

# NeuraNet

P. Baillehache

July 23, 2018

## Contents

<b>1</b>	<b>Definitions</b>	<b>2</b>
<b>2</b>	<b>Interface</b>	<b>3</b>
<b>3</b>	<b>Code</b>	<b>8</b>
3.1	pbmath.c . . . . .	8
3.2	pbmath-inline.c . . . . .	15
<b>4</b>	<b>Makefile</b>	<b>19</b>
<b>5</b>	<b>Unit tests</b>	<b>20</b>
<b>6</b>	<b>Unit tests output</b>	<b>26</b>
<b>7</b>	<b>Validation</b>	<b>28</b>
7.1	Iris data set . . . . .	28

## 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 links 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;
} 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);

// 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 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, const 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'

#ifdef 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);
        }
    #endif
    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);
        }
    #endif
    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");
            PBErrCatch(NeuraNetErr);
        }
        if (ga == NULL) {
            NeuraNetErr->_type = PBErrTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'ga' is null");
            PBErrCatch(NeuraNetErr);
        }
        if (GAGetLengthAdnFloat(ga) != NNGetGAAdnFloatLength(that)) {
            NeuraNetErr->_type = PBErrTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'ga' 's float genes dimension doesn't\
matches 'that' 's max nb of bases (%d=%d)",
                GAGetLengthAdnFloat(ga), NNGetGAAdnFloatLength(that));
            PBErrCatch(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 = PBErrTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'that' is null");
            PBErrCatch(NeuraNetErr);
        }
        if (ga == NULL) {
            NeuraNetErr->_type = PBErrTypeNullPointer;
            sprintf(NeuraNetErr->_msg, "'ga' is null");
            PBErrCatch(NeuraNetErr);
        }
        if (GAGetLengthAdnInt(ga) != NNGetGAAdnIntLength(that)) {
            NeuraNetErr->_type = PBErrTypeInvalidArg;
            sprintf(NeuraNetErr->_msg, "'ga' 's int genes dimension doesn't\
matches 'that' 's max nb of links (%d==%d)",
                GAGetLengthAdnInt(ga), NNGetGAAdnIntLength(that));
            PBErrCatch(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);  
    }  
    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;
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;
}

// 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);
    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(&json);
    // 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);
    }
    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, const 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_NBPARAMLINK, -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 = PErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PErrCatch(NeuraNetErr);
    }
#endif
    return that->_nbMaxBases;
}

// 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 = PErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(NeuraNetErr->_msg, "'that' is null");
        PErrCatch(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) {
#if 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'
#if BUILDMODE != 0
inline
#endif
float NNGetHiddenValue(const NeuraNet* const that, const int iVal) {
#if 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]
#if BUILDMODE != 0
inline
#endif
void NNSetBases(NeuraNet* const that, const VecFloat* const bases) {
#if 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);
    }
#endif
}

```

```

        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=../PBMake/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() {
    srand(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) * PB_MATH_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->_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 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 (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) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNGetNbOutput failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNBases(nn) != nn->_bases) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNBases failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNLinks(nn) != nn->_links) {

```

```

        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNLinks failed");
        PBErrCatch(NeuraNetErr);
    }
    if (NNHiddenValues(nn) != nn->_hidVal) {
        NeuraNetErr->_type = PBErrTypeUnitTestFailed;
        sprintf(NeuraNetErr->_msg, "NNHiddenValues failed");
        PBErrCatch(NeuraNetErr);
    }
    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) {
            NeuraNetErr->_type = PBErrTypeUnitTestFailed;
            sprintf(NeuraNetErr->_msg, "NNSetBases failed");
            PBErrCatch(NeuraNetErr);
        }
    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]) {
            NeuraNetErr->_type = PBErrTypeUnitTestFailed;
            sprintf(NeuraNetErr->_msg, "NNSetLinks failed");
            PBErrCatch(NeuraNetErr);
        }
    VecFree(&links);
    NeuraNetFree(&nn);
    printf("UnitTestNeuraNetGetSet OK\n");
}

void UnitTestNeuraNetSaveLoad() {
    int nbIn = 10;
    int nbOut = 20;
    int nbHid = 30;
    int nbBase = 4;
    int nbLink = 5;
    NeuraNet* nn = NeuraNetCreate(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() {
    srand(RANDOMSEED);
    //srand(time(NULL));
    int nbIn = 3;
    int nbOut = 3;
    int nbHid = 3;
    int nbBase = 3;
    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);
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 + PBMMATH_EPSILON) {
        best = ev;
        printf("%lu %f\n", GAGetCurEpoch(ga), best);
    }
} 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();
    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
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,-0.500>
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 -0.604786
6 -0.508945
9 -0.500208
13 -0.429264
15 -0.317419
33 -0.305838
35 -0.288066
36 -0.282106
54 -0.205324
113 -0.205192
134 -0.199950
138 -0.160578
139 -0.155495
156 -0.155047
213 -0.153278
223 -0.151992
226 -0.151385
228 -0.150002
237 -0.149743
264 -0.149105
454 -0.149088
712 -0.147986
784 -0.147838
1016 -0.147825
1099 -0.147753
1146 -0.147734
1147 -0.147686
1209 -0.147620
1434 -0.147559
1531 -0.147531
1770 -0.147511
1926 -0.125417
1958 -0.086862
2606 -0.078863
2704 -0.063884
2757 -0.046113
2901 -0.012406
3580 -0.008830
4857 -0.008061
4884 -0.006819
5579 -0.006043
6200 -0.004625
7966 -0.004608
9220 -0.004588
9966 -0.004560
13969 -0.004186
```

```

14481 -0.004130
16733 -0.003722
28011 -0.003665
29249 -0.003654
best after 30000 epochs: -0.003654
nbInput: 3
nbOutput: 3
nbHidden: 3
nbMaxBases: 3
nbMaxLinks: 7
bases: <-0.509,0.460,0.482,0.500,-0.242,0.242,0.293,-0.590,0.297>
links: <0,0,4,2,0,4,2,1,3,1,1,7,1,3,4,1,4,6,-1,4,6>
hidden values: <0.500,-0.010,0.000>
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"]
  },
  "_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": "3",
  "_nbMaxLinks": "7",
  "_bases": {
    "_dim": "9",
    "_val": ["-0.509184", "0.459776", "0.481844", "0.500367", "-0.241875", "0.241957", "0.293099", "-0.590250", "0.296628"]
  },
  "_links": {
    "_dim": "21",
    "_val": ["0", "0", "4", "2", "0", "4", "2", "1", "3", "1", "1", "7", "1", "3", "4", "1", "4", "6", "-1", "4", "6"]
  }
}

```

## 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 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 1000
// 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 = -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;
        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));
    // 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) {
        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);
    GAInit(ga);
}
// Start learning process
printf("Learning...\n");
printf("Will stop when curEpoch >= %lu or bestVal >= %f\n",
    limitEpoch, STOP_LEARNING_AT_VAL);
fflush(stdout);
// Declare a variable to memorize the best value in the current epoch
float curBest = bestVal;
while (fabs(bestVal) < STOP_LEARNING_AT_VAL &&
    GAGetCurEpoch(ga) < limitEpoch) {
    // For each adn in the GenAlg
    for (int 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;
        // Display infos about the current epoch
        //printf("ep%lu ent%3d(age%6lu) val%.4f bestEpo%.4f bestAll%.4f\n",
        //    GAGetCurEpoch(ga), iEnt, GAAdnGetAge(adn), value, curBest,
        //    bestVal);
        fflush(stdout);
    }
    // Step the GenAlg
    GAStep(ga);
    // If there has been improvement during this epoch
    if (curBest > bestVal) {
        bestVal = curBest;
        // Display info about the improvment
        printf("\nImprovement at epoch %lu: %f\n",
            GAGetCurEpoch(ga), bestVal);
        fflush(stdout);
        // Set the links and base functions of the NeuraNet according
        // to the best adn
        if (GABestAdnF(ga) != NULL)
            NNSetBases(nn, GABestAdnF(ga));
        if (GABestAdnI(ga) != NULL)
            NNSetLinks(nn, GABestAdnI(ga));
        // 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;
        }
        printf("Saved the best NeuraNet in ./bestnn.txt\n");
        fclose(fd);
    }
}

```

```

    // 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;
}

printf("\nLearning complete\n");
// 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);
    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;
printf("Prediction: %s\n", irisCatNames[pred]);

// 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;
}

```

learning:

```

Learning...
Will stop when curEpoch >= 1000 or bestVal >= 0.999000

Improvement at epoch 1: 0.560000
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 3: 0.666667
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 29: 0.720000
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 51: 0.773333
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 54: 0.866667
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 217: 0.960000
Saved the best NeuraNet in ./bestnn.txt

Improvement at epoch 295: 0.973333
Saved the best NeuraNet in ./bestnn.txt

Learning complete

