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 links has 3 parameters: the base function index and the indices of two 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 average value of all these links is used. However if several links have same first and second value, these values are multiplied instead of average (but they can still be part of an average value due to other links having same second value).

The generic base functions is a linear function. However by using several links with same first and second value it is possible to simulate any polynomial function. Also, there is no concept of layer inside hidden values, but the first value index is constrained to be lower than the second 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, all 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 in the unit tests (see below). It also provides functions to save and load the neural network (in JSON format).

It uses the `PBErr` library.

1 Definitions

The generic base function is defined as follow:

$$B(x) = [tan(1.57079 * b_o)(x + b_1) + b_2] \cap [-1.0, 1.0] \tag{1}$$

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

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 ip)
  // 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'
#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
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) {
#if 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 a vector to memorize the nb of links in input of each
    // hidden values and output values
```

```
VecShort* nbIn =
  VecShortCreate(NNGetNbMaxHidden(that) + NNGetNbOutput(that));
// 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)
      VecSetAdd(that->_hidVal, prevLink[1] - startHid,
        prevOut);
    else
      VecSetAdd(output, prevLink[1] - startOut, prevOut);
    // Increment the nb of input on this output
    VecSetAdd(nbIn, prevLink[1] - startHid, 1);
    // 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 {
    int n = VecGet(nbIn, prevLink[0] - startHid);
    if (n > 0)
      x = NNGetHiddenValue(that, prevLink[0] - startHid) /
        (float)(VecGet(nbIn, prevLink[0] - startHid));
    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)
  VecSetAdd(that->_hidVal, prevLink[1] - startHid, prevOut);
else
  VecSetAdd(output, prevLink[1] - startOut, prevOut);
// Normalise output
```

```
    for (int iVal = VecGetDim(output); iVal--;) {
      int n = VecGet(nbIn, NNGetNbMaxHidden(that) + iVal);
      if (n > 0)
        VecSet(output, iVal, VecGet(output, iVal) / (float)(n));
    }
    // Free memory
    VecFree(&nbIn);
  }
}

// Function which return the JSON encoding of 'that'
JSONNode* NNEncodeAsJSON(const NeuraNet* const that) {
#if 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) {
#if 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) {
#if 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) {
#if 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) {
#if 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
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, 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) {
#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]));
}

// ----- 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 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) {
#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'
#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);
    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?=0

