga, fd, COMPACT)) {
        printf("Couldn't save the GenAlg\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
    int ret = system("mv ./bestga.tmp ./bestga.txt");
    (void)ret;
}
// Step the GenAlg
GAStep(ga);
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
printf("\nLearning complete (in %d:%d:%d:ds)\n",
    day, hour, min, sec);
// Free memory
NeuraNetFree(&nn);
GenAlgFree(&ga);
DataSetFree(&dataset);
}

// Check the NeuraNet 'that' on the DataSetCat 'cat'
void Validate(const NeuraNet* const that, const DataSetCat cat) {
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Evaluate the NeuraNet
    float value = Evaluate(that, dataset);
    // Display the result
    printf("Value: %.6f\n", value);
    // Free memory
    DataSetFree(&dataset);
}

```

```

// Predict using the NeuraNet 'that' on 'inputs' (given as an array of
// 'nbInp' char*)
void Predict(const NeuraNet* const that, const int nbInp,
char** const inputs) {
    // Check the number of inputs
    if (nbInp != NNGetNbInput(that)) {
        printf("Wrong number of inputs, there should %d, there was %d\n",
            NNGetNbInput(that), nbInp);
        return;
    }
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Set the input
    for (int iInp = 0; iInp < nbInp; ++iInp) {
        float v = 0.0;
        sscanf(inputs[iInp], "%f", &v);
        VecSet(input, iInp, v);
    }
    // Predict
    NNEval(that, input, output);
    printf("Prediction: %f rings\n", VecGet(output, 0));
    // Free memory
    VecFree(&input);
    VecFree(&output);
}

int main(int argc, char** argv) {
    // Declare a variable to memorize the mode (learning/checking)
    int mode = -1;
    // Declare a variable to memorize the dataset used
    DataSetCat cat = unknownDataSet;
    // Decode mode from arguments
    if (argc >= 3) {
        if (strcmp(argv[1], "-learn") == 0) {
            mode = 0;
            cat = GetCategoryFromName(argv[2]);
        } else if (strcmp(argv[1], "-check") == 0) {
            mode = 1;
            cat = GetCategoryFromName(argv[2]);
        } else if (strcmp(argv[1], "-predict") == 0) {
            mode = 2;
        }
    }
    // If the mode is invalid print some help
    if (mode == -1) {
        printf("Select a mode from:\n");
        printf("-learn <dataset name>\n");
        printf("-check <dataset name>\n");
        printf("-predict <input values>\n");
        return 0;
    }
    if (mode == 0) {
        Learn(cat);
    } else if (mode == 1) {
        NeuraNet* nn = NULL;
        FILE* fd = fopen("./bestnn.txt", "r");
        if (!NNLoad(&nn, fd)) {
            printf("Couldn't load the best NeuraNet\n");
            return 0;
        }
        fclose(fd);
    }
}

```



```

    Validate(nn, cat);
    NeuraNetFree(&nn);
} else if (mode == 2) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Predict(nn, argc - 2, argv + 2);
    NeuraNetFree(&nn);
}
// Return success code
return 0;
}

```

## 7.3 Arrhythmia data set

Source: <https://archive.ics.uci.edu/ml/datasets/arrhythmia>

main.c:

```

#include <stdlib.h>
#include <stdio.h>
#include <time.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/time.h>
#include "pberr.h"
#include "genalg.h"
#include "neuranet.h"

// https://archive.ics.uci.edu/ml/datasets/arrhythmia

// Nb of step between each save of the GenAlg
// Saving it allows to restart a stop learning process but is
// very time consuming if there are many input/hidden/output
// If 0 never save
#define SAVE_GA_EVERY 100
// Nb input and output of the NeuraNet
#define NB_INPUT 279
#define NB_OUTPUT 16
// Nb max of hidden values, links and base functions
#define NB_MAXHIDDEN 50
#define NB_MAXLINK 1000
#define NB_MAXBASE NB_MAXLINK
// Size of the gene pool and elite pool
#define ADN_SIZE_POOL 500
#define ADN_SIZE_ELITE 20
// Initial best value during learning, must be lower than any
// possible value returned by Evaluate()
#define INIT_BEST_VAL -100000.0
// Value of the NeuraNet above which the learning process stops
#define STOP_LEARNING_AT_VAL 0.999
// Number of epoch above which the learning process stops

```

```

#define STOP_LEARNING_AT_EPOCH 25000
// Save NeuraNet in compact format
#define COMPACT true

// Categories of data sets

typedef enum DataSetCat {
    unknownDataSet,
    datalearn,
    datatest,
    dataall
} DataSetCat;
#define NB_DATASET 4
const char* dataSetNames[NB_DATASET] = {
    "unknownDataSet", "datalearn", "datatest", "dataall"
};

const char* catNames[NB_OUTPUT] = {
    "Normal",
    "Ischemic changes (Coronary Artery Disease)",
    "Old Anterior Myocardial Infarction",
    "Old Inferior Myocardial Infarction",
    "Sinus tachycardy",
    "Sinus bradycardy",
    "Ventricular Premature Contraction (PVC)",
    "Supraventricular Premature Contraction",
    "Left bundle branch block",
    "Right bundle branch block",
    "1. degree AtrioVentricular block",
    "2. degree AV block",
    "3. degree AV block",
    "Left ventricle hypertrophy",
    "Atrial Fibrillation or Flutter",
    "Others"
};

typedef struct Arrhythmia {
    float _props[NB_INPUT];
    int _cat;
} Arrhythmia;

typedef struct DataSet {
    // Category of the data set
    DataSetCat _cat;
    // Number of sample
    int _nbSample;
    // Samples
    Arrhythmia* _samples;
} DataSet;

