GenAlg

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July 21, 2018

Contents

Introduction

GenAlg is a C library providing structures and functions implementing a Genetic Algorithm.

The genes are memorized as a VecFloat and/or VecShort. The user can defined a range of possible values for each gene. The user can define the size of the pool of entities and the size of the breeding pool. Selection, reproduction and mutation are designed to efficiently explore all the possible gene combination, and avoid local optimum. It is also possible to save and load

the GenAlg.

It uses the `PBErr`, `PBMath` and `GSet` libraries.

1 Definitions

A genetic algorithm has 3 steps. In a pool of entities it discards a given number of entities based on their ranking (given by a mean external to the algorithm). Then it replaces each of the discarded entity by a new one created from two selected entities from hte non discarded one. The newly created entity's properties are a mix of these two selected entities, plus a certain amount of random modification. The detail of the implementation in GenAlg of these 3 steps (selection, reproduction and mutation) are given below.

1.1 Selection

The non discarded entities are called 'elite' in GenAlg. The size of the pool of elite is configurable by the user. The selection of two elite entities is simply a random selection in the pool of elites. Selection of the same elite twice is allowed.

1.2 Reproduction

The reproduction step copies the genes of the elite entity into the new entity. Each gene has a probability of 50% to be chosen in one or the other elite.

1.3 Mutation

The mutation occurs as follow. First we calculate the probability of mutation for every gene as follow: $P = \frac{rank}{nbEntity}$ where rank is the rank of the discarded entity in the pool of entities, and nbEntity is the number of entities in the pool. A gene affected by a mutation according to this probability is modified as follow. The amplitude of the mutation is equal to $1 - \frac{1}{\sqrt{age+1}}$ where age is the age of the oldest elite entity used during the reproduction step for the entity. Then the new value of the gene is equals

to $gene + range * amp * (rnd + delta)$ where gene is the current value of the gene, range is equal to $max_{gene} - min_{gene}$ (the difference of the maximum allowed value for this gene and its minimum value), amp is the amplitude calculated above, rnd is a random value between -0.5 and 0.5, and delta is the mutation that has been applied to this gene in the corresponding elite entity. Genes' value is kept in bounds by bouncing it on the bounds when necessary ($gene = 2 * bound - gene$)

To counteract inbreeding (the algorithm getting stuck into a local minimum), we also apply mutation to all the entities except the best one when the diversity level of the elite pool fall below a threshold (set to 0.01 by default). The diversity level is calculated as follow $\frac{1}{nbElite} \sum_{i=1}^{nbElite} \frac{||\overrightarrow{adn}(elite_i) - \overrightarrow{adn}(elite_0)||}{||\overrightarrow{bound}_{max} - \overrightarrow{bound}_{min}||}$ where nbElite is the number of elite entities, $\overrightarrow{adn}(elite_i)$ is the genes vector of the i-th elite entity, and $\overrightarrow{bound}_{max}$ and $\overrightarrow{bound}_{min}$ are the vector of maximum and minimum values of the genes.

Some explanation: delta bias the mutation toward the direction that improved the result at previous step; in the pool of discarded entities high ranked ones tend to have few mutations and low ranked ones tend to have more mutation, this tends to cover any posibilities of evolution; entities newly entered in the elite pool tends to produce new entities near to them (in term of distance in the genes space), while older ones tend to produce more diverse new entities, thus the exploration of solution space occurs from the vicinity of newly better solutions toward larger areas; from the previous point, a good entity tends to create a lot of similar entity, which may lead to an elite pool saturated with very similar entities (inbreeding) from which the algorithm can't escape, this is prevented by the forced mutation of elites when the inbreeding level gets too high.

2 Interface

```
// ============ GENALG.H ================

#ifndef GENALG_H
#define GENALG_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"

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

#define GENALG_NBENTITIES 100
#define GENALG_NBELITES 20
#define GENALG_DIVERSITYTHRESHOLD 0.01

// ------------- GenAlgAdn

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

typedef struct GenAlg GenAlg;

typedef struct GenAlgAdn {
  // ID
  unsigned long int _id;
  // Age
  unsigned long int _age;
  // Adn for floating point value
  VecFloat* _adnF;
  // Delta Adn during mutation for floating point value
  VecFloat* _deltaAdnF;
  // Adn for integer point value
  VecShort* _adnI;
} GenAlgAdn;

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

// Create a new GenAlgAdn with ID 'id', 'lengthAdnF' and 'lengthAdnI'
// 'lengthAdnF' and 'lengthAdnI' must be greater than or equal to 0
GenAlgAdn* GenAlgAdnCreate(const int id, const int lengthAdnF,
  const int lengthAdnI);

// Free memory used by the GenAlgAdn 'that'
void GenAlgAdnFree(GenAlgAdn** that);

// Return the adn for floating point values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* GAAdnAdnF(const GenAlgAdn* const that);

// Return the delta of adn for floating point values of the
// GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* GAAdnDeltaAdnF(const GenAlgAdn* const that);

// Return the adn for integer values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecShort* GAAdnAdnI(const GenAlgAdn* const that);

// Initialise randomly the genes of the GenAlgAdn 'that' of the
// GenAlg 'ga'
void GAAdnInit(const GenAlgAdn* const that, const GenAlg* ga);
```

```
// Get the 'iGene'-th gene of the adn for floating point values of the
// GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
float GAAdnGetGeneF(const GenAlgAdn* const that, const int iGene);

// Get the delta of the 'iGene'-th gene of the adn for floating point
// values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
float GAAdnGetDeltaGeneF(const GenAlgAdn* const that, const int iGene);

// Get the 'iGene'-th gene of the adn for int values of the
// GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
int GAAdnGetGeneI(const GenAlgAdn* const that, const int iGene);

// Set the 'iGene'-th gene of the adn for floating point values of the
// GenAlgAdn 'that' to 'gene'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetGeneF(GenAlgAdn* const that, const int iGene,
  const float gene);

// Set the delta of the 'iGene'-th gene of the adn for floating point
// values of the GenAlgAdn 'that' to 'delta'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetDeltaGeneF(GenAlgAdn* const that, const int iGene,
  const float delta);

// Set the 'iGene'-th gene of the adn for int values of the
// GenAlgAdn 'that'to 'gene'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetGeneI(GenAlgAdn* const that, const int iGene,
  const short gene);

// Get the id of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAAdnGetId(const GenAlgAdn* const that);

// Get the age of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAAdnGetAge(const GenAlgAdn* const that);

// Print the information about the GenAlgAdn 'that' on the
// stream 'stream'
void GAAdnPrintln(const GenAlgAdn* const that, FILE* const stream);
```

```
// Return true if the GenAlgAdn 'that' is new, i.e. is age equals 1
// Return false
#if BUILDMODE != 0
inline
#endif
bool GAAdnIsNew(const GenAlgAdn* const that);

// ------------- GenAlg

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

#define GABestAdnF(that) GAAdnAdnF(GAAdn(that, 0))
#define GABestAdnI(that) GAAdnAdnI(GAAdn(that, 0))

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

typedef struct GenAlg {
  // GSet of GenAlgAdn, sortval == score so the head of the set is the
  // worst adn and the tail of the set is the best
  GSet* _adns;
  // Current epoch
  unsigned long int _curEpoch;
  // Nb elite entities in population
  int _nbElites;
  // Id of the next new GenAlgAdn
  unsigned long int _nextId;
  // Length of adn for floating point value
  const int _lengthAdnF;
  // Length of adn for integer value
  const int _lengthAdnI;
  // Bounds (min, max) for floating point values adn
  VecFloat2D* _boundsF;
  // Bounds (min, max) for integer values adn
  VecShort2D* _boundsI;
  // Diversity threshold for KTEvent
  float _diversityThreshold;
  // Norm of the range value for adns (optimization for diversity
  // calculation)
  float _normRangeFloat;
  float _normRangeInt;
} GenAlg;

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

// Create a new GenAlg with 'nbEntities', 'nbElites', 'lengthAdnF'
// and 'lengthAdnI'
// 'nbEntities' must greater than 2
// 'nbElites' must greater than 1
// 'lengthAdnF' and 'lengthAdnI' must be greater than or equal to 0
GenAlg* GenAlgCreate(const int nbEntities, const int nbElites,
  const int lengthAdnF, const int lengthAdnI);

// Free memory used by the GenAlg 'that'
void GenAlgFree(GenAlg** that);

// Return the GSet of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
GSet* GAAdns(const GenAlg* const that);

// Return the nb of entities of the GenAlg 'that'
```

```
#if BUILDMODE != 0
inline
#endif
int GAGetNbAdns(const GenAlg* const that);

// Return the nb of elites of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
int GAGetNbElites(const GenAlg* const that);

// Return the diversity threshold of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
float GAGetDiversityThreshold(const GenAlg* const that);

// Set the diversity threshold of the GenAlg 'that' to 'div'
#if BUILDMODE != 0
inline
#endif
void GASetDiversityThreshold(GenAlg* const that, const float div);

// Return the current epoch of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAGetCurEpoch(const GenAlg* const that);

// Set the nb of entities of the GenAlg 'that' to 'nb'
// 'nb' must be greater than 1, if 'nb' is lower than the current nb
// of elite the number of elite is set to 'nb' - 1
void GASetNbEntities(GenAlg* const that, const int nb);

// Set the nb of elites of the GenAlg 'that' to 'nb'
// 'nb' must be greater than 0, if 'nb' is greater or equal to the
// current nb of entities the number of entities is set to 'nb' + 1
void GASetNbElites(GenAlg* const that, const int nb);

// Get the length of adn for floating point value
#if BUILDMODE != 0
inline
#endif
int GAGetLengthAdnFloat(const GenAlg* const that);

// Get the length of adn for integer value
#if BUILDMODE != 0
inline
#endif
int GAGetLengthAdnInt(const GenAlg* const that);

// Get the bounds for the 'iGene'-th gene of adn for floating point
// values
#if BUILDMODE != 0
inline
#endif
const VecFloat2D* GABoundsAdnFloat(const GenAlg* const that,
  const int iGene);

// Get the bounds for the 'iGene'-th gene of adn for integer values
#if BUILDMODE != 0
inline
```

```
#endif
const VecShort2D* GABoundsAdnInt(const GenAlg* const that,
  const int iGene);

// Set the bounds for the 'iGene'-th gene of adn for floating point
// values to a copy of 'bounds'
#if BUILDMODE != 0
inline
#endif
void GASetBoundsAdnFloat(GenAlg* const that, const int iGene,
  const VecFloat2D* const bounds);

// Set the bounds for the 'iGene'-th gene of adn for integer values
// to a copy of 'bounds'
#if BUILDMODE != 0
inline
#endif
void GASetBoundsAdnInt(GenAlg* const that, const int iGene,
  const VecShort2D* bounds);

// Get the GenAlgAdn of the GenAlg 'that' currently at rank 'iRank'
#if BUILDMODE != 0
inline
#endif
GenAlgAdn* GAAdn(const GenAlg* const that, const int iRank);

// Init the GenAlg 'that'
// Must be called after the bounds have been set
// The random generator must have been initialised before calling this
// function
void GAInit(GenAlg* const that);

// Step an epoch for the GenAlg 'that' with the current ranking of
// GenAlgAdn
void GAStep(GenAlg* const that);

// Print the information about the GenAlg 'that' on the stream 'stream'
void GAPrintln(const GenAlg* const that, FILE* const stream);

// Get the average diversity of current entities of the GenAlg 'that'
// The return value is in [0.0, 1.0]
// 0.0 means all the elite entities have exactly the same adns
// 1.0 means all the elite entities except the first one have adns
// as different compare to the first one's adn as possible given the
// range of adn values
float GAGetDiversity(const GenAlg* const that);

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

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

// Load the GenAlg 'that' from the stream 'stream'
// If the GenAlg is already allocated, it is freed before loading
// Return true in case of success, else false
bool GALoad(GenAlg** that, FILE* const stream);

// Save the GenAlg 'that' to the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true in case of success, else false
```

```
bool GASave(const GenAlg* const that, FILE* const stream,
  const bool compact);

// Set the value of the GenAlgAdn 'adn' of the GenAlg 'that' to 'val'
#if BUILDMODE != 0
inline
#endif
void GASetAdnValue(GenAlg* const that, const GenAlgAdn* const adn,
  const float val);

// Update the norm of the range value for adans of the GenAlg 'that'
void GAUpdateNormRange(GenAlg* const that);


// ================= Polymorphism ==================

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

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


#endif
```

