GenAlg

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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 $\frac{1}{nbElite} \sum_{i=1}^{nbElite} \frac{||\overrightarrow{adn}(elite_i) - \overrightarrow{adn}(elite_0)||}{||\overrightarrow{bound}_{max} - \overrightarrow{bound}_{min}|| * Age(elite_i)}$ 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
  int _id;
  // Age
  int _age;
  // Adn for floating point value
  VecFloat* _adnF;
  // Delta Adn during mutation
  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(int id, int lengthAdnF,
  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
VecFloat* GAAdnAdnF(GenAlgAdn* that);

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

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

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

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

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

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

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

// ------------- 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
  int _curEpoch;
  // Nb elite entities in population
  int _nbElites;
  // Id of the next new GenAlgAdn
  int _nextId;
  // Length of adn for floating point value
  int _lengthAdnF;
  // Length of adn for integer value
  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;
} 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(int nbEntities, int nbElites, int lengthAdnF,
  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(GenAlg* that);

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

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

// Return the diversity threshold of the GenAlg 'that'
#if BUILDMODE != 0
inline
```

```
#endif
float GAGetDiversityThreshold(GenAlg* that);

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

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

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

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

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

// Get the bounds for the 'iGene'-th gene of adn for integer values
#if BUILDMODE != 0
inline
#endif
VecShort2D* GABoundsAdnInt(GenAlg* that, 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* that, int iGene, VecFloat2D* 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* that, int iGene, VecShort2D* bounds);

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

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

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

// Get the level of diversity of curent 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
float GAGetDiversity(GenAlg* that);

// 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* stream);

// Save the GenAlg 'that' to the stream 'stream'
// Return true in case of success, else false
bool GASave(GenAlg* that, FILE* stream);

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

// ================= 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(int id, int lengthAdnF,
  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(GenAlgAdn* that, GenAlg* 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(GenAlgAdn* that, FILE* 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:%d age:%d", 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(GenAlg* that, int* 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* that, int* parents, 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* that, int* parents, int iChild);

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

// ================ 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(int nbEntities, int nbElites, int lengthAdnF,
  int lengthAdnI) {
  // Allocate memory
  GenAlg* that = PBErrMalloc(GenAlgErr, sizeof(GenAlg));
  // Set the properties
  that->_adns = GSetCreate();
  that->_curEpoch = 0;
  that->_lengthAdnF = lengthAdnF;
  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->_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* that, 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* that, 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* 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* 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);
  do {
    // Get the adn
    GenAlgAdn* adn = GSetIterGet(&iter);
    // 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* 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 < GENALG_DIVERSITYTHRESHOLD) {
    // Break the diversity by applying 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(GenAlg* that, int* 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* that, int* parents, 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* that, int* parents, 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
      VecFloat2D* 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
      VecShort2D* 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(GenAlg* that, FILE* 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:%d\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));
}

// Get the level of diversity of curent 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
float GAGetDiversity(GenAlg* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  // Declare a variable to memorize the result
  float diversity = 0.0;
  // Declare a variable for calculation
  int nb = 1;
```

```
  // If there are adn for floating point values
  if (GAGetLengthAdnFloat(that) > 0) {
    // Declare a vector to memorize the ranges in 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
    float normRange = VecNorm(range);
    // For each elite entity except the first one
    for (int iEnt = 1; iEnt < GAGetNbElites(that); ++iEnt) {
      // Get the difference in adn with the first entity
      VecFloat* diff = VecGetOp(GAAdnAdnF(GAAdn(that, iEnt)), 1.0,
        GAAdnAdnF(GAAdn(that, 0)), -1.0);
      // Calculate the diversity
      diversity += VecNorm(diff) /
        (normRange * (float)GAAdnGetAge(GAAdn(that, iEnt)));
      // Free memory
      VecFree(&diff);
    }
    // Calculate the diversity
    nb += GAGetNbElites(that);
    // Free memory
    VecFree(&range);
  }
  // If there are adn for floating point values
  if (GAGetLengthAdnInt(that) > 0) {
    // Declare a vector to memorize the ranges in gene values
    VecFloat* range = VecFloatCreate(GAGetLengthAdnInt(that));
    // Calculate the ranges in gene values
    for (int iGene = GAGetLengthAdnInt(that); iGene--;)
      VecSet(range, iGene,
        (float)(VecGet(GABoundsAdnInt(that, iGene), 1) -
        VecGet(GABoundsAdnInt(that, iGene), 0)));
    // Calculate the norm of the range
    float normRange = VecNorm(range);
    // For each elite entity except the first one
    for (int iEnt = 1; iEnt < GAGetNbElites(that); ++iEnt) {
      // Get the difference in adn with the first entity
      VecShort* diff = VecGetOp(GAAdnAdnI(GAAdn(that, iEnt)), 1,
        GAAdnAdnI(GAAdn(that, 0)), -1);
      VecFloat* diffF = VecShortToFloat(diff);
      // Calculate the diversity
      diversity += VecNorm(diffF) /
        (normRange * (float)GAAdnGetAge(GAAdn(that, iEnt)));
      // Free memory
      VecFree(&diffF);
      VecFree(&diff);
    }
    // Calculate the diversity
    nb += GAGetNbElites(that);
    // Free memory
    VecFree(&range);
  }
  // Calculate the diversity
  diversity /= (float)nb;
  // Return the result
  return diversity;
}
```