// Get the DataSetCat from its 'name'
DataSetCat GetCategoryFromName(const char* const name) {
    // Declare a variable to memorize the DataSetCat
    DataSetCat cat = unknownDataSet;
    // Search the dataset
    for (int iSet = NB_DATASET; iSet--;)
        if (strcmp(name, dataSetNames[iSet]) == 0)
            cat = iSet;
    // Return the category
    return cat;
}

```

```

}

// Load the data set of category 'cat' in the DataSet 'that'
// Return true on success, else false
bool DataSetLoad(DataSet* const that, const DataSetCat cat) {
    // Set the category
    that->_cat = cat;

    // Load the data according to 'cat'
    FILE* f = fopen("./arrhythmia.data", "r");
    if (f == NULL) {
        printf("Couldn't open the data set file\n");
        return false;
    }
    int ret = 0;
    if (cat == datalearn) {
        that->_nbSample = 300;
        that->_samples =
            PBErrMalloc(NeuraNetErr, sizeof(Arrhythmia) * that->_nbSample);
        for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
            for (int iProp = 0; iProp < NB_INPUT; ++iProp) {
                ret = fscanf(f, "%f,",
                    that->_samples[iSample]._props + iProp);
                if (ret == EOF) {
                    printf("Couldn't read the dataset\n");
                    fclose(f);
                    return false;
                }
            }
            ret = fscanf(f, "%d", &(that->_samples[iSample]._cat));
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
    } else if (cat == datatest) {
        char buffer[1000];
        for (int iSample = 0; iSample < 300; ++iSample) {
            ret = fscanf(f, "%s", buffer);
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
        that->_nbSample = 152;
        that->_samples =
            PBErrMalloc(NeuraNetErr, sizeof(Arrhythmia) * that->_nbSample);
        for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
            for (int iProp = 0; iProp < NB_INPUT; ++iProp) {
                ret = fscanf(f, "%f,",
                    that->_samples[iSample]._props + iProp);
                if (ret == EOF) {
                    printf("Couldn't read the dataset\n");
                    fclose(f);
                    return false;
                }
            }
        }
        ret = fscanf(f, "%d", &(that->_samples[iSample]._cat));
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");

```

```

        fclose(f);
        return false;
    }
}
} else if (cat == dataall) {
    that->_nbSample = 452;
    that->_samples =
        PBErrMalloc(NeuraNetErr, sizeof(Arrhythmia) * that->_nbSample);
    for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
        for (int iProp = 0; iProp < NB_INPUT; ++iProp) {
            ret = fscanf(f, "%f,",
                that->_samples[iSample]._props + iProp);
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
        ret = fscanf(f, "%d", &(that->_samples[iSample]._cat));
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
} else {
    printf("Invalid dataset\n");
    fclose(f);
    return false;
}
fclose(f);

// Return success code
return true;
}

// Free memory for the DataSet 'that'
void DataSetFree(DataSet** that) {
    if (*that == NULL) return;
    // Free the memory
    free((*that)->_samples);
    free(*that);
    *that = NULL;
}

// Evaluation function for the NeuraNet 'that' on the DataSet 'dataset'
// Return the value of the NeuraNet, the bigger the better
float Evaluate(const NeuraNet* const that,
    const DataSet* const dataset) {
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Declare a variable to memorize the value
    float val = 0.0;

    // Evaluate

    int countCat[NB_OUTPUT] = {0};
    int countOk[NB_OUTPUT] = {0};
    int countNg[NB_OUTPUT] = {0};
    for (int iSample = dataset->_nbSample; iSample--;) {
        for (int iInp = 0; iInp < NNGetNbInput(that); ++iInp) {

```

```

        VecSet(input, iInp,
            dataset->_samples[iSample]._props[iInp]);
    }
    NNEval(that, input, output);
    int pred = VecGetIMaxVal(output) + 1;
    ++(countCat[dataset->_samples[iSample]._cat - 1]);
    if (pred == dataset->_samples[iSample]._cat) {
        ++(countOk[dataset->_samples[iSample]._cat - 1]);
    } else if (dataset->_cat == datalearn) {
        ++(countNg[dataset->_samples[iSample]._cat - 1]);
    }
}

int nbCat = 0;
for (int iCat = 0; iCat < NB_OUTPUT; ++iCat) {
    if (countCat[iCat] > 0) {
        ++nbCat;
        float perc = 0.0;
        if (dataset->_cat != datalearn) {
            perc = (float)(countOk[iCat]) / (float)(countCat[iCat]);
            printf("%43s (%3d): %f\n", catNames[iCat], countCat[iCat], perc);
            val += countOk[iCat];
        } else {
            perc = (float)(countOk[iCat] - countNg[iCat]) /
                (float)(countCat[iCat]);
            val += perc;
        }
    }
}

if (dataset->_cat != datalearn)
    val /= (float)(dataset->_nbSample);
else
    val /= (float)nbCat;