3 Code

3.1 genalg.c

```
// ============ GENALG.C ================

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

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

// ------------- GenAlgAdn

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

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

// Create a new GenAlgAdn with ID 'id', 'lengthAdnF' and 'lengthAdnI'
// 'lengthAdnF' and 'lengthAdnI' must be greater than or equal to 0
GenAlgAdn* GenAlgAdnCreate(const int id, const int lengthAdnF,
  const int lengthAdnI) {
#if BUILDMODE == 0
  if (lengthAdnF < 0) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'lengthAdnF' is invalid (%d>=0)",
      lengthAdnF);
    PBErrCatch(GenAlgErr);
  }
  if (lengthAdnI < 0) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'lengthAdnI' is invalid (%d>=0)",
```

```
      lengthAdnI);
    PBErrCatch(GenAlgErr);
  }
#endif
  // Allocate memory
  GenAlgAdn* that = PBErrMalloc(GenAlgErr, sizeof(GenAlgAdn));
  // Set the properties
  that->_age = 1;
  that->_id = id;
  if (lengthAdnF > 0) {
    that->_adnF = VecFloatCreate(lengthAdnF);
    that->_deltaAdnF = VecFloatCreate(lengthAdnF);
  } else {
    that->_adnF = NULL;
    that->_deltaAdnF = NULL;
  }
  if (lengthAdnI > 0)
    that->_adnI = VecShortCreate(lengthAdnI);
  else
    that->_adnI = NULL;
  // Return the new GenAlgAdn
  return that;
}

// Free memory used by the GenAlgAdn 'that'
void GenAlgAdnFree(GenAlgAdn** that) {
  // Check the argument
  if (that == NULL || *that == NULL) return;
  // Free memory
  if ((*that)->_adnF != NULL)
    VecFree(&((*that)->_adnF));
  if ((*that)->_deltaAdnF != NULL)
    VecFree(&((*that)->_deltaAdnF));
  if ((*that)->_adnI != NULL)
    VecFree(&((*that)->_adnI));
  free(*that);
  // Set the pointer to null
  *that = NULL;
}

// Initialise randomly the genes of the GenAlgAdn 'that' of the
// GenAlg 'ga'
void GAAdnInit(const GenAlgAdn* const that, const GenAlg* const ga) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // For each floating point value gene
  for (int iGene = GAGetLengthAdnFloat(ga); iGene--;) {
    float min = VecGet(GABoundsAdnFloat(ga, iGene), 0);
    float max = VecGet(GABoundsAdnFloat(ga, iGene), 1);
    float val = min + (max - min) * rnd();
    VecSet(that->_adnF, iGene, val);
  }
  // For each integer value gene
  for (int iGene = GAGetLengthAdnInt(ga); iGene--;) {
    short min = VecGet(GABoundsAdnInt(ga, iGene), 0);
    short max = VecGet(GABoundsAdnInt(ga, iGene), 1);
    short val = (short)round((float)min + (float)(max - min) * rnd());
```

```
    VecSet(that->_adnI, iGene, val);
  }
}

// Print the information about the GenAlgAdn 'that' on the
// stream 'stream'
void GAAdnPrintln(const GenAlgAdn* const that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (stream == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'stream' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  fprintf(stream, "id:%lu age:%lu", GAAdnGetId(that), GAAdnGetAge(that));
  fprintf(stream, "\n");
  fprintf(stream, "  adnF:");
  VecFloatPrint(GAAdnAdnF(that), stream,6);
  fprintf(stream, "\n");
  fprintf(stream, "  deltaAdnF:");
  VecFloatPrint(GAAdnDeltaAdnF(that), stream,6);
  fprintf(stream, "\n");
  fprintf(stream, "  adnI:");
  VecPrint(GAAdnAdnI(that), stream);
  fprintf(stream, "\n");
}

// ------------- GenAlg

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

// Select the rank of two parents for the SRM algorithm
// Return the ranks in 'parents', with parents[0] <= parents[1]
void GASelectParents(const GenAlg* const that, int* const parents);

// Set the genes of the entity at rank 'iChild' as a 50/50 mix of the
// genes of entities at ranks 'parents[0]' and 'parents[1]'
void GAReproduction(GenAlg* const that, const int* const parents,
  const int iChild);

// Mute the genes of the entity at rank 'iChild'
// The probability of mutation for one gene is equal to
// 'rankChild'/'that'->_nbEntities
// The amplitude of the mutation
// is equal to
// (max-min).(gauss(0.0, 1.0)+deltaAdn).ln('parents[0]'.age)
void GAMute(GenAlg* const that, const int* const parents,
  const int iChild);

// Reset the GenAlg 'that'
// Randomize all the gene except those of the first adn
void GAKTEvent(GenAlg* const that);

// Get the diversity value of 'adnA' against 'adnB'
// The diversity is equal to
float GAAdnGetDiversity(const GenAlgAdn* const adnA,
  const GenAlgAdn* const adnB, const GenAlg* const ga);
```

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

// Create a new GenAlg with 'nbEntities', 'nbElites', 'lengthAdnF'
// and 'lengthAdnI'
// 'nbEntities' must greater than 2
// 'nbElites' must greater than 1
// 'lengthAdnF' and 'lengthAdnI' must be greater than or equal to 0
GenAlg* GenAlgCreate(const int nbEntities, const int nbElites,
  const int lengthAdnF, const int lengthAdnI) {
  // Allocate memory
  GenAlg* that = PBErrMalloc(GenAlgErr, sizeof(GenAlg));
  // Set the properties
  that->_adns = GSetCreate();
  that->_curEpoch = 0;
  *(int*)&(that->_lengthAdnF) = lengthAdnF;
  *(int*)&(that->_lengthAdnI) = lengthAdnI;
  if (lengthAdnF > 0) {
    that->_boundsF =
      PBErrMalloc(GenAlgErr, sizeof(VecFloat2D) * lengthAdnF);
    for (int iGene = lengthAdnF; iGene--;)
      that->_boundsF[iGene] = VecFloatCreateStatic2D();
  } else
    that->_boundsF = NULL;
  if (lengthAdnI > 0) {
    that->_boundsI =
      PBErrMalloc(GenAlgErr, sizeof(VecShort2D) * lengthAdnI);
    for (int iGene = lengthAdnI; iGene--;)
      that->_boundsI[iGene] = VecShortCreateStatic2D();
  } else
    that->_boundsI = NULL;
  that->_normRangeFloat = 1.0;
  that->_normRangeInt = 1.0;
  that->_nbElites = 0;
  that->_nextId = 0;
  that->_diversityThreshold = GENALG_DIVERSITYTHRESHOLD;
  GASetNbEntities(that, nbEntities);
  GASetNbElites(that, nbElites);
  // Return the new GenAlg
  return that;
}

// Free memory used by the GenAlg 'that'
void GenAlgFree(GenAlg** that) {
  // Check the argument
  if (that == NULL || *that == NULL) return;
  // Free memory
  GSetIterForward iter = GSetIterForwardCreateStatic(GAAdns(*that));
  do {
    GenAlgAdn* gaEnt = GSetIterGet(&iter);
    GenAlgAdnFree(&gaEnt);
  } while (GSetIterStep(&iter));
  GSetFree(&((*that)->_adns));
  if ((*that)->_boundsF != NULL)
    free((*that)->_boundsF);
  if ((*that)->_boundsI != NULL)
    free((*that)->_boundsI);
  free(*that);
  // Set the pointer to null
  *that = NULL;
}
```

```
// Set the nb of entities of the GenAlg 'that' to 'nb'
// 'nb' must be greater than 1, if 'nb' is lower than the current nb
// of elite the number of elite is set to 'nb' - 1
void GASetNbEntities(GenAlg* const that, const int nb) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (nb <= 1) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'nb' is invalid (%d>1)", nb);
    PBErrCatch(GenAlgErr);
  }
#endif
  while (GSetNbElem(GAAdns(that)) > nb) {
    GenAlgAdn* gaEnt = GSetPop(GAAdns(that));
    GenAlgAdnFree(&gaEnt);
  }
  while (GSetNbElem(GAAdns(that)) < nb) {
    GenAlgAdn* ent = GenAlgAdnCreate(that->_nextId++,
      GAGetLengthAdnFloat(that), GAGetLengthAdnInt(that));
    GSetPush(GAAdns(that), ent);
  }
  if (GAGetNbElites(that) >= nb)
    GASetNbElites(that, nb - 1);
}