```
// 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* 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
  // If 'that' is already allocated
  if (*that != NULL) {
    // Free memory
    GenAlgFree(that);
  }
  // Load the number of entity and elite, and the length of adn
  int nbEnt, nbElite, lenAdnF, lenAdnI;
  int ret = fscanf(stream, "%d %d %d %d", &nbEnt, &nbElite,
    &lenAdnF, &lenAdnI);
  // If we couldn't fscanf
  if (ret == EOF)
    return false;
  // Check the data
  if (nbEnt < 3 || nbElite < 2 || lenAdnF < 0 || lenAdnI < 0)
    return false;
  // Allocate memory
  *that = GenAlgCreate(nbEnt, nbElite, lenAdnF, lenAdnI);
  // Load the epoch, nextId
  ret = fscanf(stream, "%d %d", &((*that)->_curEpoch),
    &((*that)->_nextId));
  // If we couldn't fscanf
  if (ret == EOF)
    return false;
  // Load the bounds
  for (int iBound = 0; iBound < lenAdnF; ++iBound) {
    VecFloat* b = NULL;
    if (VecLoad(&b, stream) == false)
      return false;
    VecCopy(GABoundsAdnFloat(*that, iBound), b);
    VecFree(&b);
  }
  for (int iBound = 0; iBound < lenAdnI; ++iBound) {
    VecShort* b = NULL;
    if (VecLoad(&b, stream) == false)
      return false;
    VecCopy(GABoundsAdnInt(*that, iBound), b);
    VecFree(&b);
  }
  // Load the adns
  for (int iEnt = 0; iEnt < nbEnt; ++iEnt) {
    GSetElem* setElem = GSetGetElem(GAAdns(*that), iEnt);
    GenAlgAdn* ent = (GenAlgAdn*)(setElem->_data);
    // Load the id, age and elo
    int id, age;
    float val;
    int ret = fscanf(stream, "%d %d %f", &id, &age, &val);
```

```
    // If we couldn't fscanf
    if (ret == EOF)
      return false;
    // Set the id and elo
    ent->_id = id;
    ent->_age = age;
    setElem->_sortVal = val;
    // Load the genes
    if (lenAdnF > 0) {
      VecFloat* v = NULL;
      if (VecLoad(&v, stream) == false)
        return false;
      VecCopy(ent->_adnF, v);
      if (VecLoad(&v, stream) == false)
        return false;
      VecCopy(ent->_deltaAdnF, v);
      VecFree(&v);
    }
    if (lenAdnI > 0) {
      VecShort* v = NULL;
      if (VecLoad(&v, stream) == false)
        return false;
      VecCopy(ent->_adnI, v);
      VecFree(&v);
    }
  }
  // Return success code
  return true;
}