// Free memory
VecFree(&input);
VecFree(&output);
// Return the result of the evaluation
return val;
}

// Create the NeuralNet
NeuralNet* createNN(void) {
    // Create the NeuralNet
    int nbIn = NB_INPUT;
    int nbOut = NB_OUTPUT;
    int nbMaxHid = NB_MAXHIDDEN;
    int nbMaxLink = NB_MAXLINK;
    int nbMaxBase = NB_MAXBASE;
    NeuralNet* nn =
        NeuralNetCreate(nbIn, nbOut, nbMaxHid, nbMaxBase, nbMaxLink);

    // Return the NeuralNet
    return nn;
}

// Learn based on the DataSetCat 'cat'
void Learn(DataSetCat cat) {
    // Init the random generator
    srand(time(NULL));
    // Declare variables to measure time
    struct timespec start, stop;

```

```

// Start measuring time
clock_gettime(CLOCK_REALTIME, &start);
// Load the DataSet
DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
bool ret = DataSetLoad(dataset, cat);
if (!ret) {
    printf("Couldn't load the data\n");
    return;
}
// Create the NeuraNet
NeuraNet* nn = createNN();
// Declare a variable to memorize the best value
float bestVal = INIT_BEST_VAL;
// Declare a variable to memorize the limit in term of epoch
unsigned long int limitEpoch = STOP_LEARNING_AT_EPOCH;
// Create the GenAlg used for learning
// If previous weights are available in "./bestga.txt" reload them
GenAlg* ga = NULL;
FILE* fd = fopen("./bestga.txt", "r");
if (fd) {
    printf("Reloading previous GenAlg...\n");
    if (!GALoad(&ga, fd)) {
        printf("Failed to reload the GenAlg.\n");
        NeuraNetFree(&nn);
        DataSetFree(&dataset);
        return;
    } else {
        printf("Previous GenAlg reloaded.\n");
        if (GABestAdnF(ga) != NULL)
            NNSetBases(nn, GABestAdnF(ga));
        if (GABestAdnI(ga) != NULL)
            NNSetLinks(nn, GABestAdnI(ga));
        bestVal = Evaluate(nn, dataset);
        printf("Starting with best at %f.\n", bestVal);
        limitEpoch += GAGetCurEpoch(ga);
    }
    fclose(fd);
} else {
    ga = GenAlgCreate(ADN_SIZE_POOL, ADN_SIZE_ELITE,
        NNGetGAAdnFloatLength(nn), NNGetGAAdnIntLength(nn));
    NNSetGABoundsBases(nn, ga);
    NNSetGABoundsLinks(nn, ga);
    // Must be declared as a GenAlg applied to a NeuraNet or links will
    // get corrupted
    GASetTypeNeuraNet(ga, NB_INPUT, NB_MAXHIDDEN, NB_OUTPUT);
    GAInit(ga);
}
// If there is a NeuraNet available, reload it into the GenAlg
fd = fopen("./bestnn.txt", "r");
if (fd) {
    printf("Reloading previous NeuraNet...\n");
    if (!NNLoad(&nn, fd)) {
        printf("Failed to reload the NeuraNet.\n");
        NeuraNetFree(&nn);
        DataSetFree(&dataset);
        return;
    } else {
        printf("Previous NeuraNet reloaded.\n");
        bestVal = Evaluate(nn, dataset);
        printf("Starting with best at %f.\n", bestVal);
        GenAlgAdn* adn = GAAdn(ga, 0);
        VecCopy(adn->adnF, nn->bases);
    }
}

```

```

    VecCopy(adn->_adnI, nn->_links);
}
fclose(fd);
}
// Start learning process
printf("Learning...\n");
printf("Will stop when curEpoch >= %lu or bestVal >= %f\n",
    limitEpoch, STOP_LEARNING_AT_VAL);
printf("Will save the best NeuraNet in ./bestnn.txt at each improvement\n");
fflush(stdout);
// Declare a variable to memorize the best value in the current epoch
float curBest = 0.0;
float curWorst = 0.0;
// Declare a variable to manage the save of GenAlg
int delaySave = 0;
// Learning loop
while (bestVal < STOP_LEARNING_AT_VAL &&
    GAGetCurEpoch(ga) < limitEpoch) {
    curWorst = curBest;
    curBest = INIT_BEST_VAL;
    int curBestI = 0;
    unsigned long int ageBest = 0;
    // For each adn in the GenAlg
    //for (int iEnt = GAGetNbAdns(ga); iEnt--;) {
    for (int iEnt = 0; iEnt < GAGetNbAdns(ga); ++iEnt) {
        // Get the adn
        GenAlgAdn* adn = GAAdn(ga, iEnt);
        // Set the links and base functions of the NeuraNet according
        // to this adn
        if (GABestAdnF(ga) != NULL)
            NNSetBases(nn, GAAdnAdnF(adn));
        if (GABestAdnI(ga) != NULL)
            NNSetLinks(nn, GAAdnAdnI(adn));
        // Evaluate the NeuraNet
        float value = Evaluate(nn, dataset);
        // Update the value of this adn
        GASetAdnValue(ga, adn, value);
        // Update the best value in the current epoch
        if (value > curBest) {
            curBest = value;
            curBestI = iEnt;
            ageBest = GAAdnGetAge(adn);
        }
        if (value < curWorst)
            curWorst = value;
    }
    // Measure time
    clock_gettime(CLOCK_REALTIME, &stop);
    float elapsed = stop.tv_sec - start.tv_sec;
    int day = (int)floor(elapsed / 86400);
    elapsed -= (float)(day * 86400);
    int hour = (int)floor(elapsed / 3600);
    elapsed -= (float)(hour * 3600);
    int min = (int)floor(elapsed / 60);
    elapsed -= (float)(min * 60);
    int sec = (int)floor(elapsed);
    // If there has been improvement during this epoch
    if (curBest > bestVal) {
        bestVal = curBest;
        // Display info about the improvment
        printf("Improvement at epoch %05lu: %f(%03d) (in %02d:%02d:%02d:%02ds) \n",
            GAGetCurEpoch(ga), bestVal, curBestI, day, hour, min, sec);
    }
}

```