// Set the nb of elites of the GenAlg 'that' to 'nb'
// 'nb' must be greater than 0, if 'nb' is greater or equal to the
// current nb of entities the number of entities is set to 'nb' + 1
void GASetNbElites(GenAlg* const that, const int nb) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (nb <= 1) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'nb' is invalid (%d>1)", nb);
    PBErrCatch(GenAlgErr);
  }
#endif
  if (GAGetNbAdns(that) <= nb)
    GASetNbEntities(that, nb + 1);
  that->_nbElites = nb;
}

// Init the GenAlg 'that'
// Must be called after the bounds have been set
// The random generator must have been initialised before calling this
// function
void GAInit(GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
```

```
  // For each adn
  GSetIterForward iter = GSetIterForwardCreateStatic(GAAdns(that));
  do {
    // Get the adn
    GenAlgAdn* adn = GSetIterGet(&iter);
    // Initialise randomly the genes of the adn
    GAAdnInit(adn, that);
  } while (GSetIterStep(&iter));
}

// Reset the GenAlg 'that'
// Randomize all the gene except those of the best adn
void GAKTEvent(GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // For each adn except the best one
  GSetIterBackward iter = GSetIterBackwardCreateStatic(GAAdns(that));
  GSetIterStep(&iter);
  // We suppose here thre is at least 2 adns in the pool
  do {
    // Get the adn
    GenAlgAdn* adn = GSetIterGet(&iter);
    // Get the diversity of this adn against the first one
    float diversity = GAAdnGetDiversity(adn, GAAdn(that, 0), that);
    // If the diversity is under the threhsold
    if (diversity < GAGetDiversityThreshold(that)) {
      // Initialise randomly the genes of the adn
      GAAdnInit(adn, that);
      // Reset the age of the child
      adn->_age = 1;
      // Set the id of the child
      adn->_id = (that->_nextId)++;
    }
  } while (GSetIterStep(&iter));
}

// Step an epoch for the GenAlg 'that' with the current ranking of
// GenAlgAdn
void GAStep(GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Selection, Reproduction, Mutation
  // Ensure the set of adns is sorted
  GSetSort(GAAdns(that));
  // Declare a variable to memorize the parents
  int parents[2];
  // Get the diversity level
  float diversity = GAGetDiversity(that);
  // If the diversity level is too low
  if (diversity < GAGetDiversityThreshold(that)) {
    // Break the diversity by applying a KT event (in memory of
    // chickens' grand pa and grand ma)
```

```
    GAKTEvent(that);
  // Else, the diversity level is ok
  } else {
    // For each adn which is an elite
    for (int iAdn = 0; iAdn < GAGetNbElites(that); ++iAdn) {
      // Increment age
      (GAAdn(that, iAdn)->_age)++;
    }
    // For each adn which is not an elite
    for (int iAdn = GAGetNbElites(that); iAdn < GAGetNbAdns(that);
      ++iAdn) {
      // Select two parents for this adn
      GASelectParents(that, parents);
      // Set the genes of the adn as a 50/50 mix of parents' genes
      GAReproduction(that, parents, iAdn);
      // Mute the genes of the adn
      GAMute(that, parents, iAdn);
    }
  }
  // Increment the number of epochs
  ++(that->_curEpoch);
}

// Select the rank of two parents for the SRM algorithm
// Return the ranks in 'parents', with parents[0] <= parents[1]
void GASelectParents(const GenAlg* const that, int* const parents) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (parents == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'parents' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Declare a variable to memorize the parents' rank
  int p[2];
  for (int i = 2; i--;)
    // p[i] below may be equal to the rank of the highest non elite
    // adn, but it's not a problem so leave it and let's call that
    // the Hawking radiation of this function in memory of this great
    // man.
    p[i] = (int)floor(rnd() * (float)GAGetNbElites(that));
  // Memorize the sorted parents' rank
  if (p[0] < p[1]) {
    parents[0] = p[0];
    parents[1] = p[1];
  } else {
    parents[0] = p[1];
    parents[1] = p[0];
  }
}

// Set the genes of the adn at rank 'iChild' as a 50/50 mix of the
// genes of adns at ranks 'parents[0]' and 'parents[1]'
void GAReproduction(GenAlg* const that, const int* const parents,
  const int iChild) {
#if BUILDMODE == 0
  if (that == NULL) {
```

```
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (parents == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'parents' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iChild < 0 || iChild >= GAGetNbAdns(that)) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'child' is invalid (0<=%d<%d)",
      iChild, GAGetNbAdns(that));
    PBErrCatch(GenAlgErr);
  }
#endif
  // Get the parents and child
  GenAlgAdn* parentA = GAAdn(that, parents[0]);
  GenAlgAdn* parentB = GAAdn(that, parents[1]);
  GenAlgAdn* child = GAAdn(that, iChild);
  // For each gene of the adn for floating point value
  for (int iGene = GAGetLengthAdnFloat(that); iGene--;) {
    // Get the gene from one parent or the other with equal probabililty
    if (rnd() < 0.5) {
      VecSet(child->_adnF, iGene, VecGet(parentA->_adnF, iGene));
      VecSet(child->_deltaAdnF, iGene,
        VecGet(parentA->_deltaAdnF, iGene));
    } else {
      VecSet(child->_adnF, iGene, VecGet(parentB->_adnF, iGene));
      VecSet(child->_deltaAdnF, iGene,
        VecGet(parentB->_deltaAdnF, iGene));
    }
  }
  // For each gene of the adn for int value
  for (int iGene = GAGetLengthAdnInt(that); iGene--;) {
    // Get the gene from one parent or the other with equal probabililty
    if (rnd() < 0.5)
      VecSet(child->_adnI, iGene, VecGet(parentA->_adnI, iGene));
    else
      VecSet(child->_adnI, iGene, VecGet(parentB->_adnI, iGene));
  }
  // Reset the age of the child
  child->_age = 1;
  // Set the id of the child
  child->_id = (that->_nextId)++;
}

// Mute the genes of the entity at rank 'iChild'
// The probability of mutation for one gene is equal to
// 'rankChild'/'that'->_nbEntities
// The amplitude of the mutation
// is equal to (max-min).(gauss(0.0, 1.0)+deltaAdn).ln('parents[0]'.age)
void GAMute(GenAlg* const that, const int* const parents,
  const int iChild) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (parents == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(GenAlgErr->_msg, "'parents' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iChild < 0 || iChild >= GAGetNbAdns(that)) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'child' is invalid (0<=%d<%d)",
      iChild, GAGetNbAdns(that));
    PBErrCatch(GenAlgErr);
  }
#endif
  // Get the first parent and child
  GenAlgAdn* parentA = GAAdn(that, parents[0]);
  GenAlgAdn* child = GAAdn(that, iChild);
  // Get the proba amplitude of mutation
  float probMute = ((float)iChild) / ((float)GAGetNbAdns(that));
  float amp = 1.0 - 1.0 / sqrt((float)(parentA->_age + 1));
  // For each gene of the adn for floating point value
  for (int iGene = GAGetLengthAdnFloat(that); iGene--;) {
    // If this gene mutes
    if (rnd() < probMute) {
      // Get the bounds
      const VecFloat2D* const bounds = GABoundsAdnFloat(that, iGene);
      // Declare a variable to memorize the previous value of the gene
      float prevVal = GAAdnGetGeneF(child, iGene);
      // Apply the mutation
      GAAdnSetGeneF(child, iGene, GAAdnGetGeneF(child, iGene) +
        (VecGet(bounds, 1) - VecGet(bounds, 0)) * amp *
        (rnd() - 0.5 + GAAdnGetDeltaGeneF(child, iGene)));
      // Keep the gene value in bounds
      while (GAAdnGetGeneF(child, iGene) < VecGet(bounds, 0) ||
        GAAdnGetGeneF(child, iGene) > VecGet(bounds, 1)) {
        if (GAAdnGetGeneF(child, iGene) > VecGet(bounds, 1))
          GAAdnSetGeneF(child, iGene,
            2.0 * VecGet(bounds, 1) - GAAdnGetGeneF(child, iGene));
        else if (GAAdnGetGeneF(child, iGene) < VecGet(bounds, 0))
          GAAdnSetGeneF(child, iGene,
            2.0 * VecGet(bounds, 0) - GAAdnGetGeneF(child, iGene));
      }
      // Update the deltaAdn
      GAAdnSetDeltaGeneF(child, iGene,
        GAAdnGetGeneF(child, iGene) - prevVal);
    }
  }
  // For each gene of the adn for int value
  for (int iGene = GAGetLengthAdnInt(that); iGene--;) {
    // If this gene mutes
    if (rnd() < probMute) {
      // Get the bounds
      const VecShort2D* const boundsI = GABoundsAdnInt(that, iGene);
      VecFloat2D bounds = VecShortToFloat2D(boundsI);
      // Apply the mutation (as it is int value, ensure the amplitude
      // is big enough to have an effect
      float ampI = MIN(2.0,
        (float)(VecGet(&bounds, 1) - VecGet(&bounds, 0)) * amp);
      GAAdnSetGeneI(child, iGene, GAAdnGetGeneI(child, iGene) +
        (short)round(ampI * (rnd() - 0.5)));
      // Keep the gene value in bounds
      while (GAAdnGetGeneI(child, iGene) < VecGet(&bounds, 0) ||
        GAAdnGetGeneI(child, iGene) > VecGet(&bounds, 1)) {
        if (GAAdnGetGeneI(child, iGene) > VecGet(&bounds, 1))
          GAAdnSetGeneI(child, iGene,
            2 * VecGet(&bounds, 1) - GAAdnGetGeneI(child, iGene));
```

```
        else if (GAAdnGetGeneI(child, iGene) < VecGet(&bounds, 0))
          GAAdnSetGeneI(child, iGene,
            2 * VecGet(&bounds, 0) - GAAdnGetGeneI(child, iGene));
      }
    }
  }
}

// Print the information about the GenAlg 'that' on the stream 'stream'
void GAPrintln(const GenAlg* const that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (stream == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'stream' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  fprintf(stream, "epoch:%lu\n", GAGetCurEpoch(that));
  fprintf(stream, "%d entities, %d elites\n", GAGetNbAdns(that),
    GAGetNbElites(that));
  GSetIterBackward iter = GSetIterBackwardCreateStatic(GAAdns(that));
  int iEnt = 0;
  do {
    GenAlgAdn* ent = GSetIterGet(&iter);
    fprintf(stream, "#%d value:%f ", iEnt,
      GSetIterGetElem(&iter)->_sortVal);
    if (iEnt < GAGetNbElites(that))
      fprintf(stream, "elite ");
    GAAdnPrintln(ent, stream);
    ++iEnt;
  } while (GSetIterStep(&iter));
}