// Save the GenAlg 'that' to the stream 'stream'
// Return true in case of success, else false
bool GASave(GenAlg* that, FILE* 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
  // Save the number of entity and elite, and the length of adn
  int ret = fprintf(stream, "%d %d %d %d\n", GAGetNbAdns(that),
    GAGetNbElites(that), GAGetLengthAdnFloat(that),
    GAGetLengthAdnInt(that));
  // If we couldn't fprintf
  if (ret < 0)
    return false;
  // Save the epoch, nextId
  ret = fprintf(stream, "%d %d\n", GAGetCurEpoch(that), that->_nextId);
  // If we couldn't fprintf
  if (ret < 0)
    return false;
  // Save the bounds
  for (int iBound = 0; iBound < GAGetLengthAdnFloat(that); ++iBound)
    if (VecSave(GABoundsAdnFloat(that, iBound), stream) == false)
      return false;
  for (int iBound = 0; iBound < GAGetLengthAdnInt(that); ++iBound)
```

```
    if (VecSave(GABoundsAdnInt(that, iBound), stream) == false)
      return false;
  // Save the adns
  for (int iEnt = 0; iEnt < GAGetNbAdns(that); ++iEnt) {
    GSetElem* setElem = GSetGetElem(GAAdns(that), iEnt);
    GenAlgAdn* ent = (GenAlgAdn*)(setElem->_data);
    // Save the id, age and elo
    int ret = fprintf(stream, "%d %d %f\n", ent->_id, ent->_age,
      setElem->_sortVal);
    // If we couldn't fprintf
    if (ret < 0)
      return false;
    // Save the genes
    if (GAGetLengthAdnFloat(that) > 0) {
      if (VecSave(ent->_adnF, stream) == false)
        return false;
      if (VecSave(ent->_deltaAdnF, stream) == false)
        return false;
    }
    if (GAGetLengthAdnInt(that) > 0)
      if (VecSave(ent->_adnI, stream) == false)
        return false;
  }
  // 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
VecFloat* GAAdnAdnF(GenAlgAdn* 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
VecFloat* GAAdnDeltaAdnF(GenAlgAdn* 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
VecShort* GAAdnAdnI(GenAlgAdn* 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(GenAlgAdn* that, 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(GenAlgAdn* that, 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(GenAlgAdn* that, 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* that, int iGene, 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* that, int iGene, 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* that, int iGene, 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
int GAAdnGetId(GenAlgAdn* 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
int GAAdnGetAge(GenAlgAdn* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenAlgErr->_type = PBErrTypeNullPointer;
    sprintf(GenAlgErr->_msg, "'that' is null");
    PBErrCatch(GenAlgErr);
  }
#endif
  return that->_age;
}

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

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

// Return the GSet of the GenAlg 'that'
#if BUILDMODE != 0
inline
#endif
GSet* GAAdns(GenAlg* 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(GenAlg* 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(GenAlg* 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
int GAGetCurEpoch(GenAlg* 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(GenAlg* 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(GenAlg* 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* that, int iGene, VecFloat2D* 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);
}

// 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* that, int iGene, VecShort2D* 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);
}

// Get the bounds for the 'iGene'-th gene of adn for floating point
// values
#if BUILDMODE != 0
inline
#endif
VecFloat2D* GABoundsAdnFloat(GenAlg* that, 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
VecShort2D* GABoundsAdnInt(GenAlg* that, 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(GenAlg* that, 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* that, GenAlgAdn* adn, 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
  GSetGetFirstElem(GAAdns(that), adn)->_sortVal = val;
}

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

```
#directory
PBERRDIR=../PBErr
PBMATHDIR=../PBMath
GSETDIR=../GSet
BCURVEDIR=../BCurve
SHAPOIDDIR=../Shapoid

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

include $(PBERRDIR)/Makefile.inc

INCPATH=-I./ -I$(PBERRDIR)/ -I$(GSETDIR)/ -I$(PBMATHDIR)/ -I$(ELORANKDIR)/ -I$(BCURVEDIR)/ -I$(SHAPOIDDIR)/
```

```
BUILDOPTIONS=$(BUILDPARAM) $(INCPATH)

# compiler
COMPILER=gcc

#rules
all : main getSCurve

main: main.o pberr.o gset.o pbmath.o genalg.o genalg.o Makefile
$(COMPILER) main.o pberr.o gset.o  pbmath.o genalg.o $(LINKOPTIONS) -o main

main.o : main.c $(PBERRDIR)/pberr.h $(GSETDIR)/gset.h $(ELORANKDIR)/ genalg.h genalg-inline.c Makefile
$(COMPILER) $(BUILDOPTIONS) -c main.c

getSCurve: getSCurve.o pberr.o gset.o pbmath.o genalg.o genalg.o bcurve.o shapoid.o Makefile
$(COMPILER) getSCurve.o pberr.o gset.o  pbmath.o genalg.o bcurve.o shapoid.o $(LINKOPTIONS) -o getSCurve

getSCurve.o : getSCurve.c $(PBERRDIR)/pberr.h $(GSETDIR)/gset.h $(ELORANKDIR)/ $(BCURVEDIR)/bcurve.h genalg.h genalg
$(COMPILER) $(BUILDOPTIONS) -c getSCurve.c

genalg.o : genalg.c genalg.h genalg-inline.c Makefile
$(COMPILER) $(BUILDOPTIONS) -c genalg.c

shapoid.o : $(SHAPOIDDIR)/shapoid.c $(SHAPOIDDIR)/shapoid.h $(SHAPOIDDIR)/shapoid-inline.c Makefile
$(COMPILER) $(BUILDOPTIONS) -c $(SHAPOIDDIR)/shapoid.c

bcurve.o : $(BCURVEDIR)/bcurve.c $(BCURVEDIR)/bcurve.h $(BCURVEDIR)/bcurve-inline.c Makefile
$(COMPILER) $(BUILDOPTIONS) -c $(BCURVEDIR)/bcurve.c

pberr.o : $(PBERRDIR)/pberr.c $(PBERRDIR)/pberr.h Makefile
$(COMPILER) $(BUILDOPTIONS) -c $(PBERRDIR)/pberr.c

pbmath.o : $(PBMATHDIR)/pbmath.c $(PBMATHDIR)/pbmath-inline.c $(PBMATHDIR)/pbmath.h Makefile $(PBERRDIR)/pberr.h
$(COMPILER) $(BUILDOPTIONS) -c $(PBMATHDIR)/pbmath.c

gset.o : $(GSETDIR)/gset.c $(GSETDIR)/gset-inline.c $(GSETDIR)/gset.h Makefile $(PBERRDIR)/pberr.h
$(COMPILER) $(BUILDOPTIONS) -c $(GSETDIR)/gset.c

clean :
rm -rf *.o main

valgrind :
valgrind -v --track-origins=yes --leak-check=full --gen-suppressions=yes --show-leak-kinds=all ./main

unitTest :
main > unitTest.txt; diff unitTest.txt unitTestRef.txt
```

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() {
  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() {
  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);
  }
  GenAlgAdnFree(&ent);
  printf("UnitTestGenAlgAdnGetSet OK\n");
}

void UnitTestGenAlgAdnInit() {
  srandom(5);
  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);
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(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);
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(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);
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(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);
```

```
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(ga, 1), &boundsI);
  GASetNbElites(ga, 2);
  GASetNbEntities(ga, 3);
  GAInit(ga);
  if (ISEQUALF(GAGetDiversity(ga), 0.182041) == 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);
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(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);
  }
```

```
  VecCopy(GAAdn(ga, 1)->_adnF, GAAdn(ga, 0)->_adnF);
  VecCopy(GAAdn(ga, 1)->_adnI, GAAdn(ga, 0)->_adnI);
  GAStep(ga);
  printf("After StepEpoch with interbreeding:\n");
  GAPrintln(ga, stdout);
  if (ga->_nextId != 6 || GAAdnGetId(child) != 5 ||
    GAAdnGetAge(child) != 1 ||
    ISEQUALF(GAAdnGetGeneF(child, 0), 0.289982) == false ||
    ISEQUALF(GAAdnGetGeneF(child, 1), -0.910199) == false ||
    ISEQUALF(GAAdnGetDeltaGeneF(child, 0), 0.081678) == false ||
    ISEQUALF(GAAdnGetDeltaGeneF(child, 1), 0.0) == false ||
    GAAdnGetGeneI(child, 0) != 9 ||
    GAAdnGetGeneI(child, 1) != 8 ||
    GAAdn(ga, 2) != child ||
    GAAdnGetAge(GAAdn(ga, 0)) != 2 ||
    GAAdnGetAge(GAAdn(ga, 1)) != 1 ||
    GAAdnGetId(GAAdn(ga, 0)) != 0 ||
    GAAdnGetId(GAAdn(ga, 1)) != 4) {
    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);
  VecCopy(GABoundsAdnFloat(ga, 0), &boundsF);
  VecCopy(GABoundsAdnFloat(ga, 1), &boundsF);
  VecCopy(GABoundsAdnInt(ga, 0), &boundsI);
  VecCopy(GABoundsAdnInt(ga, 1), &boundsI);
  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) {
    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 ||
```