```

fflush(stdout);
// Set the links and base functions of the NeuraNet according
// to the best adn
GenAlgAdn* bestAdn = GAAdn(ga, curBestI);
if (GAAdnAdnF(bestAdn) != NULL)
    NNSetBases(nn, GAAdnAdnF(bestAdn));
if (GAAdnAdnI(bestAdn) != NULL)
    NNSetLinks(nn, GAAdnAdnI(bestAdn));
// Save the best NeuraNet
fd = fopen("./bestnn.txt", "w");
if (!NNSave(nn, fd, COMPACT)) {
    printf("Couldn't save the NeuraNet\n");
    NeuraNetFree(&nn);
    GenAlgFree(&ga);
    DataSetFree(&dataset);
    return;
}
fclose(fd);
} else {
    fprintf(stderr,
        "Epoch %05lu: v%f a%03lu(%03d) kt%03lu ",
        GAGetCurEpoch(ga), curBest, ageBest, curBestI,
        GAGetNbKTEvent(ga));
    fprintf(stderr, "(in %02d:%02d:%02ds) \r",
        day, hour, min, sec);
    fflush(stderr);
}
++delaySave;
if (SAVE_GA_EVERY != 0 && delaySave >= SAVE_GA_EVERY) {
    delaySave = 0;
    // Save the adns of the GenAlg, use a temporary file to avoid
    // loosing the previous one if something goes wrong during
    // writing, then replace the previous file with the temporary one
    fd = fopen("./bestga.tmp", "w");
    if (!GASave(ga, fd, COMPACT)) {
        printf("Couldn't save the GenAlg\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
    int ret = system("mv ./bestga.tmp ./bestga.txt");
    (void)ret;
}
// Step the GenAlg
GAStep(ga);
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
printf("\nLearning complete (in %d:%d:%d:ds)\n",
    day, hour, min, sec);
// Free memory
NeuraNetFree(&nn);

```



```

    GenAlgFree(&ga);
    DataSetFree(&dataset);
}

// Check the NeuraNet 'that' on the DataSetCat 'cat'
void Validate(const NeuraNet* const that, const DataSetCat cat) {
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Evaluate the NeuraNet
    float value = Evaluate(that, dataset);
    // Display the result
    printf("Value: %.6f\n", value);
    // Free memory
    DataSetFree(&dataset);
}

// Predict using the NeuraNet 'that' on 'inputs' (given as an array of
// 'nbInp' char*)
void Predict(const NeuraNet* const that, const int nbInp,
    char** const inputs) {
    // Start measuring time
    clock_t clockStart = clock();
    // Check the number of inputs
    if (nbInp != NNGetNbInput(that)) {
        printf("Wrong number of inputs, there should %d, there was %d\n",
            NNGetNbInput(that), nbInp);
        return;
    }
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Set the input
    for (int iInp = 0; iInp < nbInp; ++iInp) {
        float v = 0.0;
        sscanf(inputs[iInp], "%f", &v);
        VecSet(input, iInp, v);
    }
    // Predict
    NNEval(that, input, output);
    int pred = VecGetIMaxVal(output);
    // End measuring time
    clock_t clockEnd = clock();
    double timeUsed =
        ((double)(clockEnd - clockStart)) / (CLOCKS_PER_SEC * 0.001);
    // If the clock has been reset meanwhile
    if (timeUsed < 0.0)
        timeUsed = 0.0;
    printf("Prediction: %s (in %fms)\n", catNames[pred], timeUsed);

    // Free memory
    VecFree(&input);
    VecFree(&output);
}

int main(int argc, char** argv) {
    // Declare a variable to memorize the mode (learning/checking)
    int mode = -1;

```

```

// Declare a variable to memorize the dataset used
DataSetCat cat = unknownDataSet;
// Decode mode from arguments
if (argc >= 3) {
    if (strcmp(argv[1], "-learn") == 0) {
        mode = 0;
        cat = GetCategoryFromName(argv[2]);
    } else if (strcmp(argv[1], "-check") == 0) {
        mode = 1;
        cat = GetCategoryFromName(argv[2]);
    } else if (strcmp(argv[1], "-predict") == 0) {
        mode = 2;
    }
}
// If the mode is invalid print some help
if (mode == -1) {
    printf("Select a mode from:\n");
    printf("-learn <dataset name>\n");
    printf("-check <dataset name>\n");
    printf("-predict <input values>\n");
    return 0;
}
if (mode == 0) {
    Learn(cat);
} else if (mode == 1) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Validate(nn, cat);
    NeuraNetFree(&nn);
} else if (mode == 2) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Predict(nn, argc - 2, argv + 2);
    NeuraNetFree(&nn);
}
// Return success code
return 0;
}

```

## 7.4 Wisconsin Diagnostic Breast Cancer

Source: <https://archive.ics.uci.edu/ml/datasets/Breast+Cancer+Wisconsin+Diagnostic>

main.c:

```

#include <stdlib.h>
#include <stdio.h>

```

```

#include <time.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/time.h>
#include "pberr.h"
#include "genalg.h"
#include "neuranet.h"

// https://archive.ics.uci.edu/ml/datasets/Breast+Cancer+Wisconsin+%28Diagnostic%29

// Nb of step between each save of the GenAlg
// Saving it allows to restart a stop learning process but is
// very time consuming if there are many input/hidden/output
// If 0 never save
#define SAVE_GA_EVERY 100
// Nb input and output of the NeuraNet
#define NB_INPUT 30
#define NB_OUTPUT 2
// Nb max of hidden values, links and base functions
#define NB_MAXHIDDEN 0
#define NB_MAXLINK 300
#define NB_MAXBASE NB_MAXLINK
// Size of the gene pool and elite pool
#define ADN_SIZE_POOL 100
#define ADN_SIZE_ELITE 20
// Initial best value during learning, must be lower than any
// possible value returned by Evaluate()
#define INIT_BEST_VAL -1000.0
// Value of the NeuraNet above which the learning process stops
#define STOP_LEARNING_AT_VAL 0.999
// Number of epoch above which the learning process stops
#define STOP_LEARNING_AT_EPOCH 5000
// Save NeuraNet in compact format
#define COMPACT true

// Categories of data sets

typedef enum DataSetCat {
    unknownDataSet,
    datalearn,
    datatest,
    dataall
} DataSetCat;
#define NB_DATASET 4
const char* dataSetNames[NB_DATASET] = {
    "unknownDataSet", "datalearn", "datatest", "dataall"
};

const char* catNames[NB_OUTPUT] = {
    "Malignant",
    "Benign"
};

// Structure for the data set

typedef struct Sample {
    float _props[NB_INPUT];
    int _cat;
    int _id;
} Sample;

```

```

typedef struct DataSet {
    // Category of the data set
    DataSetCat _cat;
    // Number of sample
    int _nbSample;
    // Samples
    Sample* _samples;
} DataSet;

// Get the DataSetCat from its 'name'
DataSetCat GetCategoryFromName(const char* const name) {
    // Declare a variable to memorize the DataSetCat
    DataSetCat cat = unknownDataSet;
    // Search the dataset
    for (int iSet = NB_DATASET; iSet--;)
        if (strcmp(name, dataSetNames[iSet]) == 0)
            cat = iSet;
    // Return the category
    return cat;
}

// Load the data set of category 'cat' in the DataSet 'that'
// Return true on success, else false
bool DataSetLoad(DataSet* const that, const DataSetCat cat) {
    // Set the category
    that->_cat = cat;

    // Load the data according to 'cat'
    FILE* f = fopen("./wdbc.data", "r");
    if (f == NULL) {
        printf("Couldn't open the data set file\n");
        return false;
    }
    int ret = 0;
    if (cat == datalearn) {
        that->_nbSample = 400;
        that->_samples =
            PBErrMalloc(NeuraNetErr, sizeof(Sample) * that->_nbSample);
        for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
            ret = fscanf(f, "%d,", &(that->_samples[iSample]._id));
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
            char cat;
            ret = fscanf(f, "%c,", &cat);
            if (ret == EOF) {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
            if (cat == 'M')
                that->_samples[iSample]._cat = 0;
            else if (cat == 'B')
                that->_samples[iSample]._cat = 1;
            else {
                printf("Couldn't read the dataset\n");
                fclose(f);
                return false;
            }
        }
        for (int iProp = 0; iProp < NB_INPUT; ++iProp) {

```

```

        ret = fscanf(f, "%f,",
            that->_samples[iSample]._props + iProp);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
}
} else if (cat == datatest) {
    char buffer[1000];
    for (int iSample = 0; iSample < 400; ++iSample) {
        ret = fscanf(f, "%s", buffer);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
    that->_nbSample = 169;
    that->_samples =
        PBErrMalloc(NeuraNetErr, sizeof(Sample) * that->_nbSample);
    for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
        ret = fscanf(f, "%d,", &(that->_samples[iSample]._id));
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
        char cat;
        ret = fscanf(f, "%c,", &cat);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
        if (cat == 'M')
            that->_samples[iSample]._cat = 0;
        else if (cat == 'B')
            that->_samples[iSample]._cat = 1;
        else {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
    for (int iProp = 0; iProp < NB_INPUT; ++iProp) {
        ret = fscanf(f, "%f,",
            that->_samples[iSample]._props + iProp);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
}
} else if (cat == dataall) {
    that->_nbSample = 569;
    that->_samples =
        PBErrMalloc(NeuraNetErr, sizeof(Sample) * that->_nbSample);
    for (int iSample = 0; iSample < that->_nbSample; ++iSample) {
        ret = fscanf(f, "%d,", &(that->_samples[iSample]._id));
        if (ret == EOF) {

```