// Update the norm of the range value for adans of the GenAlg 'that'
void GAUpdateNormRange(GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // If there are float adn
  if (GAGetLengthAdnFloat(that) > 0) {
    // Declare a vector to memorize the ranges in float gene values
    VecFloat* range = VecFloatCreate(GAGetLengthAdnFloat(that));
    // Calculate the ranges in gene values
    for (int iGene = GAGetLengthAdnFloat(that); iGene--;)
      VecSet(range, iGene,
        VecGet(GABoundsAdnFloat(that, iGene), 1) -
        VecGet(GABoundsAdnFloat(that, iGene), 0));
    // Calculate the norm of the range
    that->_normRangeFloat = VecNorm(range);
    // Free memory
    VecFree(&range);
  }
```

```
  // If there are int adn
  if (GAGetLengthAdnInt(that) > 0) {
    // Declare a vector to memorize the ranges in int gene values
    VecFloat* range = VecFloatCreate(GAGetLengthAdnInt(that));
    // Calculate the ranges in gene values
    for (int iGene = GAGetLengthAdnInt(that); iGene--;)
      VecSet(range, iGene,
        VecGet(GABoundsAdnInt(that, iGene), 1) -
        VecGet(GABoundsAdnInt(that, iGene), 0));
    // Calculate the norm of the range
    that->_normRangeInt = VecNorm(range);
    // Free memory
    VecFree(&range);
  }
}


// Get the diversity value of 'adnA' against 'adnB'
// The diversity is equal to
float GAAdnGetDiversity(const GenAlgAdn* const adnA,
  const GenAlgAdn* const adnB, const GenAlg* const ga) {
#if BUILDMODE == 0
  if (adnA == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'adnA' is null");
    PBErrCatch(GenAlgErr);
  }
  if (adnB == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'adnB' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Declare a variable to memorize the result
  float diversity = 0.0;
  // If there are adn for floating point values
  if (GAAdnAdnF(adnA) != NULL && GAAdnAdnF(adnB) != NULL) {
    // Get the difference in adn with the first entity
    VecFloat* diff =
      VecGetOp(GAAdnAdnF(adnA), 1.0, GAAdnAdnF(adnB), -1.0);
    // Calculate the diversity
    diversity += VecNorm(diff) / ga->_normRangeFloat;
    // Free memory
    VecFree(&diff);
  }
  // If there are adn for int values
  if (GAAdnAdnI(adnA) != NULL && GAAdnAdnI(adnB) != NULL) {
    // Get the difference in adn with the first entity
    VecShort* diffI =
      VecGetOp(GAAdnAdnI(adnA), 1, GAAdnAdnI(adnB), -1);
    VecFloat* diff = VecShortToFloat(diffI);
    // Calculate the diversity
    diversity += VecNorm(diff) / ga->_normRangeInt;
    // Free memory
    VecFree(&diffI);
    VecFree(&diff);
  }
  // Correct diversity if there was both float and int adns
  if (GAAdnAdnF(adnA) != NULL && GAAdnAdnF(adnB) != NULL &&
    GAAdnAdnI(adnA) != NULL && GAAdnAdnI(adnB) != NULL)
    diversity /= 2.0;
  // Return the result
```

```
  return diversity;
}

// Get the average diversity of current entities of the GenAlg 'that'
// The return value is in [0.0, 1.0]
// 0.0 means all the elite entities have exactly the same adns
// 1.0 means all the elite entities except the first one have adns
// as different compare to the first one's adn as possible given the
// range of adn values
float GAGetDiversity(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Declare a variable for calculation of the average of diversities
  float sumDiversity = 0.0;
  // For each elite entity except the first one
  for (int iEnt = 1; iEnt < GAGetNbElites(that); ++iEnt) {
    // Sum the diversity of this entity against the first one
    // for float values
    sumDiversity +=
      GAAdnGetDiversity(GAAdn(that, 0), GAAdn(that, iEnt), that);
  }
  // Calculate the average diversity
  float diversity = sumDiversity / (float)(GAGetNbElites(that) - 1);
  // Return the result
  return diversity;
}

// Function which return the JSON encoding of 'that'
JSONNode* GAAdnEncodeAsJSON(const GenAlgAdn* const that,
  const float elo) {
#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 id
  sprintf(val, "%lu", that->_id);
  JSONAddProp(json, "_id", val);
  // Encode the age
  sprintf(val, "%lu", that->_age);
  JSONAddProp(json, "_age", val);
  // Encode the elo
  sprintf(val, "%f", elo);
  JSONAddProp(json, "_elo", val);
  // Encode the genes
  if (that->_adnF != NULL) {
    JSONAddProp(json, "_adnF", VecEncodeAsJSON(that->_adnF));
    JSONAddProp(json, "_deltaAdnF", VecEncodeAsJSON(that->_deltaAdnF));
  }
  if (that->_adnI != NULL)
    JSONAddProp(json, "_adnI", VecEncodeAsJSON(that->_adnI));
```

```
  // Return the created JSON
  return json;
}

// Function which return the JSON encoding of 'that'
JSONNode* GAEncodeAsJSON(const GenAlg* 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 diversity threshold
  sprintf(val, "%f", GAGetDiversityThreshold(that));
  JSONAddProp(json, "_diversityThreshold", val);
  // Encode the nb adns
  sprintf(val, "%d", GAGetNbAdns(that));
  JSONAddProp(json, "_nbAdns", val);
  // Encode the nb elites
  sprintf(val, "%d", GAGetNbElites(that));
  JSONAddProp(json, "_nbElites", val);
  // Encode the length adn float
  sprintf(val, "%d", GAGetLengthAdnFloat(that));
  JSONAddProp(json, "_lengthAdnF", val);
  // Encode the length adn int
  sprintf(val, "%d", GAGetLengthAdnInt(that));
  JSONAddProp(json, "_lengthAdnI", val);
  // Encode the epoch
  sprintf(val, "%lu", GAGetCurEpoch(that));
  JSONAddProp(json, "_curEpoch", val);
  // Encode the next id
  sprintf(val, "%lu", that->_nextId);
  JSONAddProp(json, "_nextId", val);
  // Encode the bounds
  JSONArrayStruct setBoundFloat = JSONArrayStructCreateStatic();
  if (GAGetLengthAdnFloat(that) > 0) {
    for (int iBound = 0; iBound < GAGetLengthAdnFloat(that); ++iBound)
      JSONArrayStructAdd(&setBoundFloat,
        VecEncodeAsJSON((VecFloat*)GABoundsAdnFloat(that, iBound)));
    JSONAddProp(json, "_boundFloat", &setBoundFloat);
  }
  JSONArrayStruct setBoundInt = JSONArrayStructCreateStatic();
  if (GAGetLengthAdnInt(that) > 0) {
    for (int iBound = 0; iBound < GAGetLengthAdnInt(that); ++iBound)
      JSONArrayStructAdd(&setBoundInt,
        VecEncodeAsJSON((VecShort*)GABoundsAdnInt(that, iBound)));
    JSONAddProp(json, "_boundInt", &setBoundInt);
  }
  // Save the adns
  JSONArrayStruct setAdn = JSONArrayStructCreateStatic();
  for (int iEnt = 0; iEnt < GAGetNbAdns(that); ++iEnt) {
    GenAlgAdn* ent = GSetElemData(GSetElement(GAAdns(that), iEnt));
    float sortVal = GSetElemGetSortVal(GSetElement(GAAdns(that), iEnt));
    JSONArrayStructAdd(&setAdn, GAAdnEncodeAsJSON(ent, sortVal));
  }
  JSONAddProp(json, "_adns", &setAdn);
  // Free memory
```

```
  JSONArrayStructFlush(&setBoundFloat);
  JSONArrayStructFlush(&setBoundInt);
  JSONArrayStructFlush(&setAdn);
  // Return the created JSON
  return json;
}

// Function which decode from JSON encoding 'json' to 'that'
bool GAAdnDecodeAsJSON(GenAlgAdn** 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
    GenAlgAdnFree(that);
  // Get the id from the JSON
  JSONNode* prop = JSONProperty(json, "_id");
  if (prop == NULL) {
    return false;
  }
  int id = strtoul(JSONLabel(JSONValue(prop, 0)), NULL, 10);
  // Get the lengthAdnF from the JSON
  int lengthAdnF = 0;
  prop = JSONProperty(json, "_adnF");
  if (prop != NULL) {
    JSONNode* subprop = JSONProperty(prop, "_dim");
    lengthAdnF = atoi(JSONLabel(JSONValue(subprop, 0)));
  }
  // Get the lengthAdnI from the JSON
  int lengthAdnI = 0;
  prop = JSONProperty(json, "_adnI");
  if (prop != NULL) {
    JSONNode* subprop = JSONProperty(prop, "_dim");
    lengthAdnI = atoi(JSONLabel(JSONValue(subprop, 0)));
  }
  // Allocate memory
  *that = GenAlgAdnCreate(id, lengthAdnF, lengthAdnI);
  // Get the age from the JSON
  prop = JSONProperty(json, "_age");
  if (prop == NULL) {
    return false;
  }
  (*that)->_age = strtoul(JSONLabel(JSONValue(prop, 0)), NULL, 10);
  // Get the adnF from the JSON
  prop = JSONProperty(json, "_adnF");
  if (prop != NULL) {
    if (!VecDecodeAsJSON(&((*that)->_adnF), prop)) {
      return false;
    }
    prop = JSONProperty(json, "_deltaAdnF");
    if (prop == NULL) {
      return false;
```

```
    }
    if (!VecDecodeAsJSON(&((*that)->_deltaAdnF), prop)) {
      return false;
    }
  }
  // Get the adnI from the JSON
  prop = JSONProperty(json, "_adnI");
  if (prop != NULL)
    if (!VecDecodeAsJSON(&((*that)->_adnI), prop)) {
      return false;
    }
  // Return the success code
  return true;
}

// Function which decode from JSON encoding 'json' to 'that'
bool GADecodeAsJSON(GenAlg** 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
    GenAlgFree(that);
  // Decode the nb adns
  JSONNode* prop = JSONProperty(json, "_nbAdns");
  if (prop == NULL) {
    return false;
  }
  int nbAdns = atoi(JSONLabel(JSONValue(prop, 0)));
  // Decode the nb elites
  prop = JSONProperty(json, "_nbElites");
  if (prop == NULL) {
    return false;
  }
  int nbElites = atoi(JSONLabel(JSONValue(prop, 0)));
  // Decode the length adn float
  prop = JSONProperty(json, "_lengthAdnF");
  if (prop == NULL) {
    return false;
  }
  int lengthAdnF = atoi(JSONLabel(JSONValue(prop, 0)));
  // Decode the length adn int
  prop = JSONProperty(json, "_lengthAdnI");
  if (prop == NULL) {
    return false;
  }
  int lengthAdnI = atoi(JSONLabel(JSONValue(prop, 0)));
  // Allocate memory
  *that = GenAlgCreate(nbAdns, nbElites, lengthAdnF, lengthAdnI);
  // Decode the diversity threshold
  prop = JSONProperty(json, "_diversityThreshold");
  if (prop == NULL) {
```