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() {
  srandom(RANDOMSEED);
  float param[4];
  float x = 0.0;
  float check[100] = {
    -1.000000, -1.000000, -1.000000, -1.000000, -1.000000, -0.942763,
    -0.198322, 0.546119, 1.000000, 1.000000,
    -0.153181, -0.403978, -0.654776, -0.905573, -1.000000, -1.000000,
    -1.000000, -1.000000, -1.000000, -1.000000,
    0.586943, 0.301165, 0.015387, -0.270391, -0.556169, -0.841946,
    -1.000000, -1.000000, -1.000000, -1.000000,
    1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000,
    1.000000, 1.000000, 1.000000, 1.000000,
    0.774302, 0.903425, 1.000000, 1.000000, 1.000000, 1.000000,
    1.000000, 1.000000, 1.000000, 1.000000,
    1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000,
    0.990941, 0.769129, 0.547316, 0.325503,
    -1.000000, -1.000000, -1.000000, -1.000000, -1.000000, -1.000000,
    -1.000000, -1.000000, -1.000000, -1.000000,
    1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000,
    1.000000, 0.885544, 0.721949, 0.558353,
    -1.000000, -1.000000, -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->_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] = -input[0]^2
  // hidden[1] = input[1]
  // hidden[2] = 0
  // output[0] = 0.5*(-input[0]^2+input[1])
  // output[1] = input[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, -0.999987 * fsquare(VecGet(&input, 0)));
        VecSet(&checkhidden, 1, 0.999993 * VecGet(&input, 1));
        VecSet(&check, 0,
          MIN(1.0, MAX(-1.0,
            0.999993 * 0.5 *
            (VecGet(&checkhidden, 0) + VecGet(&checkhidden, 1)))));
        VecSet(&check, 1, 0.999993 * 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 = 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 + PBMATH_EPSILON) {
      best = ev;
      //printf("%lu %f\n", GAGetCurEpoch(ga), best);
    }
  } while (GAGetCurEpoch(ga) < 30000 && fabs(ev) > 0.001);
  //} while (GAGetCurEpoch(ga) < 1000 && 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 -0.621710
2 -0.539164
8 -0.416343
10 -0.402651
12 -0.366091
19 -0.355705
20 -0.342678
22 -0.283724
62 -0.278337
66 -0.277408
72 -0.250874
96 -0.246221
103 -0.240864
113 -0.221478
132 -0.217908
189 -0.155083
584 -0.153605
807 -0.152597
1042 -0.147290
1897 -0.121800
4131 -0.114876
5198 -0.095572
5721 -0.095323
5782 -0.074770
5783 -0.068544
5813 -0.065053
5831 -0.035593
6289 -0.035501
9837 -0.035274
10135 -0.035255
10877 -0.032974
11876 -0.032607
11894 -0.030934
13556 -0.030315
15149 -0.025750
18384 -0.017932
19108 -0.017667
19399 -0.017429
20255 -0.017124
22935 -0.014303
27486 -0.014280
29007 -0.014146
29035 -0.012076
best after 30000 epochs: -0.012076
nbInput: 3
nbOutput: 3
nbHidden: 3
nbMaxBases: 3
nbMaxLinks: 7
bases: <0.505,-0.820,0.832,-0.313,0.050,-0.576,-0.520,0.646,0.701>
links: <2,0,6,0,0,6,0,1,6,0,1,7,0,4,5,1,4,5,0,4,5>
hidden values: <0.000,0.000,-0.000>
```

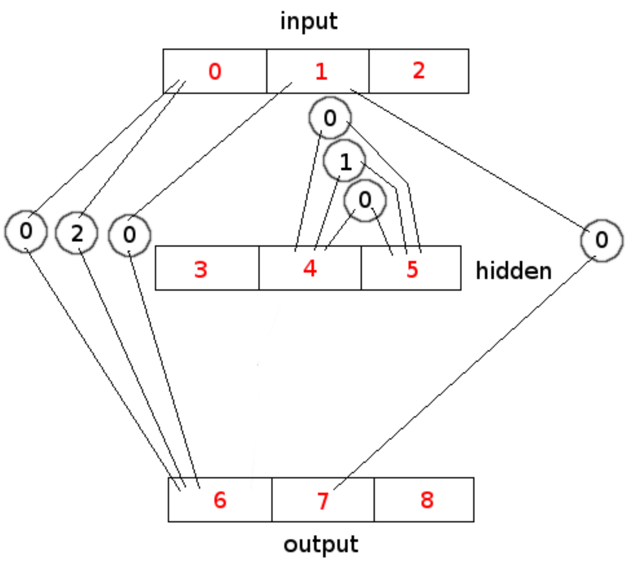
```
UnitTestNeuraNetGA OK
UnitTestNeuraNet OK
UnitTestAll OK
```

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","0.090
  },
  "_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":["0.492266","0.516816","-0.497218","-0.523279","0.228539","0.244892","-0.962093","0.683694","-0.615289"]
  },
  "_links":{
    "_dim":"21",
    "_val":["1","0","6","0","0","6","0","1","6","0","1","7","0","3","4","2","4","4","-1","4","4"]
  }
}
```



Bases:

id	B(x)
0	$tan(0.504549 * 1.57079) * (x - 0.819784) + 0.832003 = 1.014387x + 0.000414$
1	$tan(-0.313292 * 1.57079) * (x + 0.050474) - 0.576482 = -0.536109x - 0.603541$
2	$tan(-0.519646 * 1.57079) * (x + 0.646151) + 0.701341 = -1.063698x + 0.01403$

Values:

id	value
0	x
1	y
2	z
6	$(-1.079001x^2 + 0.01379x + 1.014387y + 0.000419)/2$ (target: $(-x^2 + y)/2$)
7	$1.014387y + 0.000414$ (target: y)
8	0 (target: 0)