```

        printf("Couldn't read the dataset\n");
        fclose(f);
        return false;
    }
    char cat;
    ret = fscanf(f, "%c", &cat);
    if (ret == EOF) {
        printf("Couldn't read the dataset\n");
        fclose(f);
        return false;
    }
    if (cat == 'M')
        that->_samples[iSample]._cat = 0;
    else if (cat == 'B')
        that->_samples[iSample]._cat = 1;
    else {
        printf("Couldn't read the dataset\n");
        fclose(f);
        return false;
    }
    for (int iProp = 0; iProp < NB_INPUT; ++iProp) {
        ret = fscanf(f, "%f",
            that->_samples[iSample]._props + iProp);
        if (ret == EOF) {
            printf("Couldn't read the dataset\n");
            fclose(f);
            return false;
        }
    }
}
} else {
    printf("Invalid dataset\n");
    fclose(f);
    return false;
}
fclose(f);

// Return success code
return true;
}

// Free memory for the DataSet 'that'
void DataSetFree(DataSet** that) {
    if (*that == NULL) return;
    // Free the memory

    free(*that);
    *that = NULL;
}

// Evaluation function for the NeuraNet 'that' on the DataSet 'dataset'
// Return the value of the NeuraNet, the bigger the better
float Evaluate(const NeuraNet* const that,
    const DataSet* const dataset) {
    // Declare 2 vectors to memorize the input and output values
    VecFloat* input = VecFloatCreate(NNGetNbInput(that));
    VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
    // Declare a variable to memorize the value
    float val = 0.0;

    // Evaluate

```

```

int countCat[NB_OUTPUT] = {0};
int countOk[NB_OUTPUT] = {0};
int countNg[NB_OUTPUT] = {0};
for (int iSample = dataset->_nbSample; iSample--;) {
    for (int iInp = 0; iInp < NNGetNbInput(that); ++iInp) {
        VecSet(input, iInp,
            dataset->_samples[iSample]._props[iInp]);
    }
    NNEval(that, input, output);
    int pred = VecGetIMaxVal(output);
    ++(countCat[dataset->_samples[iSample]._cat]);
    if (pred == dataset->_samples[iSample]._cat) {
        ++(countOk[dataset->_samples[iSample]._cat]);
    } else if (dataset->_cat == datalearn) {
        ++(countNg[dataset->_samples[iSample]._cat]);
    }
    if (dataset->_cat != datalearn) {
        printf("%010d %10s ", dataset->_samples[iSample]._id,
            catNames[pred]);
        if (pred == dataset->_samples[iSample]._cat)
            printf("OK");
        else
            printf("NG");
        printf("\n");
    }
}
int nbCat = 0;
for (int iCat = 0; iCat < NB_OUTPUT; ++iCat) {
    if (countCat[iCat] > 0) {
        ++nbCat;
        float perc = 0.0;
        if (dataset->_cat != datalearn) {
            perc = (float)(countOk[iCat]) / (float)(countCat[iCat]);
            printf("%10s (%3d): %f\n", catNames[iCat], countCat[iCat], perc);
            val += countOk[iCat];
        } else {
            perc = (float)(countOk[iCat] - countNg[iCat]) /
                (float)(countCat[iCat]);
            val += perc;
        }
    }
}
if (dataset->_cat != datalearn)
    val /= (float)(dataset->_nbSample);
else
    val /= (float)nbCat;

// Free memory
VecFree(&input);
VecFree(&output);
// Return the result of the evaluation
return val;
}

// Create the NeuraNet
NeuraNet* createNN(void) {
    // Create the NeuraNet
    int nbIn = NB_INPUT;
    int nbOut = NB_OUTPUT;
    int nbMaxHid = NB_MAXHIDDEN;
    int nbMaxLink = NB_MAXLINK;
    int nbMaxBase = NB_MAXBASE;

```

```

NeuraNet* nn =
    NeuraNetCreate(nbIn, nbOut, nbMaxHid, nbMaxBase, nbMaxLink);

// Set the links

//VecShort* links = VecShortCreate(nbMaxLink * NN_NBPARAMLINK);
//for (int iLink = VecGetDim(links); iLink--;) {
//    VecSet(links, iLink * NN_NBPARAMLINK, base index
//        -1 means inactive );
//    VecSet(links, iLink * NN_NBPARAMLINK + 1, input index );
//    VecSet(links, iLink * NN_NBPARAMLINK + 2, output index );
//}
//NNSetLinks(nn, links);
//VecFree(&links);

// Set the bases

//VecFloat* bases = VecFloatCreate(nbMaxBase * NN_NBPARAMBASE);
//for (int iBase = VecGetDim(bases); iBases--;) {
//    tan(param[0]*NN_THETA)*(x+param[1])+param[2]
//    param[] in [-1,1]
//    VecSet(bases, iBase * NN_NBPARAMBASE, );
//    VecSet(bases, iBase * NN_NBPARAMBASE + 1, );
//    VecSet(bases, iBase * NN_NBPARAMBASE + 2, );
//}
//NNSetBases(nn, bases);
//VecFree(&bases);