```
  return false;
}
(*that)->_diversityThreshold = atof(JSONLabel(JSONValue(prop, 0)));
// Decode the epoch
prop = JSONProperty(json, "_curEpoch");
if (prop == NULL) {
  return false;
}
(*that)->_curEpoch =
  strtoul(JSONLabel(JSONValue(prop, 0)), NULL, 10);
// Decode the next id
prop = JSONProperty(json, "_nextId");
if (prop == NULL) {
  return false;
}
(*that)->_nextId = strtoul(JSONLabel(JSONValue(prop, 0)), NULL, 10);
// Decode the bounds
prop = JSONProperty(json, "_boundFloat");
if (prop != NULL) {
  if (JSONGetNbValue(prop) != GAGetLengthAdnFloat(*that))
    return false;
  for (int iBound = 0; iBound < GAGetLengthAdnFloat(*that); ++iBound) {
    JSONNode* val = JSONValue(prop, iBound);
    VecFloat2D* b = NULL;
    if (!VecDecodeAsJSON((VecFloat**)&b, val)) {
      return false;
    }
    GASetBoundsAdnFloat(*that, iBound, b);
    VecFree((VecFloat**)&b);
  }
}
prop = JSONProperty(json, "_boundInt");
if (prop != NULL) {
  if (JSONGetNbValue(prop) != GAGetLengthAdnInt(*that))
    return false;
  for (int iBound = 0; iBound < GAGetLengthAdnInt(*that); ++iBound) {
    JSONNode* val = JSONValue(prop, iBound);
    VecShort2D* b = NULL;
    if (!VecDecodeAsJSON((VecShort**)&b, val)) {
      return false;
    }
    GASetBoundsAdnInt(*that, iBound, b);
    VecFree((VecShort**)&b);
  }
}
// Upadte the norm of the range values
GAUpdateNormRange(*that);
// Decode the adns
prop = JSONProperty(json, "_adns");
if (prop == NULL) {
  return false;
}
if (JSONGetNbValue(prop) != GAGetNbAdns(*that))
  return false;
for (int iEnt = 0; iEnt < GAGetNbAdns(*that); ++iEnt) {
  JSONNode* val = JSONValue(prop, iEnt);
  GenAlgAdn* data = GSetElemData(GSetElement(GAAdns(*that), iEnt));
  if (!GAAdnDecodeAsJSON(&data, val)) {
    return false;
  }
}
// Return the success code
```

```
  return true;
}

// Load the GenAlg 'that' from the stream 'stream'
// If the GenAlg is already allocated, it is freed before loading
// Return true in case of success, else false
bool GALoad(GenAlg** that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (stream == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'stream' is null");
    PBErrCatch(GenAlgErr);
  }
#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 (!GADecodeAsJSON(that, json)) {
    return false;
  }
  // Free the memory used by the JSON
  JSONFree(&json);
  // Return the success code
  return true;
}

// Save the GenAlg 'that' to the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true in case of success, else false
bool GASave(const GenAlg* const that, FILE* const stream,
  const bool compact) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (stream == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'stream' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Get the JSON encoding
  JSONNode* json = GAEncodeAsJSON(that);
  // Save the JSON
  if (!JSONSave(json, stream, compact)) {
    return false;
  }
  // Free memory
  JSONFree(&json);
  // Return success code
```

```
  return true;
}
```

3.2 genalg-inline.c

```
// ============ GENALG-INLINE.C ================

// ------------- GenAlgAdn

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

// Return the adn for floating point values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* GAAdnAdnF(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_adnF;
}

// Return the delta of adn for floating point values of the
// GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecFloat* GAAdnDeltaAdnF(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_deltaAdnF;
}

// Return the adn for integer values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
const VecShort* GAAdnAdnI(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_adnI;
}

// Get the 'iGene'-th gene of the adn for floating point values of the
// GenAlgAdn 'that'
```

```
#if BUILDMODE != 0
inline
#endif
float GAAdnGetGeneF(const GenAlgAdn* const that, const int iGene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return VecGet(that->_adnF, iGene);
}

// Get the delta of the 'iGene'-th gene of the adn for floating point
// values of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
float GAAdnGetDeltaGeneF(const GenAlgAdn* const that, const int iGene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return VecGet(that->_deltaAdnF, iGene);
}

// Get the 'iGene'-th gene of the adn for int values of the
// GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
int GAAdnGetGeneI(const GenAlgAdn* const that, const int iGene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return VecGet(that->_adnI, iGene);
}

// Set the 'iGene'-th gene of the adn for floating point values of the
// GenAlgAdn 'that' to 'gene'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetGeneF(GenAlgAdn* const that, const int iGene,
  const float gene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  VecSet(that->_adnF, iGene, gene);
}
```

```
// Set the delta of the 'iGene'-th gene of the adn for floating point
// values of the GenAlgAdn 'that' to 'delta'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetDeltaGeneF(GenAlgAdn* const that, const int iGene,
  const float delta) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  VecSet(that->_deltaAdnF, iGene, delta);
}

// Set the 'iGene'-th gene of the adn for int values of the
// GenAlgAdn 'that'to 'gene'
#if BUILDMODE != 0
inline
#endif
void GAAdnSetGeneI(GenAlgAdn* const that, const int iGene,
  const short gene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  VecSet(that->_adnI, iGene, gene);
}

// Get the id of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAAdnGetId(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_id;
}

// Get the age of the GenAlgAdn 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAAdnGetAge(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
```

```
  return that->_age;
}

// Return true if the GenAlgAdn 'that' is new, i.e. is age equals 1
// Return false
#if BUILDMODE != 0
inline
#endif
bool GAAdnIsNew(const GenAlgAdn* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return (that->_age == 1);
}


// ------------- GenAlg

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

// Return the GSet of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
GSet* GAAdns(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_adns;
}

// Return the nb of entities of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
int GAGetNbAdns(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return GSetNbElem(that->_adns);
}

// Return the nb of elites of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
int GAGetNbElites(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_nbElites;
}

// Return the current epoch of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
unsigned long int GAGetCurEpoch(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_curEpoch;
}

// Get the length of adn for floating point value
#if BUILDMODE != 0
inline
#endif
int GAGetLengthAdnFloat(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_lengthAdnF;
}

// Get the length of adn for integer value
#if BUILDMODE != 0
inline
#endif
int GAGetLengthAdnInt(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_lengthAdnI;
}

// Set the bounds for the 'iGene'-th gene of adn for floating point
// values to a copy of 'bounds'
#if BUILDMODE != 0
inline
#endif
void GASetBoundsAdnFloat(GenAlg* const that, const int iGene,
  const VecFloat2D* const bounds) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (bounds == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'bounds' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iGene < 0 || iGene >= that->_lengthAdnF) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'iGene' is invalid (0<=%d<%d)",
      iGene, that->_lengthAdnF);
    PBErrCatch(GenAlgErr);
  }
#endif
  VecCopy(that->_boundsF + iGene, bounds);
  GAUpdateNormRange(that);
}

// Set the bounds for the 'iGene'-th gene of adn for integer values
// to a copy of 'bounds'
#if BUILDMODE != 0
inline
#endif
void GASetBoundsAdnInt(GenAlg* const that, const int iGene,
  const VecShort2D* const bounds) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (bounds == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'bounds' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iGene < 0 || iGene >= that->_lengthAdnI) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'iGene' is invalid (0<=%d<%d)",
      iGene, that->_lengthAdnI);
    PBErrCatch(GenAlgErr);
  }
#endif
  VecCopy(that->_boundsI + iGene, bounds);
  GAUpdateNormRange(that);
}

// Get the bounds for the 'iGene'-th gene of adn for floating point
// values
#if BUILDMODE != 0
inline
#endif
const VecFloat2D* GABoundsAdnFloat(const GenAlg* const that,
  const int iGene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iGene < 0 || iGene >= that->_lengthAdnF) {
```

```
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'iGene' is invalid (0<=%d<%d)",
      iGene, that->_lengthAdnF);
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_boundsF + iGene;
}

// Get the bounds for the 'iGene'-th gene of adn for integer values
#if BUILDMODE != 0
inline
#endif
const VecShort2D* GABoundsAdnInt(const GenAlg* const that,
  const int iGene) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iGene < 0 || iGene >= that->_lengthAdnI) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'iGene' is invalid (0<=%d<%d)",
      iGene, that->_lengthAdnI);
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_boundsI + iGene;
}

// Get the GenAlgAdn of the GenAlg 'that' currently at rank 'iRank'
// (0 is the best adn)
#if BUILDMODE != 0
inline
#endif
GenAlgAdn* GAAdn(const GenAlg* const that, const int iRank) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (iRank < 0 || iRank >= GAGetNbAdns(that)) {
    GenAlgErr->_type = PBErrTypeInvalidArg;
    sprintf(GenAlgErr->_msg, "'iRank' is invalid (0<=%d<%d)",
      iRank, GAGetNbAdns(that));
    PBErrCatch(GenAlgErr);
  }
#endif
  return (GenAlgAdn*)GSetGet(that->_adns,
    GSetNbElem(that->_adns) - iRank - 1);
}

// Set the value of the GenAlgAdn 'adn' of the GenAlg 'that' to 'val'
#if BUILDMODE != 0
inline
#endif
void GASetAdnValue(GenAlg* const that, const GenAlgAdn* const adn,
  const float val) {
#if BUILDMODE == 0
  if (that == NULL) {
```

```
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
  if (adn == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'adn' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  GSetElemSetSortVal((GSetElem*)GSetFirstElem(GAAdns(that), adn), val);
}

// Return the diversity threshold of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
float GAGetDiversityThreshold(const GenAlg* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_diversityThreshold;
}