```

validation:

```

#74 pred2 real2 <-0.653,-1.009,0.000> OK
#73 pred2 real2 <-0.998,-1.386,0.000> OK
#72 pred2 real2 <-0.791,-1.386,0.000> OK
#71 pred2 real2 <-0.722,-1.386,0.000> OK
#70 pred2 real2 <-0.998,-1.386,0.000> OK
#69 pred2 real2 <-1.135,-1.386,0.000> OK
#68 pred2 real2 <-0.998,-1.386,0.000> OK
#67 pred2 real2 <-0.722,-1.386,0.000> OK
#66 pred2 real2 <-0.998,-1.386,0.000> OK
#65 pred2 real2 <-1.067,-1.386,0.000> OK
#64 pred2 real2 <-0.860,-1.386,0.000> OK
#63 pred2 real2 <-0.653,-1.009,0.000> OK
#62 pred2 real2 <-0.653,-1.009,0.000> OK
#61 pred2 real2 <-1.067,-1.386,0.000> OK
#60 pred2 real2 <-0.998,-1.386,0.000> OK
#59 pred1 real2 <-0.378,1.045,0.000> NG
#58 pred1 real2 <-0.447,0.682,0.000> NG
#57 pred2 real2 <-0.929,-1.386,0.000> OK
#56 pred2 real2 <-0.791,-1.386,0.000> OK
#55 pred2 real2 <-0.722,-1.386,0.000> OK
#54 pred1 real2 <-0.516,0.219,0.000> NG
#53 pred2 real2 <-0.860,-1.386,0.000> OK
#52 pred2 real2 <-0.653,-1.009,0.000> OK
#51 pred2 real2 <-0.653,-1.009,0.000> OK

```

```

#50 pred2 real2 <-0.653,-1.009,0.000> OK
#49 pred1 real1 <-0.309,1.307,0.000> OK
#48 pred1 real1 <-0.172,1.531,0.000> OK
#47 pred1 real1 <-0.309,1.307,0.000> OK
#46 pred1 real1 <-0.309,1.307,0.000> OK
#45 pred1 real1 <-0.240,1.469,0.000> OK
#44 pred1 real1 <-0.309,1.307,0.000> OK
#43 pred1 real1 <-0.103,1.492,0.000> OK
#42 pred1 real1 <-0.240,1.469,0.000> OK
#41 pred1 real1 <-0.378,1.045,0.000> OK
#40 pred1 real1 <-0.240,1.469,0.000> OK
#39 pred1 real1 <-0.309,1.307,0.000> OK
#38 pred1 real1 <-0.309,1.307,0.000> OK
#37 pred1 real1 <-0.309,1.307,0.000> OK
#36 pred1 real1 <-0.447,0.682,0.000> OK
#35 pred1 real1 <-0.516,0.219,0.000> OK
#34 pred1 real1 <-0.447,0.682,0.000> OK
#33 pred1 real1 <-0.516,0.219,0.000> OK
#32 pred1 real1 <-0.240,1.469,0.000> OK
#31 pred1 real1 <-0.103,1.492,0.000> OK
#30 pred1 real1 <-0.172,1.531,0.000> OK
#29 pred1 real1 <-0.103,1.492,0.000> OK
#28 pred1 real1 <-0.447,0.682,0.000> OK
#27 pred2 real1 <-0.585,-0.345,0.000> NG
#26 pred1 real1 <-0.378,1.045,0.000> OK
#25 pred1 real1 <-0.378,1.045,0.000> OK
#24 pred0 real0 <0.448,-1.386,0.000> OK
#23 pred0 real0 <0.448,-1.386,0.000> OK
#22 pred0 real0 <0.448,-1.386,0.000> OK
#21 pred0 real0 <0.448,-1.386,0.000> OK
#20 pred0 real0 <0.379,-1.386,0.000> OK
#19 pred0 real0 <0.310,-0.851,0.000> OK
#18 pred1 real0 <0.173,0.332,0.000> NG
#17 pred0 real0 <0.448,-1.386,0.000> OK
#16 pred0 real0 <0.379,-1.386,0.000> OK
#15 pred0 real0 <0.379,-1.386,0.000> OK
#14 pred0 real0 <0.448,-1.386,0.000> OK
#13 pred0 real0 <0.448,-1.386,0.000> OK
#12 pred0 real0 <0.517,-1.386,0.000> OK
#11 pred0 real0 <0.448,-1.386,0.000> OK
#10 pred0 real0 <0.448,-1.386,0.000> OK
#9 pred0 real0 <0.448,-1.386,0.000> OK
#8 pred0 real0 <0.448,-1.386,0.000> OK
#7 pred0 real0 <0.517,-1.386,0.000> OK
#6 pred0 real0 <0.310,-0.851,0.000> OK
#5 pred0 real0 <0.448,-1.386,0.000> OK
#4 pred0 real0 <0.448,-1.386,0.000> OK
#3 pred0 real0 <0.448,-1.386,0.000> OK
#2 pred0 real0 <0.448,-1.386,0.000> OK
#1 pred0 real0 <0.310,-0.851,0.000> OK
#0 pred0 real0 <0.448,-1.386,0.000> OK
Value: 0.933333

```