// Return the NeuraNet
return nn;
}

// Learn based on the SataSetCat 'cat'
void Learn(DataSetCat cat) {
    // Init the random generator
    srand(time(NULL));
    // Declare variables to measure time
    struct timespec start, stop;
    // Start measuring time
    clock_gettime(CLOCK_REALTIME, &start);
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Create the NeuraNet
    NeuraNet* nn = createNN();
    // Declare a variable to memorize the best value
    float bestVal = INIT_BEST_VAL;
    // Declare a variable to memorize the limit in term of epoch
    unsigned long int limitEpoch = STOP_LEARNING_AT_EPOCH;
    // Create the GenAlg used for learning
    // If previous weights are available in "./bestga.txt" reload them
    GenAlg* ga = NULL;
    FILE* fd = fopen("./bestga.txt", "r");
    if (fd) {
        printf("Reloading previous GenAlg...\n");
        if (!GALoad(&ga, fd)) {
            printf("Failed to reload the GenAlg.\n");
            NeuraNetFree(&nn);
        }
    }
}

```



```

    DataSetFree(&dataset);
    return;
} else {
    printf("Previous GenAlg reloaded.\n");
    if (GABestAdnF(ga) != NULL)
        NNSetBases(nn, GABestAdnF(ga));
    if (GABestAdnI(ga) != NULL)
        NNSetLinks(nn, GABestAdnI(ga));
    bestVal = Evaluate(nn, dataset);
    printf("Starting with best at %f.\n", bestVal);
    limitEpoch += GAGetCurEpoch(ga);
}
fclose(fd);
} else {
    ga = GenAlgCreate(ADN_SIZE_POOL, ADN_SIZE_ELITE,
        NNGetGAAdnFloatLength(nn), NNGetGAAdnIntLength(nn));
    NNSetGABoundsBases(nn, ga);
    NNSetGABoundsLinks(nn, ga);
    // Must be declared as a GenAlg applied to a NeuraNet or links will
    // get corrupted
    GASetTypeNeuraNet(ga, NB_INPUT, NB_MAXHIDDEN, NB_OUTPUT);
    GAInit(ga);
}
// If there is a NeuraNet available, reload it into the GenAlg
fd = fopen("./bestnn.txt", "r");
if (fd) {
    printf("Reloading previous NeuraNet...\n");
    if (!NNLoad(&nn, fd)) {
        printf("Failed to reload the NeuraNet.\n");
        NeuraNetFree(&nn);
        DataSetFree(&dataset);
        return;
    } else {
        printf("Previous NeuraNet reloaded.\n");
        bestVal = Evaluate(nn, dataset);
        printf("Starting with best at %f.\n", bestVal);
        GenAlgAdn* adn = GAAdn(ga, 0);
        VecCopy(adn->_adnF, nn->_bases);
        VecCopy(adn->_adnI, nn->_links);
    }
    fclose(fd);
}
// Start learning process
printf("Learning...\n");
printf("Will stop when curEpoch >= %lu or bestVal >= %f\n",
    limitEpoch, STOP_LEARNING_AT_VAL);
printf("Will save the best NeuraNet in ./bestnn.txt at each improvement\n");
fflush(stdout);
// Declare a variable to memorize the best value in the current epoch
float curBest = 0.0;
float curWorst = 0.0;
// Declare a variable to manage the save of GenAlg
int delaySave = 0;
// Learning loop
while (bestVal < STOP_LEARNING_AT_VAL &&
    GAGetCurEpoch(ga) < limitEpoch) {
    curWorst = curBest;
    curBest = INIT_BEST_VAL;
    int curBestI = 0;
    unsigned long int ageBest = 0;
    // For each adn in the GenAlg
    //for (int iEnt = GAGetNbAdns(ga); iEnt--;) {

```

```

for (int iEnt = 0; iEnt < GAGetNbAdns(ga); ++iEnt) {
    // Get the adn
    GenAlgAdn* adn = GAAdn(ga, iEnt);
    // Set the links and base functions of the NeuraNet according
    // to this adn
    if (GABestAdnF(ga) != NULL)
        NNSetBases(nn, GAAdnAdnF(adn));
    if (GABestAdnI(ga) != NULL)
        NNSetLinks(nn, GAAdnAdnI(adn));
    // Evaluate the NeuraNet
    float value = Evaluate(nn, dataset);
    // Update the value of this adn
    GASetAdnValue(ga, adn, value);
    // Update the best value in the current epoch
    if (value > curBest) {
        curBest = value;
        curBestI = iEnt;
        ageBest = GAAdnGetAge(adn);
    }
    if (value < curWorst)
        curWorst = value;
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
// If there has been improvement during this epoch
if (curBest > bestVal) {
    bestVal = curBest;
    // Display info about the improvment
    printf("Improvement at epoch %05lu: %f(%03d) (in %02d:%02d:%02d:%02ds) \n",
        GAGetCurEpoch(ga), bestVal, curBestI, day, hour, min, sec);
    fflush(stdout);
    // Set the links and base functions of the NeuraNet according
    // to the best adn
    GenAlgAdn* bestAdn = GAAdn(ga, curBestI);
    if (GAAdnAdnF(bestAdn) != NULL)
        NNSetBases(nn, GAAdnAdnF(bestAdn));
    if (GAAdnAdnI(bestAdn) != NULL)
        NNSetLinks(nn, GAAdnAdnI(bestAdn));
    // Save the best NeuraNet
    fd = fopen("./bestnn.txt", "w");
    if (!NNSave(nn, fd, COMPACT)) {
        printf("Couldn't save the NeuraNet\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
} else {
    fprintf(stderr,
        "Epoch %05lu: v%f a%03lu(%03d) kt%03lu ",
        GAGetCurEpoch(ga), curBest, ageBest, curBestI,
        GAGetNbKTEvent(ga));
    fprintf(stderr, "(in %02d:%02d:%02d:%02ds) \r",

```

```

        day, hour, min, sec);
    fflush(stderr);
}
++delaySave;
if (SAVE_GA_EVERY != 0 && delaySave >= SAVE_GA_EVERY) {
    delaySave = 0;
    // Save the adns of the GenAlg, use a temporary file to avoid
    // loosing the previous one if something goes wrong during
    // writing, then replace the previous file with the temporary one
    fd = fopen("./bestga.tmp", "w");
    if (!GASave(ga, fd, COMPACT)) {
        printf("Couldn't save the GenAlg\n");
        NeuraNetFree(&nn);
        GenAlgFree(&ga);
        DataSetFree(&dataset);
        return;
    }
    fclose(fd);
    int ret = system("mv ./bestga.tmp ./bestga.txt");
    (void)ret;
}
// Step the GenAlg
GAStep(ga);
}
// Measure time
clock_gettime(CLOCK_REALTIME, &stop);
float elapsed = stop.tv_sec - start.tv_sec;
int day = (int)floor(elapsed / 86400);
elapsed -= (float)(day * 86400);
int hour = (int)floor(elapsed / 3600);
elapsed -= (float)(hour * 3600);
int min = (int)floor(elapsed / 60);
elapsed -= (float)(min * 60);
int sec = (int)floor(elapsed);
printf("\nLearning complete (in %d:%d:%d:ds)\n",
    day, hour, min, sec);
// Free memory
NeuraNetFree(&nn);
GenAlgFree(&ga);
DataSetFree(&dataset);
}

// Check the NeuraNet 'that' on the DataSetCat 'cat'
void Check(const NeuraNet* const that, const DataSetCat cat) {
    // Load the DataSet
    DataSet* dataset = PBErrMalloc(NeuraNetErr, sizeof(DataSet));
    bool ret = DataSetLoad(dataset, cat);
    if (!ret) {
        printf("Couldn't load the data\n");
        return;
    }
    // Evaluate the NeuraNet
    float value = Evaluate(that, dataset);
    // Display the result
    printf("Value: %.6f\n", value);
    // Free memory
    DataSetFree(&dataset);
}

// Predict using the NeuraNet 'that' on 'inputs' (given as an array of
// 'nbInp' char*)
void Predict(const NeuraNet* const that, const int nbInp,

```

```

char** const inputs) {
// Start measuring time
clock_t clockStart = clock();
// Check the number of inputs
if (nbInp != NNGetNbInput(that)) {
    printf("Wrong number of inputs, there should %d, there was %d\n",
        NNGetNbInput(that), nbInp);
    return;
}
// Declare 2 vectors to memorize the input and output values
VecFloat* input = VecFloatCreate(NNGetNbInput(that));
VecFloat* output = VecFloatCreate(NNGetNbOutput(that));
// Set the input
for (int iInp = 0; iInp < nbInp; ++iInp) {
    float v = 0.0;
    sscanf(inputs[iInp], "%f", &v);
    VecSet(input, iInp, v);
}
// Predict
NNEval(that, input, output);

// End measuring time
clock_t clockEnd = clock();
double timeUsed =
    ((double)(clockEnd - clockStart)) / (CLOCKS_PER_SEC * 0.001);
// If the clock has been reset meanwhile
if (timeUsed < 0.0)
    timeUsed = 0.0;
//if (VecGet(output, 0) == ...)
// printf("...(in %fms)", timeUsed);

// Free memory
VecFree(&input);
VecFree(&output);
}

int main(int argc, char** argv) {
// Declare a variable to memorize the mode (learning/checking)
int mode = -1;
// Declare a variable to memorize the dataset used
DataSetCat cat = unknownDataSet;
// Decode mode from arguments
if (argc >= 3) {
    if (strcmp(argv[1], "-learn") == 0) {
        mode = 0;
        cat = GetCategoryFromName(argv[2]);
    } else if (strcmp(argv[1], "-check") == 0) {
        mode = 1;
        cat = GetCategoryFromName(argv[2]);
    } else if (strcmp(argv[1], "-predict") == 0) {
        mode = 2;
    }
}
// If the mode is invalid print some help
if (mode == -1) {
    printf("Select a mode from:\n");
    printf("-learn <dataset name>\n");
    printf("-check <dataset name>\n");
    printf("-predict <input values>\n");
    return 0;
}
if (mode == 0) {

```

```

    Learn(cat);
} else if (mode == 1) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Check(nn, cat);
    NeuraNetFree(&nn);
} else if (mode == 2) {
    NeuraNet* nn = NULL;
    FILE* fd = fopen("./bestnn.txt", "r");
    if (!NNLoad(&nn, fd)) {
        printf("Couldn't load the best NeuraNet\n");
        return 0;
    }
    fclose(fd);
    Predict(nn, argc - 2, argv + 2);
    NeuraNetFree(&nn);
}
// Return success code
return 0;
}

```