// Set the diversity threshold of the GenAlg 'that' to 'div'
#if BUILDMODE != 0
inline
#endif
void GASetDiversityThreshold(GenAlg* const that, const float div) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  that->_diversityThreshold = div;
}
```

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=genalg
$($(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 "genalg.h"

#define RANDOMSEED 2

void UnitTestGenAlgAdnCreateFree() {
  unsigned long int id = 1;
  int lengthAdnF = 2;
  int lengthAdnI = 3;
  GenAlgAdn* ent = GenAlgAdnCreate(id, lengthAdnF, lengthAdnI);
  if (ent->_age != 1 ||
    ent->_id != id ||
    VecGetDim(ent->_adnF) != lengthAdnF ||
    VecGetDim(ent->_deltaAdnF) != lengthAdnF ||
    VecGetDim(ent->_adnI) != lengthAdnI) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GenAlgAdnCreate failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgAdnFree(&ent);
  if (ent != NULL) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GenAlgAdnFree failed");
    PBErrCatch(GenAlgErr);
  }
  printf("UnitTestGenAlgAdnCreateFree OK\n");
}

void UnitTestGenAlgAdnGetSet() {
  unsigned long int id = 1;
  int lengthAdnF = 2;
  int lengthAdnI = 3;
  GenAlgAdn* ent = GenAlgAdnCreate(id, lengthAdnF, lengthAdnI);
  if (GAAdnAdnF(ent) != ent->_adnF) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAAdnAdnF failed");
    PBErrCatch(GenAlgErr);
```

```
}
if (GAAdnDeltaAdnF(ent) != ent->_deltaAdnF) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnDeltaAdnF failed");
  PBErrCatch(GenAlgErr);
}
if (GAAdnAdnI(ent) != ent->_adnI) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnAdnI failed");
  PBErrCatch(GenAlgErr);
}
GAAdnSetGeneF(ent, 0, 1.0);
if (ISEQUALF(VecGet(ent->_adnF, 0), 1.0) == false) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnSetGeneF failed");
  PBErrCatch(GenAlgErr);
}
if (ISEQUALF(GAAdnGetGeneF(ent, 0), 1.0) == false) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnGetGeneF failed");
  PBErrCatch(GenAlgErr);
}
GAAdnSetDeltaGeneF(ent, 0, 2.0);
if (ISEQUALF(VecGet(ent->_deltaAdnF, 0), 2.0) == false) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnSetDeltaGeneF failed");
  PBErrCatch(GenAlgErr);
}
if (ISEQUALF(GAAdnGetDeltaGeneF(ent, 0), 2.0) == false) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnGetDeltaGeneF failed");
  PBErrCatch(GenAlgErr);
}
GAAdnSetGeneI(ent, 0, 3);
if (VecGet(ent->_adnI, 0) != 3) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnSetGeneI failed");
  PBErrCatch(GenAlgErr);
}
if (GAAdnGetGeneI(ent, 0) != 3) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnGetGeneI failed");
  PBErrCatch(GenAlgErr);
}
if (GAAdnGetAge(ent) != 1) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnGetAge failed");
  PBErrCatch(GenAlgErr);
}
if (GAAdnGetId(ent) != id) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnGetId failed");
  PBErrCatch(GenAlgErr);
}
if (GAAdnIsNew(ent) != true) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenAlgErr->_msg, "GAAdnIsNew failed");
  PBErrCatch(GenAlgErr);
}
ent->_age = 2;
if (GAAdnIsNew(ent) != false) {
  GenAlgErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(GenAlgErr->_msg, "GAAdnIsNew failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgAdnFree(&ent);
  printf("UnitTestGenAlgAdnGetSet OK\n");
}

void UnitTestGenAlgAdnInit() {
  srandom(5);
  unsigned long int id = 1;
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlgAdn* ent = GenAlgAdnCreate(id, lengthAdnF, lengthAdnI);
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GAAdnInit(ent, ga);
  if (ISEQUALF(VecGet(ent->_adnF, 0), -0.907064) == false ||
    ISEQUALF(VecGet(ent->_adnF, 1), -0.450509) == false ||
    VecGet(ent->_adnI, 0) != 2 ||
    VecGet(ent->_adnI, 1) != 10) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAAdnInit failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
  GenAlgAdnFree(&ent);
  printf("UnitTestGenAlgAdnInit OK\n");
}

void UnitTestGenAlgAdn() {
  UnitTestGenAlgAdnCreateFree();
  UnitTestGenAlgAdnGetSet();
  UnitTestGenAlgAdnInit();
  printf("UnitTestGenAlgAdn OK\n");
}

void UnitTestGenAlgCreateFree() {
  int lengthAdnF = 2;
  int lengthAdnI = 3;
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  if (ga->_curEpoch != 0 ||
    ga->_nextId != GENALG_NBENTITIES ||
    ga->_nbElites != GENALG_NBELITES ||
    ga->_lengthAdnF != lengthAdnF ||
    ga->_lengthAdnI != lengthAdnI ||
    ISEQUALF(ga->_diversityThreshold,
      GENALG_DIVERSITYTHRESHOLD) == false ||
    GSetNbElem(GAAdns(ga)) != GENALG_NBENTITIES) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GenAlgCreate failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
```

```
  if (ga != NULL) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GenAlgFree failed");
    PBErrCatch(GenAlgErr);
  }
  printf("UnitTestGenAlgCreateFree OK\n");
}

void UnitTestGenAlgGetSet() {
  int lengthAdnF = 2;
  int lengthAdnI = 3;
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  if (GAAdns(ga) != ga->_adns) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAEloRank failed");
    PBErrCatch(GenAlgErr);
  }
  if (GAGetNbAdns(ga) != GENALG_NBENTITIES) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetNbAdns failed");
    PBErrCatch(GenAlgErr);
  }
  if (GAGetNbElites(ga) != GENALG_NBELITES) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetNbElites failed");
    PBErrCatch(GenAlgErr);
  }
  if (GAGetCurEpoch(ga) != 0) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetCurEpoch failed");
    PBErrCatch(GenAlgErr);
  }
  GASetNbEntities(ga, 10);
  if (GAGetNbAdns(ga) != 10 ||
    GAGetNbElites(ga) != 9 ||
    GSetNbElem(GAAdns(ga)) != 10) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetNbEntities failed");
    PBErrCatch(GenAlgErr);
  }
  GASetNbElites(ga, 20);
  if (GAGetNbAdns(ga) != 21 ||
    GAGetNbElites(ga) != 20 ||
    GSetNbElem(GAAdns(ga)) != 21) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetNbElites failed");
    PBErrCatch(GenAlgErr);
  }
  if (GAGetLengthAdnFloat(ga) != lengthAdnF) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetLengthAdnFloat failed");
    PBErrCatch(GenAlgErr);
  }
  if (GAGetLengthAdnInt(ga) != lengthAdnI) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetLengthAdnInt failed");
    PBErrCatch(GenAlgErr);
  }
  if (GABoundsAdnFloat(ga, 1) != ga->_boundsF + 1) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GABoundsAdnFloat failed");
```

```
    PBErrCatch(GenAlgErr);
  }
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  if (VecIsEqual(GABoundsAdnFloat(ga, 1), &boundsF) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetBoundsAdnFloat failed");
    PBErrCatch(GenAlgErr);
  }
  VecShort2D boundsS = VecShortCreateStatic2D();
  VecSet(&boundsS, 0, -1); VecSet(&boundsS, 1, 1);
  GASetBoundsAdnInt(ga, 1, &boundsS);
  if (VecIsEqual(GABoundsAdnInt(ga, 1), &boundsS) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetBoundsAdnInt failed");
    PBErrCatch(GenAlgErr);
  }
  if (GABoundsAdnInt(ga, 1) != ga->_boundsI + 1) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GABoundsAdnInt failed");
    PBErrCatch(GenAlgErr);
  }
  GASetAdnValue(ga, GAAdn(ga, 0), 1.0);
  if (ISEQUALF(ga->_adns->_tail->_sortVal, 1.0) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetAdnValue failed");
    PBErrCatch(GenAlgErr);
  }
  if (ISEQUALF(GAGetDiversityThreshold(ga),
    ga->_diversityThreshold) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetDiversityThreshold failed");
    PBErrCatch(GenAlgErr);
  }
  GASetDiversityThreshold(ga, 0.5);
  if (ISEQUALF(GAGetDiversityThreshold(ga), 0.5) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASetDiversityThreshold failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
  printf("UnitTestGenAlgGetSet OK\n");
}

void UnitTestGenAlgInit() {
  srandom(5);
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GAInit(ga);
  GenAlgAdn* ent = (GenAlgAdn*)(GAAdns(ga)->_head->_data);
  if (ISEQUALF(VecGet(ent->_adnF, 0), -0.907064) == false ||