```
    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(VecFloat* adnF, 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--;) {
    VecCopy(GABoundsAdnFloat(ga, i), &boundsF);
    VecCopy(GABoundsAdnInt(ga, i), &boundsI);
  }
  GAInit(ga);
//float best = 1.0;
//int step = 0;
/*float ev = evaluate(GABestAdnF(ga), GABestAdnI(ga));
printf("%d %f %f\n",GAGetCurEpoch(ga), ev, GAGetDiversity(ga));*/
  do {
    for (int iEnt = GAGetNbAdns(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("%d %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>
After StepEpoch with interbreeding:
epoch:2
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:4 age:1
  adnF:<0.700961,0.779526>
  deltaAdnF:<0.000000,0.000000>
  adnI:<2,4>
#2 value:1.000000 id:5 age:1
  adnF:<0.289982,-0.910199>
  deltaAdnF:<0.081678,0.000000>
  adnI:<9,8>
UnitTestGenAlgStep OK
UnitTestGenAlgLoadSave OK
target: -0.5*x^3 + 0.314*x^2 - 0.7777*x + 0.1
approx:
id:983022 age:7634
  adnF:<-0.772051,0.313140,-0.502480,0.101328>
  deltaAdnF:<-0.006612,-0.000041,0.085838,0.741578>
  adnI:<1,2,3,0>
error: 0.002613
UnitTestGenAlgTest OK
UnitTestGenAlg OK
UnitTestAll OK
```

UnitTestGenAlgLoadSave.txt:

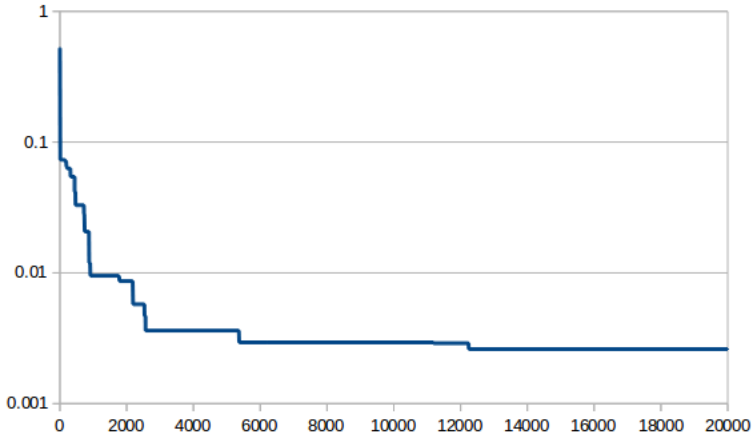
```
3 2 2 2
1 4
2 -1.000000 1.000000
2 -1.000000 1.000000
2 1 10
2 1 10
3 1 0.000000
2 0.755265 -0.209552
2 -0.032739 -0.206048
2 4 1
1 2 0.000000
2 -0.840711 -0.704622
2 0.000000 0.000000
2 5 4
0 2 0.000000
2 0.788004 -0.003504
2 0.000000 0.000000
2 3 1
```

UnitTestGenAlgTest.txt:

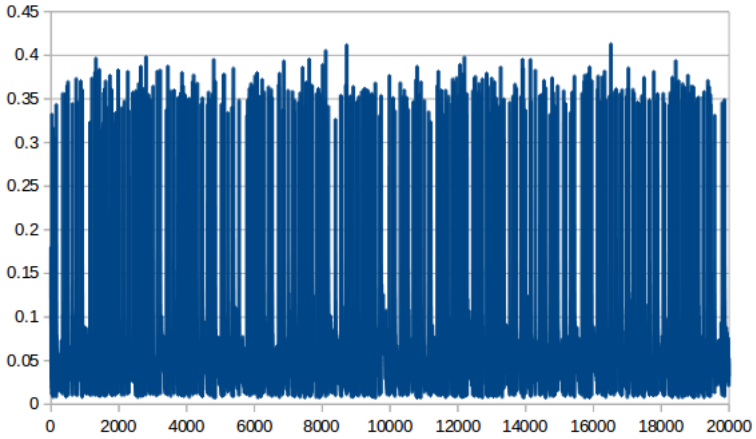
```
1 0.522828 <-0.959931,0.745928,-0.259332,0.037688> <3,2,4,3>
3 0.272741 <-0.804893,-0.743738,0.349810,0.186053> <3,1,3,2>
5 0.224411 <-0.505146,-0.496834,0.808183,-0.689687> <1,2,2,3>
6 0.150845 <-0.408103,-0.345099,0.456368,-0.569714> <3,1,2,1>
8 0.123301 <-0.590015,-0.541932,0.303166,0.005749> <3,1,2,2>
9 0.095673 <-0.547299,-0.602595,0.303166,0.037688> <3,1,2,2>
```

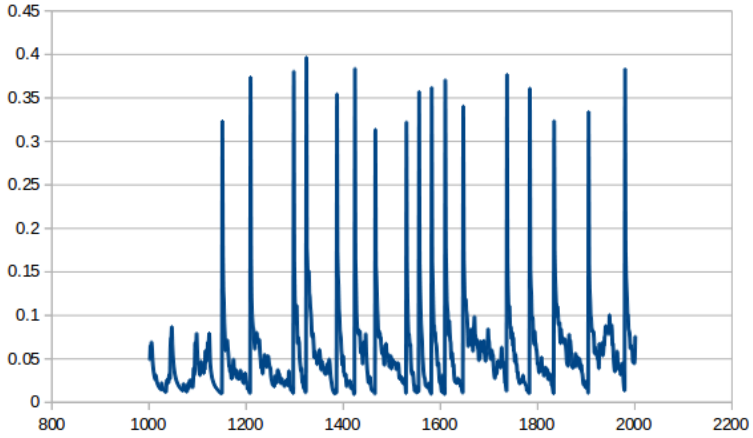
```
11 0.073451 <-0.549889,-0.646563,0.432221,-0.076964> <3,1,2,2>
59 0.073127 <-0.504843,0.334721,-0.700384,-0.077186> <3,2,1,1>
153 0.071830 <-0.389386,0.342553,-0.856339,-0.077186> <3,2,1,3>
198 0.064972 <0.353165,-0.442254,-0.461739,-0.429105> <2,1,3,1>
214 0.062897 <0.110719,0.342553,-0.461739,-0.885047> <0,2,3,1>
319 0.054397 <0.110719,0.342553,-0.461739,-0.830428> <0,2,3,1>
442 0.041706 <0.334213,-0.528332,-0.749878,0.075020> <2,3,1,0>
469 0.032929 <0.334213,-0.490436,-0.770205,0.075020> <2,3,1,0>
721 0.028211 <-0.820933,-0.490436,0.315181,0.075020> <1,3,2,0>
743 0.020676 <0.334213,-0.503733,-0.770205,0.075020> <2,3,1,0>
878 0.011919 <-0.770117,0.313181,-0.507948,0.095455> <1,2,3,0>
909 0.010774 <-0.770117,0.313181,-0.507948,0.103277> <1,2,3,0>
914 0.009503 <-0.765439,0.313181,-0.507948,0.095455> <1,2,3,0>
1773 0.009382 <-0.767748,0.313181,-0.507948,0.097955> <1,2,3,0>
1783 0.008650 <-0.765439,0.313181,-0.507948,0.097955> <1,2,3,0>
2192 0.005756 <-0.765439,0.313181,-0.503778,0.097955> <1,2,3,0>
2534 0.004692 <-0.772051,0.313181,-0.503778,0.097955> <1,2,3,0>
2565 0.003620 <-0.772051,0.313181,-0.502827,0.097955> <1,2,3,0>
5369 0.002942 <-0.772051,0.313181,-0.502827,0.101665> <1,2,3,0>
11186 0.002902 <-0.772051,0.313140,-0.502827,0.101328> <1,2,3,0>
12245 0.002613 <-0.772051,0.313140,-0.502480,0.101328> <1,2,3,0>
```

eval() of best genes over epoch:



inbreeding over epoch:


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
800
1000
1200
1400
1600
1800
2000
2200