```

```
    ISEQUALF(VecGet(ent->_adnF, 1), -0.450509) == false ||
    VecGet(ent->_adnI, 0) != 2 ||
    VecGet(ent->_adnI, 1) != 10) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAInit failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
  printf("UnitTestGenAlgInit OK\n");
}

void UnitTestGenAlgPrint() {
  srandom(5);
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlg* ga = GenAlgCreate(3, 2, lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GAInit(ga);
  GAPrintln(ga, stdout);
  GenAlgFree(&ga);
  printf("UnitTestGenAlgInit OK\n");
}

void UnitTestGenAlgGetDiversity() {
  srandom(5);
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GASetNbElites(ga, 2);
  GASetNbEntities(ga, 3);
  GAInit(ga);
  if (ISEQUALF(GAGetDiversity(ga), 0.455102) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetDiversity failed");
    PBErrCatch(GenAlgErr);
  }
  VecCopy(GAAdn(ga, 1)->_adnF, GAAdn(ga, 0)->_adnF);
  VecCopy(GAAdn(ga, 1)->_adnI, GAAdn(ga, 0)->_adnI);
  if (ISEQUALF(GAGetDiversity(ga), 0.0) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAGetDiversity failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
  printf("UnitTestGenAlgGetDiversity OK\n");
}
```

```
void UnitTestGenAlgStep() {
  srandom(2);
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlg* ga = GenAlgCreate(3, 2, lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GAInit(ga);
  for (int i = 3; i--;)
    GASetAdnValue(ga, GAAdn(ga, i), 3.0 - (float)i);
  printf("Before Step:\n");
  GAPrintln(ga, stdout);
  GenAlgAdn* child = GAAdn(ga, 2);
  GAStep(ga);
  printf("After Step:\n");
  GAPrintln(ga, stdout);
  if (ga->_nextId != 4 || GAAdnGetId(child) != 3 ||
    GAAdnGetAge(child) != 1 ||
    ISEQUALF(GAAdnGetGeneF(child, 0), 0.367611) == false ||
    ISEQUALF(GAAdnGetGeneF(child, 1), 0.174965) == false ||
    ISEQUALF(GAAdnGetDeltaGeneF(child, 0), 0.081678) == false ||
    ISEQUALF(GAAdnGetDeltaGeneF(child, 1), 0.0) == false ||
    GAAdnGetGeneI(child, 0) != 4 ||
    GAAdnGetGeneI(child, 1) != 9 ||
    GAAdn(ga, 2) != child ||
    GAAdnGetAge(GAAdn(ga, 0)) != 2 ||
    GAAdnGetAge(GAAdn(ga, 1)) != 2 ||
    GAAdnGetId(GAAdn(ga, 0)) != 0 ||
    GAAdnGetId(GAAdn(ga, 1)) != 1) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GAStep failed");
    PBErrCatch(GenAlgErr);
  }
  GenAlgFree(&ga);
  printf("UnitTestGenAlgStep OK\n");
}

void UnitTestGenAlgLoadSave() {
  srandom(5);
  int lengthAdnF = 2;
  int lengthAdnI = 2;
  GenAlg* ga = GenAlgCreate(3, 2, lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 1); VecSet(&boundsI, 1, 10);
  GASetBoundsAdnFloat(ga, 0, &boundsF);
  GASetBoundsAdnFloat(ga, 1, &boundsF);
  GASetBoundsAdnInt(ga, 0, &boundsI);
  GASetBoundsAdnInt(ga, 1, &boundsI);
  GASetDiversityThreshold(ga, 0.02);
  GAInit(ga);
  GAStep(ga);
  GSet* rank = GSetCreate();
  for (int i = 3; i--;)
```

```
    GSetAddSort(rank, GAAdn(ga, i), 3.0 - (float)i);
  FILE* stream = fopen("./UnitTestGenAlgLoadSave.txt", "w");
  if (GASave(ga, stream, false) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GASave failed");
    PBErrCatch(GenAlgErr);
  }
  fclose(stream);
  stream = fopen("./UnitTestGenAlgLoadSave.txt", "r");
  GenAlg* gaLoad = NULL;
  if (GALoad(&gaLoad, stream) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "GALoad failed");
    PBErrCatch(GenAlgErr);
  }
  fclose(stream);
  if (ga->_nextId != gaLoad->_nextId ||
    ga->_curEpoch != gaLoad->_curEpoch ||
    ga->_nbElites != gaLoad->_nbElites ||
    !ISEQUALF(ga->_diversityThreshold, gaLoad->_diversityThreshold) ||
    ga->_lengthAdnF != gaLoad->_lengthAdnF ||
    ga->_lengthAdnI != gaLoad->_lengthAdnI ||
    VecIsEqual(ga->_boundsF, gaLoad->_boundsF) == false ||
    VecIsEqual(ga->_boundsF + 1, gaLoad->_boundsF + 1) == false ||
    VecIsEqual(ga->_boundsI, gaLoad->_boundsI) == false ||
    VecIsEqual(ga->_boundsI + 1, gaLoad->_boundsI + 1) == false ||
    GAAdnGetId(GAAdn(ga, 0)) != GAAdnGetId(GAAdn(gaLoad, 0)) ||
    GAAdnGetId(GAAdn(ga, 1)) != GAAdnGetId(GAAdn(gaLoad, 1)) ||
    GAAdnGetId(GAAdn(ga, 2)) != GAAdnGetId(GAAdn(gaLoad, 2)) ||
    GAAdnGetAge(GAAdn(ga, 0)) != GAAdnGetAge(GAAdn(gaLoad, 0)) ||
    GAAdnGetAge(GAAdn(ga, 1)) != GAAdnGetAge(GAAdn(gaLoad, 1)) ||
    GAAdnGetAge(GAAdn(ga, 2)) != GAAdnGetAge(GAAdn(gaLoad, 2)) ||
    VecIsEqual(GAAdn(ga, 0)->_adnF,
      GAAdn(gaLoad, 0)->_adnF) == false ||
    VecIsEqual(GAAdn(ga, 0)->_deltaAdnF,
      GAAdn(gaLoad, 0)->_deltaAdnF) == false ||
    VecIsEqual(GAAdn(ga, 0)->_adnI,
      GAAdn(gaLoad, 0)->_adnI) == false ||
    VecIsEqual(GAAdn(ga, 1)->_adnF,
      GAAdn(gaLoad, 1)->_adnF) == false ||
    VecIsEqual(GAAdn(ga, 1)->_deltaAdnF,
      GAAdn(gaLoad, 1)->_deltaAdnF) == false ||
    VecIsEqual(GAAdn(ga, 1)->_adnI,
      GAAdn(gaLoad, 1)->_adnI) == false ||
    VecIsEqual(GAAdn(ga, 2)->_adnF,
      GAAdn(gaLoad, 2)->_adnF) == false ||
    VecIsEqual(GAAdn(ga, 2)->_deltaAdnF,
      GAAdn(gaLoad, 2)->_deltaAdnF) == false ||
    VecIsEqual(GAAdn(ga, 2)->_adnI,
      GAAdn(gaLoad, 2)->_adnI) == false) {
    GenAlgErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenAlgErr->_msg, "UnitTestGenAlgLoadSave failed");
    PBErrCatch(GenAlgErr);
  }
  GSetFree(&rank);
  GenAlgFree(&ga);
  GenAlgFree(&gaLoad);
  printf("UnitTestGenAlgLoadSave OK\n");
}

float ftarget(float x) {
  return -0.5 * fastpow(x, 3) + 0.314 * fastpow(x, 2) - 0.7777 * x + 0.1;
```

```
}

float evaluate(const VecFloat* adnF, const VecShort* adnI) {
  float delta = 0.02;
  int nb = (int)round(4.0 / delta);
  float res = 0.0;
  float x = -2.0;
  for (int i = 0; i < nb; ++i, x += delta) {
    float y = 0.0;
    for (int j = 4; j--;)
      y += VecGet(adnF, j) * fastpow(x, VecGet(adnI, j));
    res += fabs(ftarget(x) - y);
  }
  return res / (float)nb;
}

void UnitTestGenAlgTest() {
  srandom(5);
  int lengthAdnF = 4;
  int lengthAdnI = lengthAdnF;
  GenAlg* ga = GenAlgCreate(GENALG_NBENTITIES, GENALG_NBELITES,
    lengthAdnF, lengthAdnI);
  VecFloat2D boundsF = VecFloatCreateStatic2D();
  VecShort2D boundsI = VecShortCreateStatic2D();
  VecSet(&boundsF, 0, -1.0); VecSet(&boundsF, 1, 1.0);
  VecSet(&boundsI, 0, 0); VecSet(&boundsI, 1, 4);
  for (int i = lengthAdnF; i--;) {
    GASetBoundsAdnFloat(ga, i, &boundsF);
    GASetBoundsAdnInt(ga, i, &boundsI);
  }
  GAInit(ga);
  //GASetDiversityThreshold(ga, 0.0);
//float best = 1.0;
//int step = 0;
  do {
//float ev = evaluate(GABestAdnF(ga), GABestAdnI(ga));
//printf("%lu %f %f\n",GAGetCurEpoch(ga), ev, GAGetDiversity(ga));
    for (int iEnt = GAGetNbAdns(ga); iEnt--;)
      if (GAAdnIsNew(GAAdn(ga, iEnt)))
        GASetAdnValue(ga, GAAdn(ga, iEnt),
          -1.0 * evaluate(GAAdnAdnF(GAAdn(ga, iEnt)),
          GAAdnAdnI(GAAdn(ga, iEnt))));
    GAStep(ga);
//float ev = evaluate(GABestAdnF(ga), GABestAdnI(ga));
//if (step == 10){
//  printf("%d %f %f\n",GAGetCurEpoch(ga), ev, GAGetDiversity(ga));
//  step = 0;
//} else step++;
/*if (best - ev > PBMATH_EPSILON) {
  best = ev;
  printf("%lu %f ", GAGetCurEpoch(ga), best);
  VecFloatPrint(GABestAdnF(ga), stdout, 6);
  printf(" ");
  VecPrint(GABestAdnI(ga), stdout);
  printf("\n");
}*/
  } while (GAGetCurEpoch(ga) < 20000 ||
    evaluate(GABestAdnF(ga), GABestAdnI(ga)) < PBMATH_EPSILON);
  printf("target: -0.5*x^3 + 0.314*x^2 - 0.7777*x + 0.1\n");
  printf("approx: \n");
  GAAdnPrintln(GAAdn(ga, 0), stdout);
  printf("error: %f\n", evaluate(GABestAdnF(ga), GABestAdnI(ga)));
```

```
  GenAlgFree(&ga);
  printf("UnitTestGenAlgTest OK\n");
}

void UnitTestGenAlg() {
  UnitTestGenAlgCreateFree();
  UnitTestGenAlgGetSet();
  UnitTestGenAlgInit();
  UnitTestGenAlgPrint();
  UnitTestGenAlgGetDiversity();
  UnitTestGenAlgStep();
  UnitTestGenAlgLoadSave();
  UnitTestGenAlgTest();
  printf("UnitTestGenAlg OK\n");
}

void UnitTestAll() {
  UnitTestGenAlgAdn();
  UnitTestGenAlg();
  printf("UnitTestAll OK\n");
}

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

6 Unit tests output

```
UnitTestGenAlgAdnCreateFree OK
UnitTestGenAlgAdnGetSet OK
UnitTestGenAlgAdnInit OK
UnitTestGenAlgAdn OK
UnitTestGenAlgCreateFree OK
UnitTestGenAlgGetSet OK
UnitTestGenAlgInit OK
epoch:0
3 entities, 2 elites
#0 value:0.000000 elite id:0 age:1
  adnF:<0.788004,-0.003504>
  deltaAdnF:<0.000000,0.000000>
  adnI:<3,1>
#1 value:0.000000 elite id:1 age:1
  adnF:<-0.840711,-0.704622>
  deltaAdnF:<0.000000,0.000000>
  adnI:<5,4>
#2 value:0.000000 id:2 age:1
  adnF:<-0.907064,-0.450509>
  deltaAdnF:<0.000000,0.000000>
  adnI:<2,10>
UnitTestGenAlgInit OK
UnitTestGenAlgGetDiversity OK
Before Step:
epoch:0
3 entities, 2 elites
#0 value:3.000000 elite id:0 age:1
  adnF:<0.285933,0.174965>
```

```
  deltaAdnF:<0.000000,0.000000>
  adnI:<4,10>
#1 value:2.000000 elite id:1 age:1
  adnF:<-0.156076,-0.303386>
  deltaAdnF:<0.000000,0.000000>
  adnI:<2,7>
#2 value:1.000000 id:2 age:1
  adnF:<0.619353,0.401953>
  deltaAdnF:<0.000000,0.000000>
  adnI:<2,2>
After Step:
epoch:1
3 entities, 2 elites
#0 value:3.000000 elite id:0 age:2
  adnF:<0.285933,0.174965>
  deltaAdnF:<0.000000,0.000000>
  adnI:<4,10>
#1 value:2.000000 elite id:1 age:2
  adnF:<-0.156076,-0.303386>
  deltaAdnF:<0.000000,0.000000>
  adnI:<2,7>
#2 value:1.000000 id:3 age:1
  adnF:<0.367611,0.174965>
  deltaAdnF:<0.081678,0.000000>
  adnI:<4,9>
UnitTestGenAlgStep OK
UnitTestGenAlgLoadSave OK
target: -0.5*x^3 + 0.314*x^2 - 0.7777*x + 0.1
approx:
id:1448376 age:138
  adnF:<-0.501354,-0.774919,0.314189,0.099895>
  deltaAdnF:<0.000099,0.000207,-0.000430,0.000671>
  adnI:<3,1,2,0>
error: 0.001367
UnitTestGenAlgTest OK
UnitTestGenAlg OK
UnitTestAll OK
```

UnitTestGenAlgLoadSave.txt:

```
{
  "_diversityThreshold":"0.020000",
  "_nbAdns":"3",
  "_nbElites":"2",
  "_lengthAdnF":"2",
  "_lengthAdnI":"2",
  "_curEpoch":"1",
  "_nextId":"4",
  "_boundFloat":[
    {
      "_dim":"2",
      "_val":["-1.000000","1.000000"]
    },
    {
      "_dim":"2",
      "_val":["-1.000000","1.000000"]
    }
  ],
  "_boundInt":[
    {
      "_dim":"2",
```

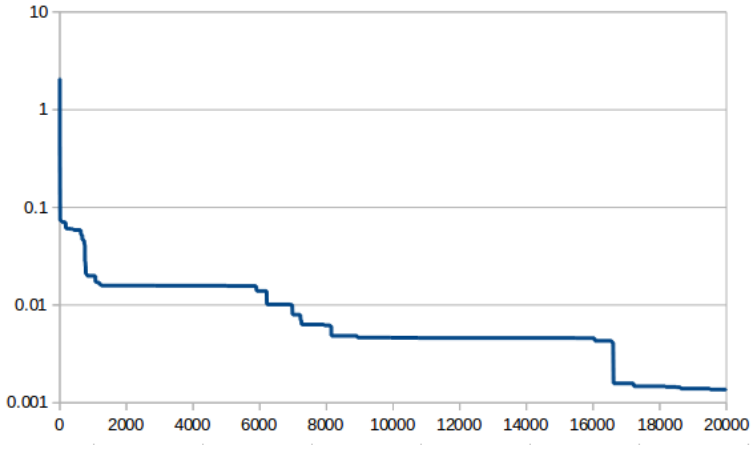
```
      "_val":["1","10"]
    },
    {
      "_dim":"2",
      "_val":["1","10"]
    }
  ],
  "_adns":[
    {
      "_id":"3",
      "_age":"1",
      "_elo":"0.000000",
      "_adnF":{
        "_dim":"2",
        "_val":["0.755265","-0.209552"]
      },
      "_deltaAdnF":{
        "_dim":"2",
        "_val":["-0.032739","-0.206048"]
      },
      "_adnI":{
        "_dim":"2",
        "_val":["4","1"]
      }
    },
    {
      "_id":"1",
      "_age":"2",
      "_elo":"0.000000",
      "_adnF":{
        "_dim":"2",
        "_val":["-0.840711","-0.704622"]
      },
      "_deltaAdnF":{
        "_dim":"2",
        "_val":["0.000000","0.000000"]
      },
      "_adnI":{
        "_dim":"2",
        "_val":["5","4"]
      }
    },
    {
      "_id":"0",
      "_age":"2",
      "_elo":"0.000000",
      "_adnF":{
        "_dim":"2",
        "_val":["0.788004","-0.003504"]
      },
      "_deltaAdnF":{
        "_dim":"2",
        "_val":["0.000000","0.000000"]
      },
      "_adnI":{
        "_dim":"2",
        "_val":["3","1"]
      }
    }
  ]
}
```

UnitTestGenAlgTest.txt:

```
1 0.522830 <-0.959931,0.745928,-0.259332,0.037688> <3,2,4,3>
3 0.272741 <-0.804893,-0.743738,0.349810,0.186053> <3,1,3,2>
5 0.224412 <-0.505146,-0.496834,0.808183,-0.689687> <1,2,2,3>
6 0.150846 <-0.408103,-0.345099,0.456368,-0.569714> <3,1,2,1>
8 0.123302 <-0.590015,-0.541932,0.303166,0.005749> <3,1,2,2>
9 0.095673 <-0.547299,-0.602595,0.303166,0.037688> <3,1,2,2>
11 0.073450 <-0.549889,-0.646563,0.432221,-0.076964> <3,1,2,2>
34 0.073053 <-0.549889,-0.668342,0.432221,-0.076964> <3,1,2,2>
50 0.072697 <-0.549889,-0.668342,0.432221,-0.064067> <3,1,2,2>
64 0.070609 <-0.547299,-0.668342,0.432221,-0.076964> <3,1,2,2>
87 0.070529 <-0.547299,-0.660726,0.432221,-0.076964> <3,1,2,2>
171 0.070492 <-0.547299,-0.660726,0.786521,-0.430374> <3,1,2,2>
184 0.060799 <-0.512247,-0.758888,0.432221,-0.076964> <3,1,2,2>
256 0.060471 <-0.512247,-0.758888,0.430695,-0.071411> <3,1,2,2>
269 0.060416 <-0.512247,-0.758888,0.430695,-0.072517> <3,1,2,2>
335 0.060040 <-0.487596,-0.820049,0.430695,-0.077548> <3,1,2,2>
370 0.059923 <-0.512247,-0.742234,0.430695,-0.072517> <3,1,2,2>
411 0.059110 <-0.512247,-0.742234,0.430695,-0.077548> <3,1,2,2>
418 0.058697 <-0.487596,-0.806099,0.430695,-0.077548> <3,1,2,2>
452 0.058641 <-0.487596,-0.727993,0.354763,-0.077548> <3,1,2,1>
628 0.058576 <-0.487596,-0.717782,0.354763,-0.089644> <3,1,2,1>
637 0.052264 <-0.487596,-0.806099,0.354763,0.012227> <3,1,2,0>
675 0.051898 <-0.487596,-0.806099,0.347155,0.012227> <3,1,2,0>
678 0.046308 <-0.487596,-0.806099,0.354763,0.028041> <3,1,2,0>
725 0.045874 <-0.487596,-0.800538,0.354763,0.028041> <3,1,2,0>
736 0.042052 <-0.487596,-0.806099,0.354763,0.057678> <3,1,2,0>
738 0.041833 <-0.487596,-0.800538,0.354763,0.045991> <3,1,2,0>
744 0.041471 <-0.487596,-0.792179,0.354763,0.045991> <3,1,2,0>
756 0.027894 <-0.487596,-0.775547,0.307387,0.104752> <3,1,2,0>
773 0.024908 <-0.487596,-0.824285,0.307387,0.123487> <3,1,2,0>
780 0.020777 <-0.487596,-0.811369,0.329454,0.074439> <3,1,2,0>
817 0.019937 <-0.484129,-0.811369,0.329454,0.081048> <3,1,2,0>
1070 0.017202 <-0.502090,-0.765516,0.329454,0.081048> <3,1,2,0>
1132 0.016983 <-0.502698,-0.765516,0.329454,0.081048> <3,1,2,0>
1197 0.016886 <-0.502698,-0.781629,0.329454,0.081048> <3,1,2,0>
1203 0.016112 <-0.502698,-0.769398,0.329454,0.081048> <3,1,2,0>
1243 0.015848 <-0.502698,-0.771443,0.329454,0.081048> <3,1,2,0>
2871 0.015816 <-0.503136,-0.771443,0.329454,0.081048> <3,1,2,0>
5008 0.015671 <-0.503136,-0.771512,0.329454,0.084652> <3,1,2,0>
5902 0.013948 <-0.493362,-0.796571,0.319417,0.106413> <3,1,2,0>
6212 0.010161 <-0.493362,-0.796571,0.315858,0.106413> <3,1,2,0>
6904 0.010081 <-0.493362,-0.796571,0.315858,0.106253> <3,1,2,0>
6984 0.007980 <-0.493362,-0.796571,0.315858,0.097262> <3,1,2,0>
7227 0.006951 <-0.495266,-0.793222,0.315858,0.097262> <3,1,2,0>
7252 0.006330 <-0.495266,-0.792201,0.315858,0.097262> <3,1,2,0>
7934 0.006205 <-0.495266,-0.792201,0.314732,0.097262> <3,1,2,0>
8113 0.006120 <-0.495266,-0.792201,0.314732,0.098331> <3,1,2,0>
8148 0.004850 <-0.495266,-0.786328,0.314732,0.098331> <3,1,2,0>
8932 0.004649 <-0.504552,-0.768060,0.314619,0.098331> <3,1,2,0>
9938 0.004629 <-0.504552,-0.768060,0.314619,0.098553> <3,1,2,0>
10750 0.004602 <-0.504552,-0.768060,0.314619,0.099105> <3,1,2,0>
15488 0.004586 <-0.504552,-0.768514,0.314619,0.099141> <3,1,2,0>
16054 0.004302 <-0.504237,-0.768514,0.314619,0.099141> <3,1,2,0>
16563 0.004162 <-0.501354,-0.770848,0.314619,0.099141> <3,1,2,0>
16613 0.001580 <-0.501354,0.099481,0.314619,-0.774215> <3,0,2,1>
17222 0.001476 <-0.501354,-0.774599,0.314619,0.099141> <3,1,2,0>
18170 0.001457 <-0.501354,-0.774599,0.314189,0.099141> <3,1,2,0>
18497 0.001441 <-0.501354,-0.774599,0.314189,0.099224> <3,1,2,0>
18632 0.001396 <-0.501354,-0.774599,0.314189,0.099895> <3,1,2,0>
```

```
19511 0.001369 <-0.501354,-0.775126,0.314189,0.099895> <3,1,2,0>
```

eval() of best genes over epoch:



inbreeding over epoch: