MiniFrame

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Contents

Introduction

MiniFrame is a C library providing a framework to implement the MiniMax algorithm.

The user can define the system to which the MiniMax algorithm is apply by implementing the set of functions in files `miniframe-model.h`, `miniframe-inline-model.c` and `miniframe-model.c`.

It supports one or several actor(s) and uses a time limit to control MiniMax expansion. MiniFrame uses time prediction to maximise the number of steps computed inside the time limit and minimize the risk of overcoming this time limit.

The user can choose if MiniFrame should try to reuse previously computed worlds or recompute several times the same world if it's reachable through several transitions. If it reuses previously computed worlds MiniFrame provide the percentage of reused worlds at each step. MiniFrame also provide the time unused and the number of computed worlds at each step to allow the user to estimate performances.

A basic example is given to illustrate how to use MiniFrame, as well as the implementation for the game of Oware.

The example of the game of Oware also contains an implementation of how to combine MiniFrame with ELORank, GenAlg and NeuraNet to train a NeuraNet later used as the evaluation function of the MiniFrame.

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

1 Interface

1.1 miniframe.h

```
// ============ MINIFRAME.H ================

#ifndef MINIFRAME_H
#define MINIFRAME_H

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

#include <stdlib.h>
```

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

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

// Default time for expansion, in millisecond
#define MF_DEFAULTTIMEEXPANSION 100
// time_ms = clock() / MF_MILLISECTOCLOCKS
#define MF_MILLISECTOCLOCKS (CLOCKS_PER_SEC * 0.001)
// Default number of transitions per world above which the MonteCarlo
// algorithm is activated during expansion
#define MF_NBTRANSMONTECARLO 100

// =========== Interface with the model implementation =============

#include "miniframe-model.h"

// ================= Data structure ==================
typedef struct MFWorld MFWorld;
typedef struct MFTransition {
  // User defined transition
  MFModelTransition _transition;
  // Reference to the world to which this action is applied
  MFWorld* _fromWorld;
  // Reference to the reached world through this action
  // if null it means this action has not been computed
  MFWorld* _toWorld;
  // Array of forecasted POV value of this transition for each actor
  float _values[MF_NBMAXACTOR];
} MFTransition;

typedef struct MFWorld {
  // User defined status of the world
  MFModelStatus _status;
  // Set of transitions reaching this world
  GSet _sources;
  // Array of value of this world from the pov of each actor
  float _values[MF_NBMAXACTOR];
  // Array to memorize the transitions from this world instance
  MFTransition _transitions[MF_NBMAXTRANSITION];
  // Number of transitions from this world
  int _nbTransition;
  // Depth, internal variable used during expansion
  int _depth;
} MFWorld;

typedef enum MFExpansionType {
  MFExpansionTypeValue,
  MFExpansionTypeWidth
} MFExpansionType;

typedef struct MiniFrame {
  // Nb of steps
  unsigned int _nbStep;
  // Current world instance
  MFWorld* _curWorld;
```

```
  // All the computed world instances, ordered by their value from the
  // pov of the preempting player at the previous step
  GSet _worlds;
  // Time limit for expansion, in millisecond
  float _maxTimeExpansion;
  // Time unused during expansion, in millisecond
  float _timeUnusedExpansion;
  // Percent of the total available time available to search for worlds
  // to expand in MFExpand(), in ]0.0, 1.0], init to 1.0
  float _timeSearchWorld;
  // Nb of worlds expanded during last call to MFExpand
  int _nbWorldExpanded;
  // Nb of worlds unexpanded during last call to MFExpand
  int _nbWorldUnexpanded;
  // Nb of removed world;
  int _nbRemovedWorld;
  // Flag to activate the reuse of previously computed same world
  bool _reuseWorld;
  // Percentage (in [0.0, 1.0]) of world reused during the last
  // MFExpand()
  float _percWorldReused;
  // Time used at end of expansion (per remaining world)
  float _timeEndExpansion;
  // The clock considered has start during expansion
  clock_t _startExpandClock;
  // Maximum depth during expansion, if -1 there is no limit
  int _maxDepthExp;
  // Type of expansion, default is MFExpansionTypeValue
  MFExpansionType _expansionType;
  // Number of transitions above which the Monte Carlo algorithm is
  // activated during expansion
  int _nbTransMonteCarlo;
} MiniFrame;


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

// Create a new MiniFrame the initial world 'initStatus'
// The current world is initialized with a copy of 'initStatus'
// Return the new MiniFrame
MiniFrame* MiniFrameCreate(const MFModelStatus* const initStatus);

// Create a new MFWorld with a copy of the MFModelStatus 'status'
// Return the new MFWorld
MFWorld* MFWorldCreate(const MFModelStatus* const status);

// Create a new static MFTransition for the MFWorld 'world' with the
// MFModelTransition 'transition'
// Return the new MFTransition
MFTransition MFTransitionCreateStatic(const MFWorld* const world,
  const MFModelTransition* const transition);

// Free memory used by the MiniFrame 'that'
void MiniFrameFree(MiniFrame** that);

// Free memory used by the MFWorld 'that'
void MFWorldFree(MFWorld** that);

// Free memory used by properties of the MFTransition 'that'
void MFTransitionFreeStatic(MFTransition* that);

// Get the current MFWorld of the MiniFrame 'that'
```

```
#if BUILDMODE != 0
inline
#endif
const MFWorld* MFCurWorld(const MiniFrame* const that);

// Get the GSet of computed MFWorlds of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorlds(const MiniFrame* const that);

// Return the number of computed worlds in the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbComputedWorld(const MiniFrame* const that);

// Return true if the expansion algorithm looks in previously
// computed worlds for same world to reuse, else false
#if BUILDMODE != 0
inline
#endif
bool MFIsWorldReusable(const MiniFrame* const that);

// Set the falg controlling if the expansion algorithm looks in
// previously computed worlds for same world to reuse to 'reuse'
#if BUILDMODE != 0
inline
#endif
void MFSetWorldReusable(MiniFrame* const that, const bool reuse);

// Add the MFWorld 'world' to the computed MFWorlds of the
// MiniFrame 'that', ordered by the world's value from the pov of
// actor 'iActor'
#if BUILDMODE != 0
inline
#endif
void MFAddWorld(MiniFrame* const that, \
  const MFWorld* const world, const int iActor);

// Get the time limit for expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetMaxTimeExpansion(const MiniFrame* const that);

// Get the time unused during last expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetTimeUnusedExpansion(const MiniFrame* const that);

// Get the time used to search world to expand during next expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetTimeSearchWorld(const MiniFrame* const that);

// Get the nb of world expanded during the last expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
```

```
inline
#endif
int MFGetNbWorldExpanded(const MiniFrame* const that);

// Get the nb of world unexpanded during the last expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldUnexpanded(const MiniFrame* const that);

// Get the nb of removed world during the last call to SetCurWorld
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldRemoved(const MiniFrame* const that);

// Get the time used at end of expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetTimeEndExpansion(const MiniFrame* const that);

// Get the percentage of resued world of the MiniFrame 'that' during
// the last MFEpxand()
#if BUILDMODE != 0
inline
#endif
float MFGetPercWordReused(const MiniFrame* const that);

// Get the clock considered has start during expansion
#if BUILDMODE != 0
inline
#endif
clock_t MFGetStartExpandClock(const MiniFrame* const that);

// Set the clock considered has start during expansion to 'c'
#if BUILDMODE != 0
inline
#endif
void MFSetStartExpandClock(MiniFrame* const that, clock_t c);

// Set the time limit for expansion of the MiniFrame 'that' to
// 'timeLimit', in millisecond
// The time is measured with the function clock(), see "man clock"
// for details
#if BUILDMODE != 0
inline
#endif
void MFSetMaxTimeExpansion(MiniFrame* const that, \
  const float timeLimit);

// Return the MFModelStatus of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const MFModelStatus* MFWorldStatus(const MFWorld* const that);

// Expand the MiniFrame 'that' until it reaches its time limit or can't
// expand anymore
void MFExpand(MiniFrame* that);
```

```
// Return the forecasted value of the MFWorld 'that' for the
// actor 'iActor'.
// This is the best value of the transitions from this world,
// or the value of this world if it has no transition.
float MFWorldGetForecastValue(const MFWorld* const that,
  const int iActor);

// Get the number of transition for the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
int MFWorldGetNbTrans(const MFWorld* const that);

// Get the number of expandable transition for the MFWorld 'that'
int MFWorldGetNbTransExpandable(const MFWorld* const that);

// Get the MFWorld which the MFTransition 'that' is leading to
#if BUILDMODE != 0
inline
#endif
const MFWorld* MFTransitionToWorld(const MFTransition* const that);

// Set the MFWorld to which the MFTransition 'that' is leading to
// 'world'
#if BUILDMODE != 0
inline
#endif
void MFTransitionSetToWorld(MFTransition* const that,
  MFWorld* const world);

// Get the MFWorld which the MFTransition 'that' is coming from
#if BUILDMODE != 0
inline
#endif
const MFWorld* MFTransitionFromWorld(const MFTransition* const that);

// Return true if the MFTransition 'that' is expandable, i.e. its
// 'toWorld' is null, else return false
bool MFTransitionIsExpandable(const MFTransition* const that);

// Get the 'iTrans' MFTransition of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const MFTransition* MFWorldTransition(const MFWorld* const that,
  const int iTrans);

// Get the set of MFTransition reaching the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorldSources(const MFWorld* const that);

// Return the array of values of the MFWorld 'that' for each actor
#if BUILDMODE != 0
inline
#endif
const float* MFWorldValues(const MFWorld* const that);

// Compute the MFModelStatus resulting from the 'iTrans' MFTransition
// of the MFWorld 'that'
```

```
#if BUILDMODE != 0
inline
#endif
MFModelStatus MFWorldComputeTransition(const MFWorld* const that,
  const int iTrans);

// Get the forecast value of the MFWorld 'that' for the actor 'iActor'
float MFWorldGetForecastValue(const MFWorld* const that, int iActor);

// Set the value of the MFTransition 'that' for the actor 'iActor' to
// 'val'
#if BUILDMODE != 0
inline
#endif
void MFTransitionSetValue(MFTransition* const that, const int iActor,
  const float val);

// Return the value of the MFTransition 'that' for the
// actor 'iActor'.
#if BUILDMODE != 0
inline
#endif
float MFTransitionGetValue(const MFTransition* const that,
  const int iActor);

// Return the value of the MFWorld 'that' for the
// actor 'iActor'.
#if BUILDMODE != 0
inline
#endif
float MFWorldGetValue(const MFWorld* const that, const int iActor);

// Get the best MFModelTransition for the 'iActor'-th actor in the
// current MFWorld of the MiniFrame 'that'
// Return an undefined MFTransition if the curernt world has no
// transition
const MFModelTransition* MFBestTransition(
  const MiniFrame* const that, const int iActor);

// Print the MFWorld 'that' on the stream 'stream'
void MFWorldPrint(const MFWorld* const that, FILE* const stream);

// Print the MFTransition 'that' on the stream 'stream'
void MFTransitionPrint(const MFTransition* const that,
  FILE* const stream);

// Print the MFWorld 'that' and its MFTransition on the stream 'stream'
void MFWorldTransPrintln(const MFWorld* const that,
  FILE* const stream);

// Set the current world of the MiniFrame 'that' to match the
// MFModelStatus 'status'
// If the world is in computed worlds reuse it, else create a new one
void MFSetCurWorld(MiniFrame* const that,
  const MFModelStatus* const world);

// Print the best forecasted story from the MFWorld 'that' for the
// actor 'iActor' on the stream 'stream'
void MFWorldPrintBestStoryln(const MFWorld* const that, const int iActor,
  FILE* const stream);

// Set the values of the MFWorld 'that' to 'values'
```

```
void MFWorldSetValues(MFWorld* const that, const float* const values);

// Return the max depth during expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetMaxDepthExp(const MiniFrame* const that);

// Set the max depth during expansion for the MiniFrame 'that' to 'depth'
// If depth is less than -1 it is converted to -1
#if BUILDMODE != 0
inline
#endif
void MFSetMaxDepthExp(MiniFrame* const that, const int depth);

// Return the type of expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
MFExpansionType MFGetExpansionType(const MiniFrame* const that);

// Set the type expansion for the MiniFrame 'that' to 'type'
#if BUILDMODE != 0
inline
#endif
void MFSetExpansionType(MiniFrame* const that, const MFExpansionType type);

// Set the nb of transitio to activate MonteCarlo during expansion
// for the MiniFrame 'that' to 'nb'
#if BUILDMODE != 0
inline
#endif
void MFSetNbTransMonteCarlo(MiniFrame* const that, const int nb);

// Set the nb of transitions to activate MonteCarlo during expansion
// for the MiniFrame 'that' to 'nb'
#if BUILDMODE != 0
inline
#endif
void MFSetNbTransMonteCarlo(MiniFrame* const that, const int nb);

// Get the nb of transitions to activate MonteCarlo during expansion
// for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbTransMonteCarlo(MiniFrame* const that);

// Return true if the MFTransition is expanded, false else
#if BUILDMODE != 0
inline
#endif
bool MFTransitionIsExpanded(const MFTransition* const that);

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

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


#endif
```

2 Code

2.1 miniframe.c

```
// ============ MINIFRAME.C ================

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

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

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

// Get the set of worlds to be expanded (having at least one transition
// whose _toWorld is null) for the MiniFrame 'that'
// Stop searching for world if clock() >= clockLimit
// Will return at least one world even if clockLimit == current clock
// The MiniFrame must have at least one world in its set of computed
// worlds
// Force the current world to the end of the returned set to ensure
// it will be the first to be expanded
GSet MFGetWorldsToExpand(MiniFrame* const that,
  const clock_t clockLimit);

// Return true if the MFWorld 'that' has at least one transition to be
// expanded
bool MFWorldIsExpandable(const MFWorld* const that);

// Search in computed worlds of the MiniFrame 'that' if there is
// one with same status as the MFModelStatus 'status'
// If there is one return it, if not return null
MFWorld* MFSearchWorld(const MiniFrame* const that,
  const MFModelStatus* const status);

// Set the MFWorld 'toWorld' has the result of the 'iTrans' transition
// of the world 'that'
// Update the value of the transition
void MFWorldSetTransitionToWorld(
  MFWorld* const that, const int iTrans, MFWorld* const toWorld);

// Update backward the forecast values for actor 'iActor' for each
// transitions leading to the MFWorld 'world' in the MiniFrame 'that'
// Use a penalty growing with each recursive call to
// MFUpdateForecastValues to give priority to fastest convergence to
// best solution
// Avoid infinite loop due to reuse of computed worlds
void MFUpdateForecastValues(MiniFrame* const that,
  const MFWorld* const world, int delayPenalty, GSet* const setWorld,
  int iActor);

// Update the values of the MFTransition 'that' for actor 'iActor' with
// 'val'
// Return true if the value has been updated, else false
bool MFTransitionUpdateValue(MFTransition* const that, const int iActor,
  const float val);

// Pop a MFTransition from the sources of the MFWorld 'that'
#if BUILDMODE != 0
inline
```

```
#endif
MFTransition* MFWorldPopSource(MFWorld* const that);

// Remove the MFTransition 'source' from the sources of the
// MFWorld 'that'
void MFWorldRemoveSource(MFWorld* const that,
  const MFTransition* const source);

// Get the best MFModelTransition for the 'iActor'-th actor in the
// MFWorld 'that'
// Return NULL if the world has no transition
const MFModelTransition* MFWorldBestTransition(
  const MFWorld* const that, const int iActor);

// Free the memory used by the disposable worlds in the computed worlds
// of the MinFrame 'that'
void MFFreeDisposableWorld(MiniFrame* const that);

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

// Create a new MiniFrame the initial world 'initStatus'
// The current world is initialized with a copy of 'initStatus'
// Return the new MiniFrame
MiniFrame* MiniFrameCreate(const MFModelStatus* const initStatus) {
#if BUILDMODE == 0
  if (initStatus == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'initStatus' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Allocate memory
  MiniFrame *that = PBErrMalloc(MiniFrameErr, sizeof(MiniFrame));
  // Set properties
  that->_nbStep = 0;
  MFSetMaxTimeExpansion(that, MF_DEFAULTTIMEEXPANSION);
  that->_curWorld = MFWorldCreate(initStatus);
  that->_worlds = GSetCreateStatic();
  MFAddWorld(that, MFCurWorld(that), MFModelStatusGetSente(initStatus));
  that->_timeSearchWorld = MF_DEFAULTTIMEEXPANSION;
  that->_nbWorldExpanded = 0;
  that->_nbWorldUnexpanded = 0;
  that->_nbRemovedWorld = 0;
  that->_timeUnusedExpansion = 0.0;
  that->_reuseWorld = false;
  that->_percWorldReused = 0.0;
  that->_startExpandClock = 0;
  that->_maxDepthExp = -1;
  that->_expansionType = MFExpansionTypeValue;
  that->_nbTransMonteCarlo = MF_NBTRANSMONTECARLO;
  // Estimate the time used at end of expansion which is the time
  // used to flush a gset
  GSet set = GSetCreateStatic();
  int nb = 100;
  float timeFlush = 0.0;
  do {
    for (int i = nb; i--;)
      GSetPush(&set, NULL);
    clock_t timeStart = clock();
    GSetFlush(&set);
    clock_t timeEnd = clock();
    timeFlush = ((double)(timeEnd - timeStart)) / MF_MILLISECTOCLOCKS;
```

```
  } while (timeFlush < 0.0);
  that->_timeEndExpansion = timeFlush / (float)nb;
  // Return the new MiniFrame
  return that;
}

// Create a new MFWorld with a copy of the MFModelStatus 'status'
// Return the new MFWorld
MFWorld* MFWorldCreate(const MFModelStatus* const status) {
#if BUILDMODE == 0
  if (status == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'status' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Allocate memory
  MFWorld *that = PBErrMalloc(MiniFrameErr, sizeof(MFWorld));
  // Set the status
  MFModelStatusCopy(status, &(that->_status));
  // Initialise the set of transitions reaching this world
  that->_sources = GSetCreateStatic();
  // Set the values
  float values[MF_NBMAXACTOR] = {0.0};
  MFModelStatusGetValues(status, values);
  MFWorldSetValues(that, values);
  // Set the possible transitions from this world
  MFModelTransition transitions[MF_NBMAXTRANSITION];
  MFModelStatusGetTrans(status, transitions, &(that->_nbTransition));
  for (int iTrans = that->_nbTransition; iTrans--;)
    that->_transitions[iTrans] =
      MFTransitionCreateStatic(that, transitions + iTrans);
  // Return the new MFWorld
  return that;
}

// Create a new static MFTransition for the MFWorld 'world' with the
// MFModelTransition 'transition'
// Return the new MFTransition
MFTransition MFTransitionCreateStatic(const MFWorld* const world,
  const MFModelTransition* const transition) {
#if BUILDMODE == 0
  if (world == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'world' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the new action
  MFTransition that;
  // Set properties
  that._transition = *transition;
  that._fromWorld = (MFWorld*)world;
  that._toWorld = NULL;
  for (int iActor = MF_NBMAXACTOR; iActor--;)
    that._values[iActor] = 0.0;
  // Return the new MFTransition
  return that;
}

// Free memory used by the MiniFrame 'that'
void MiniFrameFree(MiniFrame** that) {
```

```
  // Check argument
  if (that == NULL || *that == NULL) return;
  // Free memory
  while(GSetNbElem(&((*that)->_worlds)) > 0) {
    MFWorld* world = GSetPop(&((*that)->_worlds));
    MFWorldFree(&world);
  }
  free(*that);
  *that = NULL;
}

// Free memory used by the MFWorld 'that'
void MFWorldFree(MFWorld** that) {
  // Check argument
  if (that == NULL || *that == NULL) return;
  // Free memory
  GSetFlush(&((*that)->_sources));
  MFModelStatusFreeStatic(&((*that)->_status));
  for (int iAct = (*that)->_nbTransition; iAct--;) {
    if ((*that)->_transitions[iAct]._toWorld != NULL)
      MFTransitionFreeStatic((*that)->_transitions + iAct);
  }
  free(*that);
  *that = NULL;
}

// Free memory used by properties of the MFTransition 'that'
void MFTransitionFreeStatic(MFTransition* that) {
  // Check argument
  if (that == NULL) return;
  // Free memory
  MFModelTransitionFreeStatic(&(that->_transition));
}

// Expand the MiniFrame 'that' until it reaches its time limit or can't
// expand anymore
void MFExpand(MiniFrame* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the time at beginning of the whole
  // expansion process
  clock_t clockStart = MFGetStartExpandClock(that);
  // Declare a variable to memorize the maximum time used for one
  // step of expansion
  double maxTimeOneStep = 0.0;
  // Create the set of world instances to be expanded, ordered by
  // world's value from the point of view of the preempting actor
  // for each world
  // The time available for this step is limited to avoid spending
  // time to search for worlds to expand and finally not having time
  // to compute them
  clock_t clockLimit = clockStart +
    that->_timeSearchWorld * MF_MILLISECTOCLOCKS;
  GSet worldsToExpand = MFGetWorldsToExpand(that, clockLimit);
  // Memorize the number of worlds to expand
  int nbWorldToExpand = GSetNbElem(&worldsToExpand);
  // Declare a variable to memorize the time spend expanding
```

```
double timeUsed =
  ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
// Declare a variable to memorize the number of reused worlds
int nbReusedWorld = 0;
// Declare a variable to memorie the number of worlds to expand added
// to the original set
int nbWorldToExpandPost = 0;
// Loop until we have time for one more step of expansion or there
// is no world to expand
// Take care of clock() wrapping around
while (timeUsed >= 0.0 &&
  timeUsed + maxTimeOneStep +
  MFGetTimeEndExpansion(that) * GSetNbElem(&worldsToExpand) <
  MFGetMaxTimeExpansion(that) &&
  GSetNbElem(&worldsToExpand) > 0) {
  // Declare a variable to memorize the time at the beginning of one
  // step of expansion
  clock_t clockStartLoop = clock();
  // Drop the world to expand with highest value
  MFWorld* worldToExpand = GSetDrop(&worldsToExpand);
  // Get the sente for this world
  int sente = MFModelStatusGetSente(MFWorldStatus(worldToExpand));
  // Get the number of expandable transition
  int nbTransExpandable = MFWorldGetNbTransExpandable(worldToExpand);
  // Get the threhsold for expannsion to activate montecarlo when
  // there are too many transitions
  float thresholdMonteCarlo =
    (float)MFGetNbTransMonteCarlo(that) / (float)nbTransExpandable;
  // For each transitions from the expanded world and until we have
  // time available
  // Take care of clock() wrapping around
  for (int iTrans = 0; iTrans < MFWorldGetNbTrans(worldToExpand) &&
    timeUsed >= 0.0 &&
    timeUsed + maxTimeOneStep +
    MFGetTimeEndExpansion(that) * GSetNbElem(&worldsToExpand) <
    MFGetMaxTimeExpansion(that);
    ++iTrans) {
    // If this transition has not been computed
    const MFTransition* const trans =
      MFWorldTransition(worldToExpand, iTrans);
    if (MFTransitionIsExpandable(trans) &&
      rnd() < thresholdMonteCarlo) {
      // Expand through this transition
      MFModelStatus status =
        MFWorldComputeTransition(worldToExpand, iTrans);
      // If the resulting status has not already been computed
      MFWorld* sameWorld = MFSearchWorld(that, &status);
      if (sameWorld == NULL) {
        // Create a MFWorld for the new status
        MFWorld* expandedWorld = MFWorldCreate(&status);
        // Add the world to the set of computed world
        MFAddWorld(that, expandedWorld, sente);
        // Set the expanded world as the result of the transition
        MFWorldSetTransitionToWorld(
          worldToExpand, iTrans, expandedWorld);
        // If it's not an end status world and we haven't reached
        // the expansion limit
        if ((that->_maxDepthExp < 0 ||
          worldToExpand->_depth < that->_maxDepthExp) &&
          !MFModelStatusIsEnd(MFWorldStatus(expandedWorld))) {
          // Add the world to the set of worlds to expand
          ++nbWorldToExpand;
```

```
          expandedWorld->_depth = worldToExpand->_depth + 1;
          if (MFGetExpansionType(that) == MFExpansionTypeValue) {
            float value = MFWorldGetValue(expandedWorld, sente);
            GSetAddSort(&worldsToExpand, expandedWorld, value);
          } else if (MFGetExpansionType(that) == MFExpansionTypeWidth) {
            GSetPush(&worldsToExpand, expandedWorld);
          }
          ++nbWorldToExpandPost;
        }
      } else {
        // Increment the number of reused world
        ++nbReusedWorld;
        // Set the already computed one as the result of the
        // transition
        MFWorldSetTransitionToWorld(worldToExpand, iTrans, sameWorld);
      }
    }
    // Update the total time used from beginning of expansion
    timeUsed =
      ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
  }
  // For each actor
  for (int iActor =
    MFModelStatusGetNbActor(MFWorldStatus(worldToExpand));
    iActor--;) {
    // Update backward the forecast values for each transitions
    // leading to the expanded world according to its new transitions
    GSet setWorld = GSetCreateStatic();
    MFUpdateForecastValues(that, worldToExpand, 0, &setWorld, iActor);
    GSetFlush(&setWorld);
  }
  // Declare a variable to memorize the time at the end of one
  // step of expansion
  clock_t clockEndLoop = clock();
  // Calculate the time for this step
  double timeOneStep =
    ((double)(clockEndLoop - clockStartLoop)) / MF_MILLISECTOCLOCKS;
  // Update max time used by one step
  if (maxTimeOneStep < timeOneStep)
    maxTimeOneStep = timeOneStep;
  // Update the total time used from beginning of expansion
  timeUsed =
    ((double)(clockEndLoop - clockStart)) / MF_MILLISECTOCLOCKS;
}
// Memorize the remaining number of worlds to expand
int nbRemainingWorldToExpand =
  MAX(0, GSetNbElem(&worldsToExpand) - nbWorldToExpandPost);
// Update the total time used from beginning of expansion
timeUsed = ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
// Update the percentage of time allocated to searching for worlds
// to expand
// If there was worlds to expand
if (nbWorldToExpand > 0) {
  // If we could expand all the worlds
  if (nbRemainingWorldToExpand == 0) {
    that->_timeSearchWorld *=
      MFGetMaxTimeExpansion(that) / timeUsed;
    if (that->_timeSearchWorld > MFGetMaxTimeExpansion(that))
      that->_timeSearchWorld = MFGetMaxTimeExpansion(that);
  // Else, we had not enough time to expand all the worlds
  } else {
    that->_timeSearchWorld *=
```

```
        (float)nbRemainingWorldToExpand / (float)nbWorldToExpand;
    }
  } else {
    that->_timeSearchWorld =
      MAX(0, MFGetMaxTimeExpansion(that) - timeUsed);
  }
  // Empty the list of worlds to expand
  GSetFlush(&worldsToExpand);
  // Update the total time used from beginning of expansion
  timeUsed = ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
  // Take care of clock() wrapping around
  if (timeUsed < 0.0)
    timeUsed = MFGetMaxTimeExpansion(that);
  // Telemetry for debugging
  that->_timeUnusedExpansion = MFGetMaxTimeExpansion(that) - timeUsed;
  that->_nbWorldExpanded =
    nbWorldToExpand - nbRemainingWorldToExpand + nbReusedWorld;
  that->_nbWorldUnexpanded = nbRemainingWorldToExpand;
  if (that->_nbWorldExpanded > 0)
    that->_percWorldReused =
      (float)nbReusedWorld / (float)(that->_nbWorldExpanded);
  else
    that->_percWorldReused = 0.0;
}

// Get the set of worlds to be expanded (having at least one transition
// whose _toWorld is null) for the MiniFrame 'that'
// Stop searching for world if clock() >= clockLimit
// Will return at least one world even if clockLimit == current clock
// The MiniFrame must have at least one world in its set of computed
// worlds
// Force the current world to the end of the returned set to ensure
// it will be the first to be expanded
GSet MFGetWorldsToExpand(MiniFrame* const that,
  const clock_t clockLimit) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (GSetNbElem(MFWorlds(that)) == 0) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "The MiniFrame has no computed world");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Free the disposabe worlds
  MFFreeDisposableWorld(that);
  // Declare the set to memorize worlds to expand
  GSet set = GSetCreateStatic();
  // Loop through the computed worlds
  GSetIterForward iter = GSetIterForwardCreateStatic(MFWorlds(that));
  do {
    MFWorld* world = GSetIterGet(&iter);
    // If this world has transition to expand
    if (world != MFCurWorld(that) && MFWorldIsExpandable(world)) {
      // Add this world to the result set ordered by the value
      world->_depth = 0;
      if (MFGetExpansionType(that) == MFExpansionTypeValue) {
        int sente = MFModelStatusGetSente(MFWorldStatus(world));
        float value = MFWorldGetForecastValue(world, sente);
```

```
        GSetAddSort(&set, world, value);
      } else if (MFGetExpansionType(that) == MFExpansionTypeWidth) {
        GSetPush(&set, world);
      }
    }
  } while (GSetIterStep(&iter) && clock() < clockLimit);
  // Add the current world
  if (MFWorldIsExpandable(MFCurWorld(that))) {
    that->_curWorld->_depth = 0;
    GSetAppend(&set, MFCurWorld(that));
  }
  // Return the set of worlds to expand
  return set;
}

// Return true if the MFWorld 'that' has at least one transition to be
// expanded
bool MFWorldIsExpandable(const MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the result
  bool isExpandable = false;
  // If the world is not at the end of the game/simutation
  if (!MFModelStatusIsEnd(MFWorldStatus(that))) {
    // Loop on transitions
    for (int iTrans = that->_nbTransition; iTrans-- && !isExpandable;) {
      // If this transition has not been computed
      if (MFTransitionIsExpandable(MFWorldTransition(that, iTrans)))
        isExpandable = true;
    }
  }
  // Return the result
  return isExpandable;
}

// Search in computed worlds of the MiniFrame 'that' if there is
// one with same status as the MFModelStatus 'status'
// If there is one return it, if not return null
MFWorld* MFSearchWorld(const MiniFrame* const that,
  const MFModelStatus* const status) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (status == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'status' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the returned world
  MFWorld* sameWorld = NULL;
  // If the reuse of worlds is activated
  if (MFIsWorldReusable(that)) {
    // Loop on computed worlds
```

```
    GSetIterForward iter = GSetIterForwardCreateStatic(MFWorlds(that));
    do {
      MFWorld* world = GSetIterGet(&iter);
      // If this world is the same as the searched one
      if (MFModelStatusIsSame(status, MFWorldStatus(world))) {
        sameWorld = world;
      }
    } while (sameWorld == NULL && GSetIterStep(&iter));
  }
  // Return the found world
  return sameWorld;
}

// Set the MFWorld 'toWorld' has the result of the 'iTrans' transition
// of the MFWorld 'that'
// Update the value of the transition
void MFWorldSetTransitionToWorld(
  MFWorld* const that, const int iTrans, MFWorld* const toWorld) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iTrans < 0 || iTrans >= that->_nbTransition) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iTrans' is invalid (0<=%d<%d)",
      iTrans, that->_nbTransition);
    PBErrCatch(MiniFrameErr);
  }
  if (toWorld == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'toWorld' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the transition
  MFTransition* trans = that->_transitions + iTrans;
  // Set the transition result
  trans->_toWorld = toWorld;
  // Add the transition to the sources to the result's world
  GSetAppend(&(toWorld->_sources), trans);
  // Update the forecast value of this transition for each actor
  for (int iActor = MF_NBMAXACTOR; iActor--;)
    MFTransitionSetValue(trans, iActor,
      MFWorldGetValue(toWorld, iActor));
}

// Return true if the MFTransition 'that' is expandable, i.e. its
// 'toWorld' is null, else return false
bool MFTransitionIsExpandable(const MFTransition* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // If the transition has already been expanded
  if (MFTransitionToWorld(that) != NULL) {
    // Return false
    return false;
```

```
  // Else, the transition has not been expanded yet
  } else {
    // Get the origin of the transition
    const MFWorld* fromWorld = MFTransitionFromWorld(that);
    // Declare a variable to memorize if the transition has a brother
    // which leads to an end world
    bool hasEndWorldBrother = false;
    // For each brother transition, until we have found an end world
    for (int iTrans = MFWorldGetNbTrans(fromWorld);
      iTrans-- && !hasEndWorldBrother;) {
      // Get the brother transition's toWorld
      const MFWorld* brother =
        MFTransitionToWorld(MFWorldTransition(fromWorld, iTrans));
      // If the brother world is an end world
      if (brother != NULL &&
        MFModelStatusIsEnd(MFWorldStatus(brother))) {
        // Set the flag
        hasEndWorldBrother = true;
      }
    }
    // If the transition has a brother leading to an end world
    if (hasEndWorldBrother)
      // This transition is not expandable
      return false;
    // Else, the transition has no brother leading to an end world
    else
      // This transition is expandable
      return true;
  }
  // Should never reach here, but just in case...
  return true;
}

// Return the forecasted value of the MFWorld 'that' for the
// actor 'iActor'.
// This is the best value of the transitions from this world,
// or the value of this world if it has no transition.
float MFWorldGetForecastValue(const MFWorld* const that,
  const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the highest value among transitions
  float valBestTrans = 0.0;
  // Declare a variable to memorize the transition with highest value
  const MFTransition* bestTrans = NULL;
  // Loop on transitions
  for (int iTrans = MFWorldGetNbTrans(that); iTrans--;) {
    // Declare a variable to memorize the transition
    const MFTransition* const trans =
      MFWorldTransition(that, iTrans);
    // If this transitions has been expanded
```

```
    if (!MFTransitionIsExpandable(trans)) {
      // Get the value of the transition from the point of view of
      // the sente
      float val = MFTransitionGetValue(trans, iActor);
      // If it's not the first considered transition
      if (bestTrans != NULL) {
        // If the value is better
        if (valBestTrans < val) {
          valBestTrans = val;
          bestTrans = trans;
        }
      // Else it's the first considered transition
      } else {
        // Init the best value with the value of this transition
        valBestTrans = val;
        // Init the best transition
        bestTrans = trans;
      }
    }
  }
  // Return the value for this world
  // If there are expanded transitions
  if (bestTrans != NULL) {
    // Return the value of the best transition from the point of view
    // of the requested actor
    return MFTransitionGetValue(bestTrans, iActor);
  // Else this world has no transitions
  } else {
    // Return the value of this world from the point of view of the
    // requested actor
    return MFWorldGetValue(that, iActor);
  }
}

// Get the best MFModelTransition for the 'iActor'-th actor in the
// current MFWorld of the MiniFrame 'that'
// Return NULL if the current world has no transition
const MFModelTransition* MFBestTransition(
  const MiniFrame* const that, const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Return the best transition
  return MFWorldBestTransition(MFCurWorld(that), iActor);
}

// Get the best MFModelTransition for the 'iActor'-th actor in the
// MFWorld 'that'
// Return NULL if the world has no transition
const MFModelTransition* MFWorldBestTransition(
  const MFWorld* const that, const int iActor) {
#if BUILDMODE == 0
```

```
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the highest value among transitions
  float valBestTrans = 0.0;
  // Declare a variable to memorize the best transition
  const MFTransition* bestTrans = NULL;
  // Loop on transitions
  for (int iTrans = MFWorldGetNbTrans(that); iTrans--;) {
    // Declare a variable to memorize the transition
    const MFTransition* const trans = MFWorldTransition(that, iTrans);
    // If this transitions has been expanded
    if (MFTransitionIsExpanded(trans)) {
      // Get the value of the transition from the point of view of
      // the requested actor
      float val = MFTransitionGetValue(trans, iActor);
      // Add some random perturbation to avoid always picking
      // the same transitions between those with equal values
      val += rnd() * PBMATH_EPSILON;
      // If it's not the first considered transition
      if (bestTrans != NULL) {
        // If the value is better
        if (valBestTrans < val) {
          // Update the best value and best transition
          valBestTrans = val;
          bestTrans = trans;
        }
      // Else it's the first considered transition
      } else {
        // Init the best value with the value of this transition
        valBestTrans = val;
        // Init the best transition
        bestTrans = trans;
      }
    }
  }
  // If the bestTrans is null here it means that none of the transitions
  // for the current world were expanded yet
  // By default choose a random one
  if (bestTrans == NULL && MFWorldGetNbTrans(that) > 0) {
    bestTrans = MFWorldTransition(that,
      (int)floor(MIN(rnd(), 0.9999) * (float)MFWorldGetNbTrans(that)));
  }
  // Return the best transition
  return (const MFModelTransition*)bestTrans;
}

// Update backward the forecast values for actor 'iActor' for each
// transitions leading to the MFWorld 'world' in the MiniFrame 'that'
// Use a penalty growing with each recursive call to
// MFUpdateForecastValues to give priority to fastest convergence to
// best solution
// Avoid infinite loop due to reuse of computed worlds
```

```
void MFUpdateForecastValues(MiniFrame* const that,
  const MFWorld* const world, int delayPenalty, GSet* const setWorld,
  int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (world == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'world' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Avoid infinite loop
  if (GSetFirstElem(setWorld, world) == NULL)
    GSetAppend(setWorld, (void*)world);
  else
    return;
  // If the world has ancestors
  if (GSetNbElem(MFWorldSources(world)) > 0) {
    // Get the forecast value of the world
    float forecastVal = MFWorldGetForecastValue(world, iActor);
    // Declare a variable to memorize when the transition is updated
    bool updated = false;
    // For each transition to the world
    GSetIterForward iter =
      GSetIterForwardCreateStatic(MFWorldSources(world));
    do {
      // Get the transition
      MFTransition* const trans = GSetIterGet(&iter);
      // If we are at the first level of recursion
      if (delayPenalty == 0) {
        // Initialize the value of the transition
        MFTransitionSetValue(trans, iActor, forecastVal);
        updated = true;
      } else {
        // Update the value of the transition
        updated = MFTransitionUpdateValue(trans, iActor,
          forecastVal - (float)delayPenalty * PBMATH_EPSILON);
      }
      // If the value has been updated
      if (updated) {
        // Propagate the update from the source world
        MFUpdateForecastValues(that, MFTransitionFromWorld(trans),
          delayPenalty + 1, setWorld, iActor);
      }
    } while (GSetIterStep(&iter));
  }
}

// Update the values of the MFTransition 'that' for actor 'iActor' with
// 'val'
// Return true if the value has been updated, else false
bool MFTransitionUpdateValue(MFTransition* const that, const int iActor,
  const float val) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
```

```
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the returned flag
  bool updated = false;
#if MF_NBMAXACTOR == 1
  if (that->_values[iActor] < val) {
    updated = true;
    that->_values[iActor] = val;
  }
#else
#if MF_SIMULTANEOUS_PLAY

#else
  MFWorld* fromWorld = MFTransitionFromWorld(that);
  int sente = MFModelStatusGetSente(MFWorldStatus(fromWorld));
  if (sente == -1 || sente == iActor) {
    if (that->_values[iActor] < val) {
      updated = true;
      that->_values[iActor] = val;
    }
  } else {
    if (that->_values[iActor] > val) {
      updated = true;
      that->_values[iActor] = val;
    }
  }
#endif
#endif
  // Return the flag
  return updated;
}

// Print the MFWorld 'that' on the stream 'stream'
void MFWorldPrint(const MFWorld* const that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "(");
  MFModelStatusPrint(MFWorldStatus(that), stream);
  fprintf(stream, ") values[");
  for (int iActor = 0; iActor < MF_NBMAXACTOR; ++iActor) {
    fprintf(stream, "%f", MFWorldGetValue(that, iActor));
    if (iActor < MF_NBMAXACTOR - 1)
      fprintf(stream, ",");
  }
  fprintf(stream, "]");
  fprintf(stream, " forecast[");
```

```
  for (int iActor = 0; iActor < MF_NBMAXACTOR; ++iActor) {
    fprintf(stream, "%f", MFWorldGetForecastValue(that, iActor));
    if (iActor < MF_NBMAXACTOR - 1)
      fprintf(stream, ",");
  }
  fprintf(stream, "]");
}

// Print the MFTransition 'that' on the stream 'stream'
void MFTransitionPrint(const MFTransition* const that,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "transition from (");
  MFModelStatusPrint(
    MFWorldStatus(MFTransitionFromWorld(that)), stream);
  fprintf(stream, ") to (");
  if (MFTransitionToWorld(that) != NULL)
    MFModelStatusPrint(
      MFWorldStatus(MFTransitionToWorld(that)), stream);
  else
    fprintf(stream, "<null>");
  fprintf(stream, ") through (");
  MFModelTransitionPrint((MFModelTransition*)that, stream);
  fprintf(stream, ") values[");
  for (int iActor = 0; iActor < MF_NBMAXACTOR; ++iActor) {
    fprintf(stream, "%f", that->_values[iActor]);
    if (iActor < MF_NBMAXACTOR - 1)
      fprintf(stream, ",");
  }
  fprintf(stream, "]");
}

// Print the MFWorld 'that' and its MFTransition on the stream 'stream'
void MFWorldTransPrintln(const MFWorld* const that,
  FILE* const stream) {
  #if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  MFWorldPrint(that, stream);
  fprintf(stream, "\n");
  for (int iTrans = 0; iTrans < MFWorldGetNbTrans(that); ++iTrans) {
    fprintf(stream, "  %d) ", iTrans);
```

```
    MFTransitionPrint(MFWorldTransition(that, iTrans), stream);
    fprintf(stream, "\n");
  }
}

// Set the current world of the MiniFrame 'that' to match the
// MFModelStatus 'status'
// If the world is in computed worlds reuse it, else create a new one
void MFSetCurWorld(MiniFrame* const that,
  const MFModelStatus* const status) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (status == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'status' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a flag to memorize if we have found the world
  bool flagFound = false;
  // Loop on computed worlds
  GSetIterForward iter = GSetIterForwardCreateStatic(MFWorlds(that));
  do {
    MFWorld* world = GSetIterGet(&iter);
    // If this is the current world
    if (MFModelStatusIsSame(MFWorldStatus(world), status)) {
      // Ensure that the status is exactly the same by copying the
      // MFModelStatus struct, in case MFModelStatusIsSame refers only
      // to a subset of properties of the MFModelStatus
      memcpy(world, status, sizeof(MFModelStatus));
      // Update the curWorld in MiniFrame
      that->_curWorld = world;
      flagFound = true;
    }
  } while (!flagFound && GSetIterStep(&iter));
  // If we haven't found the searched status
  if (!flagFound) {
    // Create a new MFWorld with the current status
    MFWorld* world = MFWorldCreate(status);
    // Get the sente for the previous world
    int sente = MFModelStatusGetSente(MFWorldStatus(MFCurWorld(that)));
    // Add it to the computed worlds
    MFAddWorld(that, world, sente);
    // Update the current world
    that->_curWorld = world;
  }
}

// Free the memory used by the disposable worlds in the computed worlds
// of the MinFrame 'that'
void MFFreeDisposableWorld(MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
```

```
  // Declare a flag to memorize if we have found a disposable world
  bool flag = false;
  // Declare a flag to manage the deletion of element in the set of
  // computed worlds
  bool moved = false;
  //Declare a variable to memorize the number of removed world
  int nbRemovedWorld = 0;
  // Loop until we haven't found any disposable world
  do {
    // Reset the flag to memorize if we have found disposable world
    flag = false;
    // Loop on computed worlds
    GSetIterForward iter = GSetIterForwardCreateStatic(MFWorlds(that));
    do {
      MFWorld* world = GSetIterGet(&iter);
      moved = false;
      // If it's a disposable world
      if (that->_curWorld != world &&
        (GSetNbElem(MFWorldSources(world)) == 0 ||
        MFModelStatusIsDisposable(MFWorldStatus(world),
        MFWorldStatus(MFCurWorld(that)), MFGetNbComputedWorld(that)))) {
        // Remove this world from its sources
        while (GSetNbElem(MFWorldSources(world)) > 0) {
          MFTransition* transSource = MFWorldPopSource(world);
          MFTransitionSetToWorld(transSource, NULL);
        }
        // Remove this world from the sources of its next worlds
        for (int iTrans = MFWorldGetNbTrans(world); iTrans--;) {
          const MFTransition* trans = MFWorldTransition(world, iTrans);
          MFWorld* toWorld = (MFWorld*)MFTransitionToWorld(trans);
          if (toWorld != NULL)
            MFWorldRemoveSource(toWorld, trans);
        }
        // Remove this world from the computed worlds
        moved = GSetIterRemoveElem(&iter);
        // Free memory
        MFWorldFree(&world);
        // Increment the number of removed world
        ++nbRemovedWorld;
        // Memorize we have found a disposable world
        flag = true;
      }
    } while (moved || GSetIterStep(&iter));
  } while (flag == true);
  // Update the number of removed world
  that->_nbRemovedWorld = nbRemovedWorld;
}

// Remove the MFTransition 'source' from the sources of the
// MFWorld 'that'
void MFWorldRemoveSource(MFWorld* const that,
  const MFTransition* const source) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (source == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'source' is null");
    PBErrCatch(MiniFrameErr);
```

```
  }
#endif
  // Loop on transitions
  if (GSetNbElem(MFWorldSources(that)) > 0) {
    bool moved = false;
    GSetIterForward iter =
      GSetIterForwardCreateStatic(MFWorldSources(that));
    do {
      moved = false;
      MFTransition* trans = GSetIterGet(&iter);
      if (trans == source) {
        moved = GSetIterRemoveElem(&iter);
      }
    } while (moved || GSetIterStep(&iter));
  }
}


// Pop a MFTransition from the sources of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
MFTransition* MFWorldPopSource(MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return GSetPop(&(that->_sources));
}

// Print the best forecasted story from the MFWorld 'that' for the
// actor 'iActor' on the stream 'stream'
void MFWorldPrintBestStoryln(const MFWorld* const that, const int iActor,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the current displayed world
  const MFWorld* curWorld = that;
  // Declare a GSet to manage infinite loop
  GSet setWorld = GSetCreateStatic();
  // Loop until the end of the forecast
  while (curWorld != NULL) {
    // Display the current world
```

```
    //MFWorldPrint(curWorld, stream);
    //fprintf(stream, "\n");
    MFWorldTransPrintln(curWorld, stream);
    // Add the world to the set of visited worlds
    GSetAppend(&setWorld, (void*)curWorld);
    // If we are not at an end status
    if (!MFModelStatusIsEnd(MFWorldStatus(curWorld))) {
      // Get the sente for the current world
      int sente = MFModelStatusGetSente(MFWorldStatus(curWorld));
      // If it's a simultaneous game
      if (sente == -1)
        sente = iActor;
      // Get the best transition from this world
      const MFModelTransition* bestTrans =
        MFWorldBestTransition(curWorld, sente);
      // If there is no transition
      if (bestTrans == NULL) {
        // Stop the story here
        curWorld = NULL;
      // Else, there is a best transition
      } else {
        // Print the best transition
        fprintf(stream, "--> ");
        MFTransitionPrint((const MFTransition*)bestTrans, stream);
        fprintf(stream, "\n");
        // Move to the world resulting from the best transition
        curWorld = MFTransitionToWorld((const MFTransition*)bestTrans);
      }
    } else {
      fprintf(stream, "--> reached a end status\n");
      curWorld = NULL;
    }
    // If we reach a world already visited
    if (curWorld != NULL && GSetFirstElem(&setWorld, curWorld) != NULL) {
      MFWorldPrint(curWorld, stream);
      fprintf(stream, "\n");
      fprintf(stream, "--> infinite loop in best story, quit\n");
      curWorld = NULL;
    }
  }
  // Free memory
  GSetFlush(&setWorld);
}

// Set the values of the MFWorld 'that' to 'values'
void MFWorldSetValues(MFWorld* const that, const float* const values) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (values == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'values' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  for (int iActor = MF_NBMAXACTOR; iActor--;) {
    that->_values[iActor] = 0.0;
    for (int jActor = MF_NBMAXACTOR; jActor--;) {
      if (iActor == jActor)
```

```
        that->_values[iActor] += values[jActor];
      else
        that->_values[iActor] -= values[jActor];
    }
  }
}

// Get the number of expandable transition for the MFWorld 'that'
int MFWorldGetNbTransExpandable(const MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the result
  int nb = 0;
  // Loop on transitions
  for (int iTrans = MFWorldGetNbTrans(that); iTrans--;) {
    // Get the transition
    const MFTransition* const trans = MFWorldTransition(that, iTrans);
    // If this transition is expandable
    if (MFTransitionIsExpandable(trans))
      // Increment the result
      ++nb;
  }
  // Return the result
  return nb;
}
```

2.2 miniframe-inline.c

```
// ============ MINIFRAME_INLINE.C ================

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

// Get the time limit for expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetMaxTimeExpansion(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_maxTimeExpansion;
}

// Get the time unused during last expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetTimeUnusedExpansion(const MiniFrame* const that) {
```

```
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_timeUnusedExpansion;
}

// Get the time used to search world to expand during next expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetTimeSearchWorld(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_timeSearchWorld;
}

// Get the nb of world expanded during the last expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldExpanded(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_nbWorldExpanded;
}

// Get the nb of world unexpanded during the last expansion
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldUnexpanded(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_nbWorldUnexpanded;
}

// Get the time used at end of expansion of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
```

```
float MFGetTimeEndExpansion(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_timeEndExpansion;
}

// Get the clock considered has start during expansion
#if BUILDMODE != 0
inline
#endif
clock_t MFGetStartExpandClock(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_startExpandClock;
}

// Set the clock considered has start during expansion to 'c'
#if BUILDMODE != 0
inline
#endif
void MFSetStartExpandClock(MiniFrame* const that, clock_t c) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_startExpandClock = c;
}

// Set the time limit for expansion of the MiniFrame 'that' to
// 'timeLimit', in millisecond
// The time is measured with the function clock(), see "man clock"
// for details
#if BUILDMODE != 0
inline
#endif
void MFSetMaxTimeExpansion(MiniFrame* const that, const float timeLimit) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_maxTimeExpansion = timeLimit;
}

// Get the current MFWorld of the MiniFrame 'that'
#if BUILDMODE != 0
inline
```

```
#endif
const MFWorld* MFCurWorld(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_curWorld;
}

// Get the GSet of computed MFWorlds of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorlds(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return &(that->_worlds);
}

// Add the MFWorld 'world' to the computed MFWorlds of the
// MiniFrame 'that', ordered by the world's value from the pov of
// actor 'iActor'
#if BUILDMODE != 0
inline
#endif
void MFAddWorld(MiniFrame* const that, \
  const MFWorld* const world, const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (world == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'world' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < -1 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (-1<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  GSetAddSort(&(that->_worlds), world,
    MFWorldGetForecastValue(world, iActor));
}

// Return the MFModelStatus of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const MFModelStatus* MFWorldStatus(const MFWorld* const that) {
```

```
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return (const MFModelStatus*)that;
}

// Get the number of transition for the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
int MFWorldGetNbTrans(const MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_nbTransition;
}

// Get the percentage of resued world of the MiniFrame 'that' during
// the last MFEpxand()
#if BUILDMODE != 0
inline
#endif
float MFGetPercWordReused(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_percWorldReused;
}

// Get the 'iTrans' MFTransition of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const MFTransition* MFWorldTransition(const MFWorld* const that,
  const int iTrans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iTrans <0 || iTrans >= that->_nbTransition) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iTrans' is invalid (0<=%d<%d)",
      iTrans, that->_nbTransition);
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_transitions + iTrans;
}
```

```
// Compute the MFModelStatus resulting from the 'iTrans' MFTransition
// of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
MFModelStatus MFWorldComputeTransition(const MFWorld* const that,
  const int iTrans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iTrans <0 || iTrans >= that->_nbTransition) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iTrans' is invalid (0<=%d<%d)",
      iTrans, that->_nbTransition);
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Return the resulting MFModelStatus
  return MFModelStatusStep((const MFModelStatus* const)that,
    (const MFModelTransition* const)MFWorldTransition(that, iTrans));
}

// Return true if the expansion algorithm looks in previously
// computed worlds for same world to reuse, else false
#if BUILDMODE != 0
inline
#endif
bool MFIsWorldReusable(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_reuseWorld;
}

// Set the falg controlling if the expansion algorithm looks in
// previously computed worlds for same world to reuse to 'reuse'
#if BUILDMODE != 0
inline
#endif
void MFSetWorldReusable(MiniFrame* const that, const bool reuse) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_reuseWorld = reuse;
}

// Get the MFWorld which the MFTransition 'that' is leading to
#if BUILDMODE != 0
inline
#endif
```

```
const MFWorld* MFTransitionToWorld(const MFTransition* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_toWorld;
}

// Set the MFWorld to which the MFTransition 'that' is leading to
// 'world'
#if BUILDMODE != 0
inline
#endif
void MFTransitionSetToWorld(MFTransition* const that,
  MFWorld* const world) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_toWorld = world;
}

// Get the MFWorld which the MFTransition 'that' is coming from
#if BUILDMODE != 0
inline
#endif
const MFWorld* MFTransitionFromWorld(const MFTransition* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_fromWorld;
}

// Set the value of the MFTransition 'that' for the actor 'iActor' to
// 'val'
#if BUILDMODE != 0
inline
#endif
void MFTransitionSetValue(MFTransition* const that, const int iActor,
  const float val) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
```

```
#endif
  that->_values[iActor] = val;
}

// Return the number of computed worlds in the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbComputedWorld(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return GSetNbElem(&(that->_worlds));
}

// Get the nb of removed world during the last call to SetCurWorld
// of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldRemoved(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_nbRemovedWorld;
}


// Return the value of the MFWorld 'that' for the
// actor 'iActor'.
#if BUILDMODE != 0
inline
#endif
float MFWorldGetValue(const MFWorld* const that, const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)", \
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_values[iActor];
}

// Return the value of the MFTransition 'that' for the
// actor 'iActor'.
#if BUILDMODE != 0
inline
```

```
#endif
float MFTransitionGetValue(const MFTransition* const that,
  const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)", \
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_values[iActor];
}



// Get the set of MFTransition reaching the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorldSources(const MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return &(that->_sources);
}

// Return the array of values of the MFWorld 'that' for each actor
#if BUILDMODE != 0
inline
#endif
const float* MFWorldValues(const MFWorld* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_values;
}

// Return the max depth during expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetMaxDepthExp(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
```

```
#endif
  return that->_maxDepthExp;
}

// Set the max depth during expansion for the MiniFrame 'that' to 'depth'
// If depth is less than -1 it is converted to -1
#if BUILDMODE != 0
inline
#endif
void MFSetMaxDepthExp(MiniFrame* const that, const int depth) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_maxDepthExp = MAX(-1, depth);
}

// Return the type of expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
MFExpansionType MFGetExpansionType(const MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_expansionType;
}

// Set the type expansion for the MiniFrame 'that' to 'type'
#if BUILDMODE != 0
inline
#endif
void MFSetExpansionType(MiniFrame* const that, const MFExpansionType type) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_expansionType = type;
}

// Set the nb of transitions to activate MonteCarlo during expansion
// for the MiniFrame 'that' to 'nb'
#if BUILDMODE != 0
inline
#endif
void MFSetNbTransMonteCarlo(MiniFrame* const that, const int nb) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
```

```
  if (nb <= 0) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'nb' is invalid (%d>0)", nb);
    PBErrCatch(MiniFrameErr);
  }
#endif
  that->_nbTransMonteCarlo = nb;
}

// Get the nb of transitions to activate MonteCarlo during expansion
// for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbTransMonteCarlo(MiniFrame* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return that->_nbTransMonteCarlo;
}

// Return true if the MFTransition is expanded, false else
#if BUILDMODE != 0
inline
#endif
bool MFTransitionIsExpanded(const MFTransition* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  return (that->_toWorld != NULL);
}
```

3 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)

# Path to the model implementation
MF_MODEL_PATH=$(ROOT_DIR)/MiniFrame/Examples/BasicExample

# Rules to make the executable
```

```
repo=miniframe
$($(repo)_EXENAME): \
createLinkToModelHeader \
miniframe-model.o \
$($(repo)_EXENAME).o \
$($(repo)_EXE_DEP) \
$($(repo)_DEP)
$(COMPILER) `echo "$($(repo)_EXE_DEP) $($(repo)_EXENAME).o" | tr ' ' '\n' | sort -u` miniframe-model.o $(LINK_ARG) $(

$($(repo)_EXENAME).o: \
$(MF_MODEL_PATH)/miniframe-model.h \
$($(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)/$

createLinkToModelHeader:
ln -s -f $(MF_MODEL_PATH)/miniframe-model.h $($(repo)_DIR)/miniframe-model.h; ln -s -f $(MF_MODEL_PATH)/miniframe-inl

miniframe-model.o: \
$(MF_MODEL_PATH)/miniframe-model.h \
$(MF_MODEL_PATH)/miniframe-model.c \
Makefile
$(COMPILER) $(BUILD_ARG) -c $(MF_MODEL_PATH)/miniframe-model.c
```

4 Unit tests

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

#define RANDOMSEED 0

void UnitTestMFTransitionCreateFree() {

  MFWorld world;
  MFModelTransition trans = {._move = 1};
  MFTransition act = MFTransitionCreateStatic(&world, &trans);
  if (act._fromWorld != &world ||
    act._toWorld != NULL ||
    memcmp(&(act._transition), &(trans),
      sizeof(MFModelTransition)) != 0) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionCreateStatic failed");
    PBErrCatch(MiniFrameErr);
  }
  for (int iActor = MF_NBMAXACTOR; iActor--;)
    if (ISEQUALF(act._values[iActor], 0.0) == false) {
      MiniFrameErr->_type = PBErrTypeUnitTestFailed;
      sprintf(MiniFrameErr->_msg, "MFTransitionCreateStatic failed");
      PBErrCatch(MiniFrameErr);
```

```
    }
  MFTransitionFreeStatic(&act);

  printf("UnitTestMFTransitionCreateFree OK\n");
}

void UnitTestMFTransitionIsExpandable() {

  MFModelStatus status;
  MFWorld* world = MFWorldCreate(&status);
  MFModelTransition trans = {._move = 1};
  MFTransition act = MFTransitionCreateStatic(world, &trans);
  if (!MFTransitionIsExpandable(&act)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionIsExpandable failed");
    PBErrCatch(MiniFrameErr);
  }
  act._toWorld = world;
  if (MFTransitionIsExpandable(&act)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionIsExpandable failed");
    PBErrCatch(MiniFrameErr);
  }
  act._toWorld = NULL;
  world->_status._pos = world->_status._tgt;
  world->_transitions[0]._toWorld = world;
  if (MFTransitionIsExpandable(&act)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionIsExpandable failed");
    PBErrCatch(MiniFrameErr);
  }
  world->_transitions[0]._toWorld = NULL;
  MFTransitionFreeStatic(&act);
  MFWorldFree(&world);

  printf("UnitTestMFTransitionIsExpandable OK\n");
}

void UnitTestMFTransitionIsExpanded() {

  MFModelStatus status;
  MFWorld* world = MFWorldCreate(&status);
  MFModelTransition trans = {._move = 1};
  MFTransition act = MFTransitionCreateStatic(world, &trans);
  if (MFTransitionIsExpanded(&act)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionIsExpanded failed");
    PBErrCatch(MiniFrameErr);
  }
  act._toWorld = world;
  if (!MFTransitionIsExpanded(&act)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionIsExpanded failed");
    PBErrCatch(MiniFrameErr);
  }
  MFTransitionFreeStatic(&act);
  MFWorldFree(&world);

  printf("UnitTestMFTransitionIsExpanded OK\n");
}

void UnitTestMFTransitionGetSet() {
```

```
  MFWorld worldFrom;
  MFWorld worldTo;
  MFModelTransition trans = {._move = 1};
  MFTransition act = MFTransitionCreateStatic(&worldFrom, &trans);
  act._toWorld = &worldTo;
  if (MFTransitionToWorld(&act) != &worldTo) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionToWorld failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFTransitionFromWorld(&act) != &worldFrom) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionFromWorld failed");
    PBErrCatch(MiniFrameErr);
  }
  MFTransitionSetValue(&act, 0, 1.0);
  if (ISEQUALF(act._values[0], 1.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionSetValue failed");
    PBErrCatch(MiniFrameErr);
  }
  if (ISEQUALF(MFTransitionGetValue(&act, 0), 1.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionGetValue failed");
    PBErrCatch(MiniFrameErr);
  }
  MFWorld worldB;
  MFTransitionSetToWorld(&act, &worldB);
  if (MFTransitionToWorld(&act) != &worldB) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFTransitionSetToWorld failed");
    PBErrCatch(MiniFrameErr);
  }
  MFTransitionFreeStatic(&act);

  printf("UnitTestMFTransitionGetSet OK\n");
}

void UnitTestMFTransition() {
  UnitTestMFTransitionCreateFree();
  UnitTestMFTransitionIsExpandable();
  UnitTestMFTransitionIsExpanded();
  UnitTestMFTransitionGetSet();
  printf("UnitTestMFTransition OK\n");
}

void UnitTestMFWorldCreateFree() {

  MFModelStatus modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
  MFWorld* world = MFWorldCreate(&modelWorld);
  if (world == NULL ||
    GSetNbElem(&(world->_sources)) != 0 ||
    world->_nbTransition != 3) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldCreate failed");
    PBErrCatch(MiniFrameErr);
  }
  float val[MF_NBMAXACTOR] = {0.0};
  val[0] = -1.0;
  for (int iActor = MF_NBMAXACTOR; iActor--;)
    if (ISEQUALF(world->_values[iActor], val[iActor]) == false) {
      MiniFrameErr->_type = PBErrTypeUnitTestFailed;
```

```
      sprintf(MiniFrameErr->_msg, "MFWorldCreate failed");
      PBErrCatch(MiniFrameErr);
    }
  MFWorldFree(&world);
  if (world != NULL) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldFree failed");
    PBErrCatch(MiniFrameErr);
  }

  printf("UnitTestMFWorldCreateFree OK\n");
}

void UnitTestMFWorldGetSet() {
  MFModelStatus modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
  MFWorld* world = MFWorldCreate(&modelWorld);
  if (MFWorldStatus(world) != &(world->_status)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldStatus failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFWorldGetNbTrans(world) != 3) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetNbTrans failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFWorldSources(world) != &(world->_sources)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldSources failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFWorldValues(world) != world->_values) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldValues failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFWorldTransition(world, 0) != world->_transitions ||
    MFWorldTransition(world, 1) != world->_transitions + 1 ||
    MFWorldTransition(world, 2) != world->_transitions + 2) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldTransition failed");
    PBErrCatch(MiniFrameErr);
  }
  world->_values[0] = 1.0;
  if (ISEQUALF(MFWorldGetValue(world, 0), 1.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetValue failed");
    PBErrCatch(MiniFrameErr);
  }
  MFWorldFree(&world);
  printf("UnitTestMFWorldGetSet OK\n");
}

void UnitTestMFWorldComputeTransition() {
  MFModelStatus modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
  MFWorld* world = MFWorldCreate(&modelWorld);
  MFModelStatus statusA = {._step = 1, ._pos = -1, ._tgt = 1};
  MFModelStatus statusB = {._step = 1, ._pos = 0, ._tgt = 1};
  MFModelStatus statusC = {._step = 1, ._pos = 1, ._tgt = 1};
  MFModelStatus status = MFWorldComputeTransition(world, 0);
  if (memcmp(&status, &statusA, sizeof(MFModelStatus)) != 0) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(MiniFrameErr->_msg, "MFWorldComputeTransition failed");
    PBErrCatch(MiniFrameErr);
  }
  status = MFWorldComputeTransition(world, 1);
  if (memcmp(&status, &statusB, sizeof(MFModelStatus)) != 0) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldComputeTransition failed");
    PBErrCatch(MiniFrameErr);
  }
  status = MFWorldComputeTransition(world, 2);
  if (memcmp(&status, &statusC, sizeof(MFModelStatus)) != 0) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldComputeTransition failed");
    PBErrCatch(MiniFrameErr);
  }
  MFWorldFree(&world);
  printf("UnitTestMFWorldComputeTransition OK\n");
}

void UnitTestMFWorld() {
  UnitTestMFWorldCreateFree();
  UnitTestMFWorldGetSet();
  UnitTestMFWorldComputeTransition();
  printf("UnitTestMFWorld OK\n");
}

void UnitTestMiniFrameCreateFree() {

  MFModelStatus initStatus = {._step = 0, ._pos = 0, ._tgt = 1};
  MiniFrame* mf = MiniFrameCreate(&initStatus);
  if (mf == NULL ||
    mf->_nbStep != 0 ||
    ISEQUALF(mf->_maxTimeExpansion, MF_DEFAULTTIMEEXPANSION) == false ||
    MFModelStatusIsSame(&initStatus, &(MFCurWorld(mf)->_status)) == false ||
    MFCurWorld(mf) != GSetGet(MFWorlds(mf), 0) ||
    GSetNbElem(MFWorlds(mf)) != 1 ||
    ISEQUALF(mf->_timeUnusedExpansion, 0.0) == false ||
    ISEQUALF(mf->_percWorldReused, 0.0) == false ||
    mf->_nbWorldExpanded != 0 ||
    mf->_nbWorldUnexpanded != 0 ||
    mf->_nbRemovedWorld != 0 ||
    mf->_timeEndExpansion <= 0.0 ||
    mf->_maxDepthExp != -1 ||
    mf->_expansionType != MFExpansionTypeValue ||
    mf->_nbTransMonteCarlo != MF_NBTRANSMONTECARLO ||
    mf->_reuseWorld != false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MiniFrameCreate failed");
    PBErrCatch(MiniFrameErr);
  }
  MiniFrameFree(&mf);
  if (mf != NULL) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MiniFrameFree failed");
    PBErrCatch(MiniFrameErr);
  }

  printf("UnitTestMiniFrameCreateFree OK\n");
}

void UnitTestMiniFrameGetSet() {
  MFModelStatus initWorld = {._step = 0, ._pos = 0, ._tgt = 1};
```

```
MiniFrame* mf = MiniFrameCreate(&initWorld);
if (ISEQUALF(MFGetMaxTimeExpansion(mf),
  mf->_maxTimeExpansion) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetMaxTimeExpansion failed");
  PBErrCatch(MiniFrameErr);
}
if (MFGetNbComputedWorld(mf) != 1) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetNbComputedWorld failed");
  PBErrCatch(MiniFrameErr);
}
float t = MF_DEFAULTTIMEEXPANSION + 1.0;
MFSetMaxTimeExpansion(mf, t);
if (ISEQUALF(MFGetMaxTimeExpansion(mf), t) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFSetMaxTimeExpansion failed");
  PBErrCatch(MiniFrameErr);
}
if (ISEQUALF(MFGetTimeEndExpansion(mf),
  mf->_timeEndExpansion) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetTimeEndExpansion failed");
  PBErrCatch(MiniFrameErr);
}
if (MFCurWorld(mf) != mf->_curWorld) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFCurWorld failed");
  PBErrCatch(MiniFrameErr);
}
if (MFWorlds(mf) != &(mf->_worlds)) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFWorlds failed");
  PBErrCatch(MiniFrameErr);
}
if (MFIsWorldReusable(mf) != mf->_reuseWorld) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFIsWorldReusable failed");
  PBErrCatch(MiniFrameErr);
}
bool reuse = !MFIsWorldReusable(mf);
MFSetWorldReusable(mf, reuse);
if (MFIsWorldReusable(mf) != reuse) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFSetWorldReusable failed");
  PBErrCatch(MiniFrameErr);
}
mf->_percWorldReused = 1.0;
if (ISEQUALF(MFGetPercWordReused(mf), 1.0) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetPercWordReused failed");
  PBErrCatch(MiniFrameErr);
}
MFModelStatus modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
MFWorld* world = MFWorldCreate(&modelWorld);
MFAddWorld(mf, world, 0);
if (GSetNbElem(MFWorlds(mf)) != 2 ||
  MFModelStatusIsSame(MFWorldStatus(world),
    (MFModelStatus*)GSetGet(MFWorlds(mf), 1)) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFAddWorld failed");
  PBErrCatch(MiniFrameErr);
```

```
}
mf->_nbWorldExpanded = 1;
if (MFGetNbWorldExpanded(mf) != mf->_nbWorldExpanded) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetNbWorldExpanded failed");
  PBErrCatch(MiniFrameErr);
}
mf->_nbWorldUnexpanded = 1;
if (MFGetNbWorldUnexpanded(mf) != mf->_nbWorldUnexpanded) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetNbWorldUnexpanded failed");
  PBErrCatch(MiniFrameErr);
}
mf->_timeSearchWorld = 2.0;
if (ISEQUALF(MFGetTimeSearchWorld(mf),
  mf->_timeSearchWorld) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetTimeSearchWorld failed");
  PBErrCatch(MiniFrameErr);
}
mf->_timeUnusedExpansion = 3.0;
if (ISEQUALF(MFGetTimeUnusedExpansion(mf),
  mf->_timeUnusedExpansion) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetTimeUnusedExpansion failed");
  PBErrCatch(MiniFrameErr);
}
mf->_percWorldReused = 4.0;
if (ISEQUALF(MFGetPercWordReused(mf),
  mf->_percWorldReused) == false) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetPercWordReused failed");
  PBErrCatch(MiniFrameErr);
}
clock_t now = clock();
MFSetStartExpandClock(mf, now);
if (mf->_startExpandClock != now) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetStartExpandClock failed");
  PBErrCatch(MiniFrameErr);
}
if (MFGetStartExpandClock(mf) != now) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetStartExpandClock failed");
  PBErrCatch(MiniFrameErr);
}
if (MFGetMaxDepthExp(mf) != mf->_maxDepthExp) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFGetMaxDepthExp failed");
  PBErrCatch(MiniFrameErr);
}
MFSetMaxDepthExp(mf, 3);
if (MFGetMaxDepthExp(mf) != 3) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFSetMaxDepthExp failed");
  PBErrCatch(MiniFrameErr);
}
MFSetMaxDepthExp(mf, -2);
if (MFGetMaxDepthExp(mf) != -1) {
  MiniFrameErr->_type = PBErrTypeUnitTestFailed;
  sprintf(MiniFrameErr->_msg, "MFSetMaxDepthExp failed");
  PBErrCatch(MiniFrameErr);
```

```
  }
  if (MFGetExpansionType(mf) != mf->_expansionType) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetExpansionType failed");
    PBErrCatch(MiniFrameErr);
  }
  MFSetExpansionType(mf, MFExpansionTypeWidth);
  if (MFGetExpansionType(mf) != MFExpansionTypeWidth) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetExpansionType failed");
    PBErrCatch(MiniFrameErr);
  }
  if (MFGetNbTransMonteCarlo(mf) != mf->_nbTransMonteCarlo) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetNbTransMonteCarlo failed");
    PBErrCatch(MiniFrameErr);
  }
  MFSetNbTransMonteCarlo(mf, 10);
  if (MFGetNbTransMonteCarlo(mf) != 10) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetNbTransMonteCarlo failed");
    PBErrCatch(MiniFrameErr);
  }
  MiniFrameFree(&mf);
  printf("UnitTestMiniFrameGetSet OK\n");
}

void UnitTestMiniFrameExpandSetCurWorld() {
  MFModelStatus initWorld = {._step = 0, ._pos = 0, ._tgt = 2};
  MiniFrame* mf = MiniFrameCreate(&initWorld);
  MFSetStartExpandClock(mf, clock());
  MFSetWorldReusable(mf, true);
  MFExpand(mf);
  printf("Time unused by MFExpand: %f\n", MFGetTimeUnusedExpansion(mf));
  printf("Time search world to expand: %f\n", MFGetTimeSearchWorld(mf));
  printf("Nb world expanded: %d\n", MFGetNbWorldExpanded(mf));
  printf("Nb world unexpanded: %d\n", MFGetNbWorldUnexpanded(mf));
  printf("Nb world removed: %d\n", MFGetNbWorldRemoved(mf));
  printf("Perc world reused: %f\n", MFGetPercWordReused(mf));
  printf("Computed worlds:\n");
  GSetIterForward iter = GSetIterForwardCreateStatic(MFWorlds(mf));
  do {
    MFWorld* world = GSetIterGet(&iter);
    MFWorldTransPrintln(world, stdout);
  } while (GSetIterStep(&iter));
  if (mf->_timeUnusedExpansion < 0.0 ||
    MFGetNbWorldExpanded(mf) != 15 ||
    MFGetNbWorldUnexpanded(mf) != 0 ||
    MFGetNbWorldRemoved(mf) != 0 ||
    ISEQUALF(MFGetPercWordReused(mf), 0.666667) == false ||
    ISEQUALF(MFGetTimeSearchWorld(mf), 100.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFExpand failed");
    PBErrCatch(MiniFrameErr);
  }
  const MFModelTransition* bestTrans = MFBestTransition(mf, 0);
  printf("Best action: %d\n", bestTrans->_move);
  if (bestTrans->_move != 1) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetBestTransition failed");
    PBErrCatch(MiniFrameErr);
  }
```

```
  if (ISEQUALF(MFWorldGetForecastValue(MFCurWorld(mf), 0), 0.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetPOVValue failed");
    PBErrCatch(MiniFrameErr);
  }
  if (ISEQUALF(
    MFWorldGetForecastValue(MFCurWorld(mf), 0), 0.0) == false) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetForecastValue failed");
    PBErrCatch(MiniFrameErr);
  }
  MFModelStatus nextWorld = {._pos = -1, ._tgt = 2};
  MFSetCurWorld(mf, &nextWorld);
  if (MFCurWorld(mf) != GSetGet(MFWorlds(mf), 2) ||
    MFGetNbComputedWorld(mf) != 6) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetCurWorld failed");
    PBErrCatch(MiniFrameErr);
  }
  MiniFrameFree(&mf);
  printf("UnitTestMiniFrameExpandSetCurWorld OK\n");
}

void UnitTestMiniFrameFullExample() {
  // Initial world
  MFModelStatus curWorld = {._step = 0, ._pos = 0, ._tgt = 2};
  // Create the MiniFrame
  MiniFrame* mf = MiniFrameCreate(&curWorld);
  // Set reusable worlds
  MFSetWorldReusable(mf, true);
  // Loop until end of game
  int tgt[7] = {2,2,-1,-1,-1,-1,-1};
  while (!MFModelStatusIsEnd(&curWorld)) {
    // Set the start clock
    MFSetStartExpandClock(mf, clock());
    // Correct the current world in the MiniFrame
    MFSetCurWorld(mf, &curWorld);
    // Expand
    MFExpand(mf);
    // Get best transition
    const MFModelTransition* bestTrans = MFBestTransition(mf, 0);
    if (bestTrans != NULL) {
      // Step with best transition
      curWorld = MFModelStatusStep(&curWorld, bestTrans);
    }
    // Apply external forces to the world
    curWorld._tgt = tgt[curWorld._step];
    // Display the current world
    printf("mf(");
    MFModelStatusPrint(MFWorldStatus(MFCurWorld(mf)), stdout);
    printf(") real(");
    MFModelStatusPrint(&curWorld, stdout);
    printf(")\n");
    /*MFWorldTransPrintln(MFCurWorld(mf), stdout);
    printf("--- start of best story ---\n");
    MFWorldPrintBestStoryln(MFCurWorld(mf), 0, stdout);
    printf("--- end of best story ---\n");
    printf("\n");*/
  }
  MiniFrameFree(&mf);
  printf("UnitTestMiniFrameFullExample OK\n");
}
```

```
void UnitTestMiniFrame() {
  UnitTestMiniFrameCreateFree();
  UnitTestMiniFrameGetSet();
  UnitTestMiniFrameExpandSetCurWorld();
  UnitTestMiniFrameFullExample();
  printf("UnitTestMiniFrame OK\n");
}

void UnitTestAll() {
  UnitTestMFTransition();
  UnitTestMFWorld();
  UnitTestMiniFrame();
  printf("UnitTestAll OK\n");
}

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

5 Unit tests output

```
UnitTestMFTransitionCreateFree OK
UnitTestMFTransitionIsExpandable OK
UnitTestMFTransitionIsExpanded OK
UnitTestMFTransitionGetSet OK
UnitTestMFTransition OK
UnitTestMFWorldCreateFree OK
UnitTestMFWorldGetSet OK
UnitTestMFWorldComputeTransition OK
UnitTestMFWorld OK
UnitTestMiniFrameCreateFree OK
UnitTestMiniFrameGetSet OK
Time unused by MFExpand: 99.987000
Time search world to expand: 100.000000
Nb world expanded: 15
Nb world unexpanded: 0
Nb world removed: 0
Perc world reused: 0.666667
Computed worlds:
(step:3 pos:-3 tgt:2) values[-5.000000] forecast[-0.000030]
  0) transition from (step:3 pos:-3 tgt:2) to (step:3 pos:-3 tgt:2) through (move:-1) values[-4.000000]
  1) transition from (step:3 pos:-3 tgt:2) to (step:3 pos:-3 tgt:2) through (move:0) values[-4.000000]
  2) transition from (step:3 pos:-3 tgt:2) to (step:2 pos:-2 tgt:2) through (move:1) values[-0.000030]
(step:2 pos:-2 tgt:2) values[-4.000000] forecast[-0.000020]
  0) transition from (step:2 pos:-2 tgt:2) to (step:3 pos:-3 tgt:2) through (move:-1) values[-4.000000]
  1) transition from (step:2 pos:-2 tgt:2) to (step:2 pos:-2 tgt:2) through (move:0) values[-0.000030]
  2) transition from (step:2 pos:-2 tgt:2) to (step:1 pos:-1 tgt:2) through (move:1) values[-0.000020]
(step:1 pos:-1 tgt:2) values[-3.000000] forecast[-0.000010]
  0) transition from (step:1 pos:-1 tgt:2) to (step:2 pos:-2 tgt:2) through (move:-1) values[-0.000030]
  1) transition from (step:1 pos:-1 tgt:2) to (step:1 pos:-1 tgt:2) through (move:0) values[-0.000020]
  2) transition from (step:1 pos:-1 tgt:2) to (step:0 pos:0 tgt:2) through (move:1) values[-0.000010]
(step:0 pos:0 tgt:2) values[-2.000000] forecast[0.000000]
  0) transition from (step:0 pos:0 tgt:2) to (step:1 pos:-1 tgt:2) through (move:-1) values[-0.000020]
  1) transition from (step:0 pos:0 tgt:2) to (step:0 pos:0 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:0 pos:0 tgt:2) to (step:1 pos:1 tgt:2) through (move:1) values[0.000000]
```

```
(step:1 pos:1 tgt:2) values[-1.000000] forecast[0.000000]
  0) transition from (step:1 pos:1 tgt:2) to (step:0 pos:0 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:1 pos:1 tgt:2) to (step:1 pos:1 tgt:2) through (move:0) values[0.000000]
  2) transition from (step:1 pos:1 tgt:2) to (step:2 pos:2 tgt:2) through (move:1) values[0.000000]
(step:2 pos:2 tgt:2) values[0.000000] forecast[0.000000]
Best action: 1
UnitTestMiniFrameExpandSetCurWorld OK
mf(step:0 pos:0 tgt:2) real(step:1 pos:1 tgt:2)
mf(step:1 pos:1 tgt:2) real(step:2 pos:2 tgt:-1)
mf(step:2 pos:2 tgt:-1) real(step:3 pos:1 tgt:-1)
mf(step:3 pos:1 tgt:-1) real(step:4 pos:0 tgt:-1)
mf(step:4 pos:0 tgt:-1) real(step:5 pos:-1 tgt:-1)
UnitTestMiniFrameFullExample OK
UnitTestMiniFrame OK
UnitTestAll OK
```

6 Examples

6.1 Basic example

6.1.1 miniframe-model.h

```
// ============ MINIFRAME_MODEL.H ================

// As an example the code below implements a world where one actor
// moves along a discrete axis by step of one unit to reach a fixed
// target position
// Status of the world is defined by the current actor position and
// the target position
// Available actions are -1, 0, +1 (next position = current position
// + action) if the actor hasn't reached the target, else no actions
// The position of the actor is bounded to -5, 5
// The value of the world is given by -abs(position-target)

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

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include <stdbool.h>
#include <time.h>
#include "/home/bayashi/GitHub/PBErr/pberr.h"

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

// True if all actors act simultaneously, else false. As no effect if
// MF_NBMAXACTOR equals 1
#define MF_SIMULTANEOUS_PLAY false
// Max number of actors in the world
// must be at least one
#define MF_NBMAXACTOR 1
// Max number of transitions possible from any given status
// must be at least one
#define MF_NBMAXTRANSITION 3

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

```
// Structure describing the transition from one instance of
// MFModelStatus to another
typedef struct MFModelTransition {
  int _move;
} MFModelTransition;

// Structure describing the status of the world at one instant
typedef struct MFModelStatus {
  int _step;
  int _pos;
  int _tgt;
} MFModelStatus;

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

// Get the number of active actors
int MFModelStatusGetNbActor(const MFModelStatus* const that);

// Copy the properties of the MFModelStatus 'that' into the
// MFModelStatus 'tho'
// Dynamically allocated properties must be cloned
void MFModelStatusCopy(const MFModelStatus* const that,
  MFModelStatus* const tho);

// Free memory used by the properties of the MFModelStatus 'that'
// The memory used by the MFModelStatus itself is managed by MiniFrame
void MFModelStatusFreeStatic(MFModelStatus* that);

// Free memory used by the properties of the MFModelTransition 'that'
// The memory used by the MFModelTransition itself is managed by
// MiniFrame
void MFModelTransitionFreeStatic(MFModelTransition* that);

// Return true if 'that' and 'tho' are to be considered as the same
// by MiniFrame when trying to reuse previously computed status,
// else false
bool MFModelStatusIsSame(const MFModelStatus* const that,
  const MFModelStatus* const tho);

// Return the index of the actor who has preemption in the MFModelStatus
// 'that'
// If no actor has preemption (all the actor act simultaneously)
// return -1
int MFModelStatusGetSente(const MFModelStatus* const that);

// Return true if the actor 'iActor' is active given the MFModelStatus
// 'that'
bool MFModelStatusIsActorActive(const MFModelStatus* const that,
  const int iActor);

// Get the possible transitions from the MFModelStatus 'that' and
// memorize them in the array of MFModelTransition 'transitions', and
// memorize the number of transitions in 'nbTrans'
// 'transitions' as MF_NBMAXTRANSITION size, got MFModelTransition are
// expected in transitions[0~(nbTrans-1)]
void MFModelStatusGetTrans(const MFModelStatus* const that,
  MFModelTransition* const transitions, int* const nbTrans);

// Get the values of the MFModelStatus 'that' from the point of view
// of each actor and  memorize them in the array of float 'values'
// 'values' as MF_NBMAXACTOR size, all values are set to 0.0 before
// calling this function
```

```
void MFModelStatusGetValues(const MFModelStatus* const that,
  float* const values);

// Return the MFModelStatus resulting from applying the
// MFModelTransition 'trans' to the MFModelStatus 'that'
MFModelStatus MFModelStatusStep(const MFModelStatus* const that,
  const MFModelTransition* const trans);

// Print the MFModelStatus 'that' on the stream 'stream'
void MFModelStatusPrint(const MFModelStatus* const that,
  FILE* const stream);

// Print the MFModelTransition 'that' on the stream 'stream'
void MFModelTransitionPrint(const MFModelTransition* const that,
  FILE* const stream);

// Return true if the MFStatus 'that' is disposable (its memory can be
// freed) given the current status 'curStatus' and the number of
// world instances in memory, else false
// As many as possible should be kept in memory, especially if worlds
// are reusable, but its up to the user to decide which and when whould
// be discarded to fit the physical memory available
// Having too many world instances in memory also slow down the
// exploration of worlds during expansion
bool MFModelStatusIsDisposable(const MFModelStatus* const that,
  const MFModelStatus* const curStatus, const int nbStatus);

// Return true if the MFModelStatus 'that' is the end of the
// game/simulation, else false
bool MFModelStatusIsEnd(const MFModelStatus* const that);

// Init the board
void MFModelStatusInit(MFModelStatus* const that);

#if BUILDMODE != 0
inline
#endif
void toto();

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

#if BUILDMODE != 0
#include "miniframe-inline-model.c"
#endif
```

6.1.2 miniframe-model.c

```
// ============ MINIFRAME_MODEL.C ================

// As an example the code below implements a world where one actor
// moves along a discrete axis by step of one unit to reach a fixed
// target position
// Status of the world is defined by the current actor position and
// the target position
// Available actions are -1, 0, +1 (next position = current position
// + action) if the actor hasn't reached the target, else no actions
// The position of the actor is bounded to -5, 5
// The value of the world is given by -abs(position-target)

// ================ Include =================
```

```
#include "miniframe-model.h"
#if BUILDMODE == 0
#include "miniframe-inline-model.c"
#endif

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

// Get the number of active actors
int MFModelStatusGetNbActor(const MFModelStatus* const that) {
  (void)that;
  return MF_NBMAXACTOR;
}

// Copy the properties of the MFModelStatus 'that' into the
// MFModelStatus 'tho'
// Dynamically allocated properties must be cloned
void MFModelStatusCopy(const MFModelStatus* const that,
  MFModelStatus* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (tho == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'tho' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)memcpy(tho, that, sizeof(MFModelStatus));
}

// Free memory used by the properties of the MFModelStatus 'that'
// The memory used by the MFModelStatus itself is managed by MiniFrame
void MFModelStatusFreeStatic(MFModelStatus* that) {
  (void)that;

}

// Free memory used by the properties of the MFModelTransition 'that'
// The memory used by the MFModelTransition itself is managed by
// MiniFrame
void MFModelTransitionFreeStatic(MFModelTransition* that) {
  (void)that;

}

// Return true if 'that' and 'tho' are to be considered as the same
// by MiniFrame when trying to reuse previously computed status,
// else false
bool MFModelStatusIsSame(const MFModelStatus* const that,
  const MFModelStatus* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (tho == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'tho' is null");
```

```
    PBErrCatch(MiniFrameErr);
  }
#endif
  if (that->_pos == tho->_pos &&
    that->_tgt == tho->_tgt)
    return true;
  else
    return false;
}

// Return the index of the actor who has preemption in the MFModelStatus
// 'that'
// If no actor has preemption (all the actor act simultaneously)
// return -1
int MFModelStatusGetSente(const MFModelStatus* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)that;
  return 0;
}

// Return true if the actor 'iActor' is active given the MFModelStatus
// 'that'
bool MFModelStatusIsActorActive(const MFModelStatus* const that, const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)", \
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)that;(void)iActor;

  return true;
}

// Get the possible transitions from the MFModelStatus 'that' and
// memorize them in the array of MFModelTransition 'transitions', and
// memorize the number of transitions in 'nbTrans'
// 'transitions' as MF_NBMAXTRANSITION size, got MFModelTransition are
// expected in transitions[0~(nbTrans-1)]
void MFModelStatusGetTrans(const MFModelStatus* const that,
  MFModelTransition* const transitions, int* const nbTrans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (transitions == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(MiniFrameErr->_msg, "'transitions' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (nbTrans == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'nbTrans' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  if (that->_pos == that->_tgt) {
    *nbTrans = 0;
  } else {
    *nbTrans = 3;
    transitions[0]._move = -1;
    transitions[1]._move = 0;
    transitions[2]._move = 1;
  }
}

// Get the values of the MFModelStatus 'that' from the point of view
// of each actor and  memorize them in the array of float 'values'
// 'values' as MF_NBMAXACTOR size, all values are set to 0.0 before
// calling this function
void MFModelStatusGetValues(const MFModelStatus* const that,
  float* const values) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (values == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'values' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  values[0] = -1.0 * fabs(that->_tgt - that->_pos);
}

// Return the MFModelStatus resulting from applying the
// MFModelTransition 'trans' to the MFModelStatus 'that'
MFModelStatus MFModelStatusStep(const MFModelStatus* const that,
  const MFModelTransition* const trans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (trans == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'trans' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the resulting status
  MFModelStatus status;
  // Apply the transition
  status._step = that->_step + 1;
  status._tgt = that->_tgt;
  status._pos = that->_pos + trans->_move;
```

```
  int limit = 3;
  if (status._pos < -limit) status._pos = -limit;
  if (status._pos > limit) status._pos = limit;
  // Return the status
  return status;
}

// Print the MFModelStatus 'that' on the stream 'stream'
void MFModelStatusPrint(const MFModelStatus* const that,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "step:%d pos:%d tgt:%d", that->_step,
    that->_pos, that->_tgt);
}

// Print the MFModelTransition 'that' on the stream 'stream'
void MFModelTransitionPrint(const MFModelTransition* const that,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "move:%d", that->_move);
}

// Return true if the MFStatus 'that' is disposable (its memory can be
// freed) given the current status 'curStatus' and the number of
// world instances in memory, else false
// As many as possible should be kept in memory, especially if worlds
// are reusable, but its up to the user to decide which and when whould
// be discarded to fit the physical memory available
// Having too many world instances in memory also slow down the
// exploration of worlds during expansion
bool MFModelStatusIsDisposable(const MFModelStatus* const that,
  const MFModelStatus* const curStatus, const int nbStatus) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (curStatus == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(MiniFrameErr->_msg, "'curStatus' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  if (nbStatus > 0) {
    if (abs(that->_pos - curStatus->_pos) > 2)
      return true;
    else
      return false;
  } else {
    return false;
  }
}

// Return true if the MFModelStatus 'that' is the end of the
// game/simulation, else false
bool MFModelStatusIsEnd(const MFModelStatus* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  if (that->_step >= 6 || that->_pos == that->_tgt) {
    return true;
  } else {
    return false;
  }
}
```

6.1.3 miniframe-inline-model.c

```
// ============ MINIFRAME-INLINE-MODEL.C ================

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

#if BUILDMODE != 0
inline
#endif
void toto() {

}
```

6.2 Oware

6.2.1 miniframe-model.h

```
// ============ MINIFRAME_MODEL.H ================

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

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include <stdbool.h>
#include <time.h>
```

```
#include "/home/bayashi/GitHub/PBErr/pberr.h"
#include "/home/bayashi/GitHub/NeuraNet/neuranet.h"

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

// Current implementation doesn't allow more than 2 players
// due to undefined end condition
#define NBPLAYER 2
#define NBHOLEPLAYER 6
#define NBHOLE (NBHOLEPLAYER * NBPLAYER)
#define NBINITSTONEPERHOLE 4
#define NBSTONE (NBHOLE * NBINITSTONEPERHOLE)
#define NBMAXTURN 200

#define MF_MODEL_NN_NBINPUT NBHOLE
#define MF_MODEL_NN_NBOUTPUT 10
#define MF_MODEL_NN_NBHIDDEN 1
#define MF_MODEL_NN_NBBASES 100
#define MF_MODEL_NN_NBLINKS 100

// True if all actors act simultaneously, else false. As no effect if
// MF_NBMAXACTOR equals 1
#define MF_SIMULTANEOUS_PLAY false
// Max number of actors in the world
// must be at least one
#define MF_NBMAXACTOR NBPLAYER
// Max number of transitions possible from any given status
// must be at least one
#define MF_NBMAXTRANSITION NBHOLEPLAYER

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

// Structure describing the transition from one instance of
// MFModelStatus to another
typedef struct MFModelTransition {
  // Index of the hole from where stones are moved by the current player
  int _iHole;
} MFModelTransition;

// Structure describing the status of the world at one instant
typedef struct MFModelStatus {
  int _nbTurn;
  int _nbStone[NBHOLE];
  int _score[NBPLAYER];
  // Flag for special end condition
  char _end;
  // Index of the player who has the sente
  int _curPlayer;
  // NeuraNet for each player
  NeuraNet* _nn[NBPLAYER];
} MFModelStatus;

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

// Get the number of active actors
int MFModelStatusGetNbActor(const MFModelStatus* const that);

// Copy the properties of the MFModelStatus 'that' into the
// MFModelStatus 'tho'
// Dynamically allocated properties must be cloned
void MFModelStatusCopy(const MFModelStatus* const that,
  MFModelStatus* const tho);
```

```
// Free memory used by the properties of the MFModelStatus 'that'
// The memory used by the MFModelStatus itself is managed by MiniFrame
void MFModelStatusFreeStatic(MFModelStatus* that);

// Free memory used by the properties of the MFModelTransition 'that'
// The memory used by the MFModelTransition itself is managed by
// MiniFrame
void MFModelTransitionFreeStatic(MFModelTransition* that);

// Return true if 'that' and 'tho' are to be considered as the same
// by MiniFrame when trying to reuse previously computed status,
// else false
bool MFModelStatusIsSame(const MFModelStatus* const that,
  const MFModelStatus* const tho);

// Return the index of the actor who has preemption in the MFModelStatus
// 'that'
// If no actor has preemption (all the actor act simultaneously)
// return -1
int MFModelStatusGetSente(const MFModelStatus* const that);

// Return true if the actor 'iActor' is active given the MFModelStatus
// 'that'
bool MFModelStatusIsActorActive(const MFModelStatus* const that,
  const int iActor);

// Get the possible transitions from the MFModelStatus 'that' and
// memorize them in the array of MFModelTransition 'transitions', and
// memorize the number of transitions in 'nbTrans'
// 'transitions' as MF_NBMAXTRANSITION size, got MFModelTransition are
// expected in transitions[0~(nbTrans-1)]
void MFModelStatusGetTrans(const MFModelStatus* const that,
  MFModelTransition* const transitions, int* const nbTrans);

// Get the values of the MFModelStatus 'that' from the point of view
// of each actor and  memorize them in the array of float 'values'
// 'values' as MF_NBMAXACTOR size, all values are set to 0.0 before
// calling this function
void MFModelStatusGetValues(const MFModelStatus* const that,
  float* const values);

// Return the MFModelStatus resulting from applying the
// MFModelTransition 'trans' to the MFModelStatus 'that'
MFModelStatus MFModelStatusStep(const MFModelStatus* const that,
  const MFModelTransition* const trans);

// Print the MFModelStatus 'that' on the stream 'stream'
void MFModelStatusPrint(const MFModelStatus* const that,
  FILE* const stream);

// Print the MFModelTransition 'that' on the stream 'stream'
void MFModelTransitionPrint(const MFModelTransition* const that,
  FILE* const stream);

// Return true if the MFStatus 'that' is disposable (its memory can be
// freed) given the current status 'curStatus' and the number of
// world instances in memory, else false
// As many as possible should be kept in memory, especially if worlds
// are reusable, but its up to the user to decide which and when whould
// be discarded to fit the physical memory available
// Having too many world instances in memory also slow down the
```

```
// exploration of worlds during expansion
bool MFModelStatusIsDisposable(const MFModelStatus* const that,
  const MFModelStatus* const curStatus, const int nbStatus);

// Return true if the MFModelStatus 'that' is the end of the
// game/simulation, else false
bool MFModelStatusIsEnd(const MFModelStatus* const that);

// Init the board
void MFModelStatusInit(MFModelStatus* const that);

#if BUILDMODE != 0
inline
#endif
void toto();

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

#if BUILDMODE != 0
#include "miniframe-inline-model.c"
#endif
```

6.2.2 miniframe-model.c

```
// ============ MINIFRAME_MODEL.C ================

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

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

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

// Get the number of active actors
int MFModelStatusGetNbActor(const MFModelStatus* const that) {
  (void)that;
  return MF_NBMAXACTOR;
}

// Copy the properties of the MFModelStatus 'that' into the
// MFModelStatus 'tho'
// Dynamically allocated properties must be cloned
void MFModelStatusCopy(const MFModelStatus* const that,
  MFModelStatus* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (tho == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'tho' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)memcpy(tho, that, sizeof(MFModelStatus));
}
```

```
// Free memory used by the properties of the MFModelStatus 'that'
// The memory used by the MFModelStatus itself is managed by MiniFrame
void MFModelStatusFreeStatic(MFModelStatus* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)that;
}

// Free memory used by the properties of the MFModelTransition 'that'
// The memory used by the MFModelTransition itself is managed by
// MiniFrame
void MFModelTransitionFreeStatic(MFModelTransition* that) {
  (void)that;

}

// Return true if 'that' and 'tho' are to be considered as the same
// by MiniFrame when trying to reuse previously computed status,
// else false
bool MFModelStatusIsSame(const MFModelStatus* const that,
  const MFModelStatus* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (tho == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'tho' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  bool ret = true;
  if (that->_curPlayer != tho->_curPlayer ||
    that->_end != tho->_end)
    ret = false;
  for (int iPlayer = NBPLAYER; iPlayer-- && ret;)
    if (that->_score[iPlayer] != tho->_score[iPlayer])
      ret = false;
  for (int iHole = NBHOLE; iHole-- && ret;)
    if (that->_nbStone[iHole] != tho->_nbStone[iHole])
      ret = false;
  return ret;
}

// Return the index of the actor who has preemption in the MFModelStatus
// 'that'
// If no actor has preemption (all the actor act simultaneously)
// return -1
int MFModelStatusGetSente(const MFModelStatus* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
```

```
#endif
  return that->_curPlayer;
}

// Return true if the actor 'iActor' is active given the MFModelStatus
// 'that'
bool MFModelStatusIsActorActive(const MFModelStatus* const that, const int iActor) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
    MiniFrameErr->_type = PBErrTypeInvalidArg;
    sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)", \
      iActor, MF_NBMAXACTOR);
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)that;(void)iActor;
  // Incorrect if NBPLAYER > 2
  return true;
}

// Get the possible transitions from the MFModelStatus 'that' and
// memorize them in the array of MFModelTransition 'transitions', and
// memorize the number of transitions in 'nbTrans'
// 'transitions' as MF_NBMAXTRANSITION size, got MFModelTransition are
// expected in transitions[0~(nbTrans-1)]
void MFModelStatusGetTrans(const MFModelStatus* const that,
  MFModelTransition* const transitions, int* const nbTrans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (transitions == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'transitions' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (nbTrans == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'nbTrans' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  *nbTrans = 0;
  for (int iHole = that->_curPlayer * NBHOLEPLAYER;
    iHole < (that->_curPlayer + 1) * NBHOLEPLAYER;
    ++iHole) {
    if (that->_nbStone[iHole] > 0) {
      transitions[*nbTrans]._iHole = iHole;
      ++(*nbTrans);
    }
  }
}

// Get the values of the MFModelStatus 'that' from the point of view
// of each actor and  memorize them in the array of float 'values'
```

```
// 'values' as MF_NBMAXACTOR size, all values are set to 0.0 before
// calling this function
void MFModelStatusGetValues(const MFModelStatus* const that,
  float* const values) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (values == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'values' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  VecFloat* input = VecFloatCreate(MF_MODEL_NN_NBINPUT);
  VecFloat* output = VecFloatCreate(MF_MODEL_NN_NBOUTPUT);
  for (int iPlayer = NBPLAYER; iPlayer--;) {
    if (that->_nn[iPlayer] == NULL) {
      values[iPlayer] = that->_score[iPlayer];
    } else {
      for (int iHole = NBHOLE; iHole--;) {
        int jHole = iHole + iPlayer * NBHOLEPLAYER;
        if (jHole >= NBHOLE)
          jHole -= NBHOLE;
        VecSet(input, iHole, that->_nbStone[jHole]);
      }
      NNEval(that->_nn[iPlayer], input, output);
      float valMax = VecGetMaxVal(output);
      values[iPlayer] = MAX(valMax, that->_score[iPlayer]);
    }
    if (values[iPlayer] * 2 > NBSTONE)
      values[iPlayer] = NBSTONE;
  }
  VecFree(&input);
  VecFree(&output);
}

// Return the MFModelStatus resulting from applying the
// MFModelTransition 'trans' to the MFModelStatus 'that'
MFModelStatus MFModelStatusStep(const MFModelStatus* const that,
  const MFModelTransition* const trans) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (trans == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'trans' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  // Declare a variable to memorize the resulting status
  MFModelStatus status;
  // Apply the transition

  MFModelStatusCopy(that, &status);
  int nbStone = status._nbStone[trans->_iHole];
  // Remove stones from starting hole
```

```
  status._nbStone[trans->_iHole] = 0;
  // Distribute stones
  int jHole = trans->_iHole;
  while (nbStone > 0) {
    ++jHole;
    if (jHole == NBHOLE) jHole = 0;
    // Jump over starting hole
    if (jHole == trans->_iHole) ++jHole;
    if (jHole == NBHOLE) jHole = 0;
    ++(status._nbStone[jHole]);
    --nbStone;
  }
  // Check for captured stones
  char flagCaptured = 0;
  while ((jHole < status._curPlayer * NBHOLEPLAYER ||
    jHole >= (status._curPlayer + 1) * NBHOLEPLAYER) &&
    (status._nbStone[jHole] == 2 ||
    status._nbStone[jHole] == 3)) {
    status._score[status._curPlayer] += status._nbStone[jHole];
    status._nbStone[jHole] = 0;
    flagCaptured = 1;
    --jHole;
  }
  // Check for special end conditions
  // First, check that the opponent is not starving
  int nbStoneOpp = 0;
  for (int iHole = 0; iHole < NBHOLE; ++iHole) {
    if (iHole < status._curPlayer * NBHOLEPLAYER ||
      iHole >= (status._curPlayer + 1) * NBHOLEPLAYER)
      nbStoneOpp += status._nbStone[iHole];
  }
  // If the opponent is starving
  if (nbStoneOpp == 0) {
    if (flagCaptured == 1) {
      // If there has been captured stones, it means the current
      // player has starved the opponent. The current player looses.
      status._end = 1;
      status._score[status._curPlayer] = 0.0;
    } else {
      // If there was no captured stones, it means the opponent
      // starved itself. The current player catches all his own stones.
      status._end = 1;
      for (int iHole = 0; iHole < NBHOLE; ++iHole) {
        if (iHole >= status._curPlayer * NBHOLEPLAYER &&
          iHole < (status._curPlayer + 1) * NBHOLEPLAYER)
          status._score[status._curPlayer] +=
            status._nbStone[iHole];
      }
    }
  }
  // Step the current player
  ++(status._curPlayer);
  if (status._curPlayer == NBPLAYER)
    status._curPlayer = 0;
  // Increment the nb of turn
  ++(status._nbTurn);


  // Return the status
  return status;
}
```

```
// Print the MFModelStatus 'that' on the stream 'stream'
void MFModelStatusPrint(const MFModelStatus* const that,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "#%d: ", that->_nbTurn);
  for (int iHole = 0; iHole < NBHOLE; ++iHole)
    fprintf(stream, "%d ", that->_nbStone[iHole]);
  fprintf(stream, " score: ");
  for (int iPlayer = 0; iPlayer < NBPLAYER; ++iPlayer) {
    if (iPlayer == MFModelStatusGetSente(that))
      fprintf(stream, "^");
    fprintf(stream, "%d", that->_score[iPlayer]);
    if (iPlayer < NBPLAYER - 1)
      fprintf(stream, ":");
  }
}

// Print the MFModelTransition 'that' on the stream 'stream'
void MFModelTransitionPrint(const MFModelTransition* const that,
  FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
  if (stream == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'stream' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  fprintf(stream, "move:%d", that->_iHole);
}

// Return true if the MFStatus 'that' is disposable (its memory can be
// freed) given the current status 'curStatus' and the number of
// world instances in memory, else false
// As many as possible should be kept in memory, especially if worlds
// are reusable, but its up to the user to decide which and when whould
// be discarded to fit the physical memory available
// Having too many world instances in memory also slow down the
// exploration of worlds during expansion
bool MFModelStatusIsDisposable(const MFModelStatus* const that,
  const MFModelStatus* const curStatus, const int nbStatus) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
```

```
  if (curStatus == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'curStatus' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif
  (void)nbStatus;
  int nbRemainStoneCurStatus = 0;
  for (int iHole = NBHOLE; iHole--;)
    nbRemainStoneCurStatus += curStatus->_nbStone[iHole];
  int nbRemainStone = 0;
  for (int iHole = NBHOLE; iHole--;)
    nbRemainStone += that->_nbStone[iHole];
  if (nbRemainStone > nbRemainStoneCurStatus)
    return true;
  else
    return false;
}

// Return true if the MFModelStatus 'that' is the end of the
// game/simulation, else false
bool MFModelStatusIsEnd(const MFModelStatus* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
  }
#endif

  /*if (that->_score[0] > 0 || that->_score[1] > 0)
    return true;
  else
    return false;*/

  if (that->_end == 1 ||
    that->_nbTurn == NBMAXTURN)
    return true;
  bool ret = false;
  for (int iPlayer = NBPLAYER; iPlayer--;) {
    // Incorrect if NBPLAYER > 2
    if (that->_score[iPlayer] * 2 > NBSTONE)
      ret = true;
  }
  // For the case NBPLAYER > 2
  /*if (ret == false) {
    int nbRemainStone = 0;
    for (int iHole = NBHOLE; iHole-- && ret == false;)
      nbRemainStone += that->_nbStone[iHole];
    if (nbRemainStone == 0)
      ret = true;
  }*/
  return ret;
}

// Init the board
void MFModelStatusInit(MFModelStatus* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'that' is null");
    PBErrCatch(MiniFrameErr);
```

```
  }
#endif
  that->_end = 0;
  for (int iPlayer = NBPLAYER; iPlayer--;) {
    that->_score[iPlayer] = 0;
    that->_nn[iPlayer] = NULL;
  }
  for (int iHole = NBHOLE; iHole--;)
    that->_nbStone[iHole] = NBINITSTONEPERHOLE;
  that->_curPlayer = 0;
  that->_nbTurn = 0;
}
```

6.2.3 miniframe-inline-model.c

```
// ============ MINIFRAME-INLINE-MODEL.C ================

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

#if BUILDMODE != 0
inline
#endif
void toto() {

}
```

6.2.4 main.c

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

#define RANDOMSEED 0

void RunDemo(float expansionTime, bool useNN) {
  // Initial world
  MFModelStatus curWorld;
  MFModelStatusInit(&curWorld);
  // Display the current world
  MFModelStatusPrint(&curWorld, stdout);
  printf("\n");
  // Create the MiniFrame
  MiniFrame* mf = MiniFrameCreate(&curWorld);
  // If we use a NeuraNet as evaluation for player #0
  if (useNN) {
    // Try to load the NeuraNet from ./bestnn.txt
    FILE* stream = fopen("./bestnn.txt", "r");
    if (stream != NULL) {
      if (!NNLoad(curWorld._nn, stream)) {
```

```
      printf("Couldn't reload the NeuraNet from ./bestnn.txt\n");
      printf("Will use the default evaluation function\n");
    }
    fclose(stream);
  } else {
    printf("Couldn't reload the NeuraNet from ./bestnn.txt\n");
    printf("Will use the default evaluation function\n");
  }
}
// Set the expansion time
MFSetMaxTimeExpansion(mf, expansionTime);
// Set reusable worlds
MFSetWorldReusable(mf, true);
// Flag to end the game
bool flagEnd = false;
// Loop until end of game
while (!MFModelStatusIsEnd(&curWorld) && !flagEnd) {
  printf("-----------\n");
  // Set the start clock
  MFSetStartExpandClock(mf, clock());
  // Correct the current world in the MiniFrame
  MFSetCurWorld(mf, &curWorld);
  // Expand
  MFExpand(mf);
  //MFWorldTransPrintln(MFCurWorld(mf), stdout);
  /*printf("--- start of best story ---\n");
  MFWorldPrintBestStoryln(MFCurWorld(mf),
    curWorld._curPlayer, stdout);
  printf("--- end of best story ---\n");*/
  // Display info about exansion
  printf("exp: %d ", MFGetNbWorldExpanded(mf));
  printf("unexp: %d ", MFGetNbWorldUnexpanded(mf));
  printf("comp: %d ", MFGetNbComputedWorld(mf));
  printf("removed: %d ", MFGetNbWorldRemoved(mf));
  printf("reused: %f ", MFGetPercWordReused(mf));
  printf("unused: %fms\n", MFGetTimeUnusedExpansion(mf));
  if (MFGetTimeUnusedExpansion(mf) < 0.0) {
    flagEnd = true;
    curWorld._score[curWorld._curPlayer] = -1;
  } else {
    // Get best transition
    const MFModelTransition* bestTrans =
      MFBestTransition(mf, MFModelStatusGetSente(&curWorld));
    if (bestTrans != NULL) {
      // Display the transition's information
      printf("sente: %d ", curWorld._curPlayer);
      MFModelTransitionPrint(bestTrans, stdout);
      printf(" forecast: %f",
        MFTransitionGetValue((MFTransition*)bestTrans,
        curWorld._curPlayer));
      printf("\n");
      // Step with best transition
      curWorld = MFModelStatusStep(&curWorld, bestTrans);
    } else {
      flagEnd = true;
    }
    // Apply external forces to the world
    // curWorld. = ... ;
  }
  // Display the current world
  MFModelStatusPrint(&curWorld, stdout);
  printf("\n");
```

```
    fflush(stdout);
  }
  // Free memory
  for (int iPlayer = NBPLAYER; iPlayer--;) {
    if (curWorld._nn[iPlayer] != NULL)
      NeuraNetFree(curWorld._nn + iPlayer);
  }
  MiniFrameFree(&mf);
}

void TrainOneGame(float expansionTime, GenAlgAdn** adns, GSet* result) {
  // Initial world
  MFModelStatus curWorld;
  MFModelStatusInit(&curWorld);
  // Create the MiniFrame
  MiniFrame* mf = MiniFrameCreate(&curWorld);
  // Set the NeuraNet for each actor
  for (int iActor = 0; iActor < NBPLAYER; ++iActor) {
    if (adns[iActor] != (void*)1) {
      NeuraNet* neuraNet = NeuraNetCreate(MF_MODEL_NN_NBINPUT,
        MF_MODEL_NN_NBOUTPUT, MF_MODEL_NN_NBHIDDEN,
        MF_MODEL_NN_NBBASES, MF_MODEL_NN_NBLINKS);
      NNSetBases(neuraNet, GAAdnAdnF(adns[iActor]));
      NNSetLinks(neuraNet, GAAdnAdnI(adns[iActor]));
      curWorld._nn[iActor] = neuraNet;
    } else {
      curWorld._nn[iActor] = NULL;
    }
  }
  // Set the expansion time
  MFSetMaxTimeExpansion(mf, expansionTime);
  // Set reusable worlds
  MFSetWorldReusable(mf, true);
  // Flag to end the game
  bool flagEnd = false;
  // Loop until end of game
  while (!MFModelStatusIsEnd(&curWorld) && !flagEnd) {
    // Set the start clock
    MFSetStartExpandClock(mf, clock());
    // Correct the current world in the MiniFrame
    MFSetCurWorld(mf, &curWorld);
    // Expand
    MFExpand(mf);
    if (MFGetTimeUnusedExpansion(mf) < 0.0) {
      flagEnd = true;
      curWorld._score[curWorld._curPlayer] = -1;
    } else {
      // Get best transition
      const MFModelTransition* bestTrans =
        MFBestTransition(mf, MFModelStatusGetSente(&curWorld));
      if (bestTrans != NULL) {
        // Step with best transition
        curWorld = MFModelStatusStep(&curWorld, bestTrans);
      } else {
        flagEnd = true;
      }
    }
  }
  // Update result
  GSetFlush(result);
  for (int iActor = 0; iActor < NBPLAYER; ++iActor)
    GSetAddSort(result, adns[iActor], curWorld._score[iActor]);
```

```
  // Free memory
  for (int iPlayer = NBPLAYER; iPlayer--;) {
    if (curWorld._nn[iPlayer] != NULL)
      NeuraNetFree(curWorld._nn + iPlayer);
  }
  MiniFrameFree(&mf);
}

void Train(int nbEpoch, int sizePool, int nbElite, int nbGameEpoch,
  float expansionTime) {
  // Display parameters
  printf("Will train with following parameters:\n");
  printf("nbEpoch: %d\n", nbEpoch);
  printf("sizePool: %d\n", sizePool);
  printf("nbElite: %d\n", nbElite);
  printf("nbGameEpoch: %d\n", nbGameEpoch);
  printf("expansionTime: %fms\n", expansionTime);
  // Create a NeuraNet
  NeuraNet* neuraNet = NeuraNetCreate(MF_MODEL_NN_NBINPUT,
    MF_MODEL_NN_NBOUTPUT, MF_MODEL_NN_NBHIDDEN,
    MF_MODEL_NN_NBBASES, MF_MODEL_NN_NBLINKS);
  // Create the GenAlg
  GenAlg* genAlg = GenAlgCreate(sizePool, nbElite,
    NNGetGAAdnFloatLength(neuraNet), NNGetGAAdnIntLength(neuraNet));
  NNSetGABoundsBases(neuraNet, genAlg);
  NNSetGABoundsLinks(neuraNet, genAlg);
  GASetTypeNeuraNet(genAlg, MF_MODEL_NN_NBINPUT,
    MF_MODEL_NN_NBHIDDEN, MF_MODEL_NN_NBOUTPUT);
  GAInit(genAlg);
  // Reload the GenAlg if possible
  FILE* stream = fopen("./bestga.txt", "r");
  if (stream != NULL) {
    printf("Reload the previous GenAlg from ./bestga.txt\n");
    if (GALoad(&genAlg, stream)) {
      printf("Couldn't reload the GenAlg\n");
      exit(1);
    }
  }
  // Declare a stream to save results
  FILE* streamRes = fopen("./res.txt", "w");
  if (streamRes == NULL) {
    printf("Couldn't open ./res.txt\n");
    exit(1);
  }
  // Declare a GSet to memorize the result
  GSet result = GSetCreateStatic();
  // Declare a variable to memorize the current epoch
  int iEpoch = 0;
  // Loop on epochs
  while (iEpoch < nbEpoch) {
    // Create the ELORank
    ELORank* eloRank = ELORankCreate();
    for (int iAdn = 0; iAdn < sizePool; ++iAdn)
      ELORankAdd(eloRank, GSetGet(GAAdns(genAlg), iAdn));
    ELORankAdd(eloRank, (GenAlgAdn*)GABestAdn(genAlg));
    ELORankAdd(eloRank, (void*)1);
    // Declare a variable to memorize the current game
    int iGame = 0;
    // Loop on games
    while (iGame < nbGameEpoch) {
      fprintf(stderr, "Epoch %05d/%05d Game %03d/%03d   \r",
        iEpoch + 1, nbEpoch, iGame + 1, nbGameEpoch);
```

```
  fflush(stderr);
  // Select randomly two adns
  GenAlgAdn* adns[NBPLAYER] = {NULL};
  int iAdn = (int)round(rnd() * (float)(sizePool) - 1.0);
  if (rnd() < 0.5) {
    adns[0] = (void*)1;
    if (iAdn == -1)
      adns[1] = (GenAlgAdn*)GABestAdn(genAlg);
    else
      adns[1] = GSetGet(GAAdns(genAlg), iAdn);
  } else {
    adns[1] = (void*)1;
    if (iAdn == -1)
      adns[0] = (GenAlgAdn*)GABestAdn(genAlg);
    else
      adns[0] = GSetGet(GAAdns(genAlg), iAdn);
  }
  // Play the game
  TrainOneGame(expansionTime, adns, &result);
  // Update the ELORank with the result
  ELORankUpdate(eloRank, &result);
  // Increment the current game
  ++iGame;
}
fprintf(stderr, "\n");
fflush(stderr);
// Update the values of each adn in the GenAlg with their ELORank
for (int iAdn = 0; iAdn < sizePool; ++iAdn) {
  GenAlgAdn* adn = GSetGet(GAAdns(genAlg), iAdn);
  float elo = ELORankGetELO(eloRank, adn);
  GASetAdnValue(genAlg, adn, elo);
}
// Update the value of the best adn too
GenAlgAdn* bestAdn = (GenAlgAdn*)GABestAdn(genAlg);
bestAdn->_val = ELORankGetELO(eloRank, bestAdn);
// Step the GenAlg
GAStep(genAlg);
// Display the elo of the best and the reference
float eloRef = ELORankGetELO(eloRank, (void*)1);
float eloBest = GAAdnGetVal(bestAdn);
printf("best: %f(age %ld) ref: %f(rank %d)\n", eloBest,
  GAAdnGetAge(bestAdn), eloRef, ELORankGetRank(eloRank, (void*)1));
fflush(stdout);
// Save the result
fprintf(streamRes, "%ld %f %f %d\n", GAGetCurEpoch(genAlg), eloBest,
  eloRef, ELORankGetRank(eloRank, (void*)1));
fflush(streamRes);
// Save the best NeuraNet to ./bestnn.txt
NNSetBases(neuraNet, GAAdnAdnF(bestAdn));
NNSetLinks(neuraNet, GAAdnAdnI(bestAdn));
stream = fopen("./bestnn.txt", "w");
if (stream == NULL) {
  printf("Couldn't open ./bestnn.txt");
  exit(1);
}
if (!NNSave(neuraNet, stream, true)) {
  printf("Couldn't open ./bestnn.txt");
  exit(1);
}
fclose(stream);
// Save the GenAlg to ./bestga.txt
stream = fopen("./bestga.txt", "w");
```

```
    if (stream == NULL) {
      printf("Couldn't open ./bestga.txt");
      exit(1);
    }
    if (!GASave(genAlg, stream, true)) {
      printf("Couldn't save ./bestga.txt");
      exit(1);
    }
    fclose(stream);
    // Increment the current epoch
    ++iEpoch;
    // Free memory
    ELORankFree(&eloRank);
  }
  // Free memory
  fclose(streamRes);
  GSetFlush(&result);
  GenAlgFree(&genAlg);
  NeuraNetFree(&neuraNet);
}

int main(int argc, char** argv) {
  // Init the random generator
  srandom(time(NULL));
  // Declare a variable to memorize the mode
  // 0: demo (default)
  // 1: train mode
  // 2: demo with trained NeuraNet as player #0
  int mode = 0;
  // Declare a variable to memorize the expansion time (in millisec)
  float expansionTime = 100.0;
  // Declare a variable to memorize the number of epoch for training
  int nbEpoch = 50;
  // Declare variables to memorize the size of pool, number of elites,
  // number of game per epoch for training
  int nbElite = 5;
  int sizePool = 20;
  int nbGameEpoch = 200;
  // Process argument
  for (int iArg = 0; iArg < argc; ++iArg) {
    if (strcmp(argv[iArg], "-help") == 0) {
      printf("main [-demo] [-demoNN] [-train] [-nbEpoch <nbEpoch>] ");
      printf("[-nbElite <nbElite>] [-sizePool <sizePool>] ");
      printf("[-nbGameEpoch <nbGameEpoch>] [-expTime <expansionTime>]\n");
      exit(0);
    } else if (strcmp(argv[iArg], "-demo") == 0) {
      mode = 0;
    } else if (strcmp(argv[iArg], "-train") == 0) {
      mode = 1;
    } else if (strcmp(argv[iArg], "-demoNN") == 0) {
      mode = 2;
    } else if (strcmp(argv[iArg], "-nbEpoch") == 0 && iArg < argc - 1) {
      ++iArg;
      nbEpoch = atoi(argv[iArg]);
    } else if (strcmp(argv[iArg], "-nbElite") == 0 && iArg < argc - 1) {
      ++iArg;
      nbElite = atoi(argv[iArg]);
    } else if (strcmp(argv[iArg], "-sizePool") == 0 && iArg < argc - 1) {
      ++iArg;
      sizePool = atoi(argv[iArg]);
    } else if (strcmp(argv[iArg], "-nbGameEpoch") == 0 && iArg < argc - 1) {
      ++iArg;
```

```
      nbGameEpoch = atoi(argv[iArg]);
    } else if (strcmp(argv[iArg], "-expTime") == 0 && iArg < argc - 1) {
      ++iArg;
      expansionTime = atof(argv[iArg]);
    }
  }

  if (mode == 0) {
    RunDemo(expansionTime, false);
  } else if (mode == 1) {
    Train(nbEpoch, sizePool, nbElite, nbGameEpoch, expansionTime);
  } else if (mode == 2) {
    RunDemo(expansionTime, true);
  }

  // Return success code
  return 0;
}
```

6.2.5 Makefile

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

all: main

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

# Path to the model implementation
MF_MODEL_PATH=$(ROOT_DIR)/MiniFrame/Examples/Oware

# Include directories
MODEL_INC_DIR=-I$(ROOT_DIR)/PBErr -I$(ROOT_DIR)/GenAlg -I$(ROOT_DIR)/NeuraNet -I$(ROOT_DIR)/PBMath -I$(ROOT_DIR)/PBJs

# Rules to make the executable
main: \
createLinkToModelHeader \
main.o \
miniframe-model.o \
neuranet.o \
genalg.o \
elorank.o \
$(miniframe_EXE_DEP) \
$(miniframe_DEP)
$(COMPILER) `echo "$(miniframe_EXE_DEP) main.o" | tr ' ' '\n' | sort -u` miniframe-model.o neuranet.o genalg.o elora

main.o: \
main.c \
$(miniframe_INC_H_EXE) \
$(miniframe_EXE_DEP)
$(COMPILER) $(BUILD_ARG) $(MODEL_INC_DIR) $(miniframe_BUILD_ARG) `echo "$(miniframe_INC_DIR)" | tr ' ' '\n' | sort -u

createLinkToModelHeader:
ln -s -f $(MF_MODEL_PATH)/miniframe-model.h $(miniframe_DIR)/miniframe-model.h; ln -s -f $(MF_MODEL_PATH)/miniframe-
```

```
miniframe-model.o: miniframe-model.h miniframe-model.c Makefile
$(COMPILER) $(BUILD_ARG) $(MODEL_INC_DIR) -c miniframe-model.c
```

6.2.6 Example

exampleGame.txt:

```
#0: 4 4 4 4 4 4 4 4 4 4 4 4
score: 0:0 1:0
-----------
exp: 580 comp: 2969 unused: 0.536000ms
move:2
#1: 4 4 0 5 5 5 5 4 4 4 4 4
score: 0:0 1:0
-----------
exp: 215 comp: 4062 unused: 0.541000ms
move:11
#2: 5 5 1 6 5 5 5 4 4 4 4 0
score: 0:0 1:0
-----------
exp: 162 comp: 4885 unused: 0.762000ms
move:3
#3: 5 5 1 0 6 6 6 5 5 5 4 0
score: 0:0 1:0
-----------
exp: 131 comp: 5568 unused: 0.838000ms
move:9
#4: 6 6 0 0 6 6 6 5 5 0 5 1
score: 0:0 1:2
-----------
exp: 116 comp: 6170 unused: 1.026000ms
move:5
#5: 6 6 0 0 6 0 7 6 6 1 6 0
score: 0:2 1:2
-----------
exp: 534 comp: 2810 unused: 0.498000ms
move:9
#6: 6 6 0 0 6 0 7 6 6 0 7 0
score: 0:2 1:2
-----------
exp: 216 comp: 3877 unused: 0.557000ms
move:1
#7: 6 0 1 1 7 1 8 7 6 0 7 0
score: 0:2 1:2
-----------
exp: 161 comp: 4701 unused: 0.916000ms
move:10
#8: 7 1 2 2 8 0 8 7 6 0 0 1
score: 0:2 1:4
-----------
exp: 141 comp: 5336 unused: 0.701000ms
move:1
#9: 7 0 3 2 8 0 8 7 6 0 0 1
score: 0:2 1:4
-----------
exp: 448 comp: 3056 unused: 0.325000ms
move:8
#10: 8 1 4 2 8 0 8 7 0 1 1 2
score: 0:2 1:4
```

```
-----------
exp: 234 comp: 4200 unused: 0.514000ms
move:1
#11: 8 0 5 2 8 0 8 7 0 1 1 2
score: 0:2 1:4
-----------
exp: 180 comp: 5089 unused: 0.750000ms
move:10
#12: 8 0 5 2 8 0 8 7 0 1 0 3
score: 0:2 1:4
-----------
exp: 144 comp: 5830 unused: 0.696000ms
move:0
#13: 0 1 6 3 9 1 9 8 1 1 0 3
score: 0:2 1:4
-----------
exp: 134 comp: 6481 unused: 0.835000ms
move:6
#14: 1 2 7 4 9 1 0 9 2 2 1 4
score: 0:2 1:4
-----------
exp: 121 comp: 7066 unused: 0.919000ms
move:2
#15: 1 2 0 5 10 2 1 10 0 0 1 4
score: 0:8 1:4
-----------
exp: 123 comp: 7443 unused: 1.284000ms
move:7
#16: 2 3 1 6 11 0 1 0 1 1 2 5
score: 0:8 1:7
-----------
exp: 619 comp: 2985 unused: 0.462000ms
move:3
#17: 2 3 1 0 12 1 2 1 0 0 2 5
score: 0:12 1:7
-----------
exp: 254 comp: 4095 unused: 0.653000ms
move:10
#18: 0 3 1 0 12 1 2 1 0 0 0 6
score: 0:12 1:10
-----------
exp: 631 comp: 2820 unused: 0.337000ms
move:5
#19: 0 3 1 0 12 0 0 1 0 0 0 6
score: 0:15 1:10
-----------
exp: 254 comp: 3860 unused: 0.553000ms
move:7
#20: 0 3 1 0 12 0 0 0 1 0 0 6
score: 0:15 1:10
-----------
exp: 549 comp: 2981 unused: 0.492000ms
move:4
#21: 1 4 2 1 0 2 1 1 2 1 1 7
score: 0:15 1:10
-----------
exp: 288 comp: 4097 unused: 0.761000ms
move:8
#22: 1 4 2 1 0 2 1 1 0 2 2 7
score: 0:15 1:10
-----------
exp: 203 comp: 4957 unused: 0.663000ms
```

```
move:5
#23: 1 4 2 1 0 0 0 0 0 2 2 7
score: 0:19 1:10
-----------
exp: 177 comp: 5688 unused: 0.793000ms
move:10
#24: 0 4 2 1 0 0 0 0 0 2 0 8
score: 0:19 1:12
-----------
exp: 535 comp: 3137 unused: 0.411000ms
move:1
#25: 0 0 3 2 1 1 0 0 0 2 0 8
score: 0:19 1:12
-----------
exp: 286 comp: 4213 unused: 0.454000ms
move:9
#26: 0 0 3 2 1 1 0 0 0 0 1 9
score: 0:19 1:12
-----------
exp: 231 comp: 5065 unused: 0.754000ms
move:5
#27: 0 0 3 2 1 0 1 0 0 0 1 9
score: 0:19 1:12
-----------
exp: 201 comp: 5778 unused: 0.716000ms
move:11
#28: 1 1 4 3 2 1 2 1 1 0 1 0
score: 0:19 1:12
-----------
exp: 150 comp: 6395 unused: 1.125000ms
move:2
#29: 1 1 0 4 3 2 0 1 1 0 1 0
score: 0:22 1:12
-----------
exp: 148 comp: 6962 unused: 1.460000ms
move:7
#30: 1 1 0 4 3 2 0 0 2 0 1 0
score: 0:22 1:12
-----------
exp: 782 comp: 2977 unused: 0.257000ms
move:5
#31: 1 1 0 4 3 0 1 1 2 0 1 0
score: 0:22 1:12
-----------
exp: 376 comp: 4101 unused: 0.492000ms
move:7
#32: 1 1 0 4 3 0 1 0 3 0 1 0
score: 0:22 1:12
-----------
exp: 254 comp: 4947 unused: 0.656000ms
move:1
#33: 1 0 1 4 3 0 1 0 3 0 1 0
score: 0:22 1:12
-----------
exp: 227 comp: 5659 unused: 0.571000ms
move:6
#34: 1 0 1 4 3 0 0 1 3 0 1 0
score: 0:22 1:12
-----------
exp: 172 comp: 6268 unused: 0.976000ms
move:4
#35: 1 0 1 4 0 1 1 0 3 0 1 0
```

```
score: 0:24 1:12
-----------
exp: 169 comp: 6823 unused: 1.288000ms
move:6
#36: 1 0 1 4 0 1 0 1 3 0 1 0
score: 0:24 1:12
-----------
exp: 314 comp: 4234 unused: 0.660000ms
move:3
#37: 1 0 1 0 1 2 1 0 3 0 1 0
score: 0:26 1:12
```

training.txt:

```
Will train with following parameters:
nbEpoch: 50
sizePool: 20
nbElite: 5
nbGameEpoch: 200
expansionTime: 2.000000ms
best: 31.328260(age 1) ref: 82.931335(rank 0)
best: 22.864634(age 1) ref: 79.334846(rank 0)
best: 24.208862(age 1) ref: -10.613078(rank 18)
best: 32.224094(age 1) ref: 12.468557(rank 5)
best: 17.549753(age 2) ref: -14.585226(rank 20)
best: 21.162813(age 1) ref: -27.068129(rank 21)
best: 43.162781(age 1) ref: 49.898052(rank 0)
best: 23.102114(age 1) ref: -32.691559(rank 20)
best: 39.671085(age 1) ref: -63.786736(rank 21)
best: 25.883085(age 1) ref: -45.418316(rank 21)
best: 43.656036(age 4) ref: -70.671555(rank 21)
best: 28.096897(age 2) ref: -88.050621(rank 21)
best: 35.324615(age 1) ref: -76.103546(rank 21)
best: 29.285027(age 7) ref: -80.363495(rank 21)
best: 32.384163(age 1) ref: -39.222408(rank 21)
best: 33.087044(age 1) ref: -159.921310(rank 21)
best: 38.447403(age 1) ref: -77.489342(rank 21)
best: 29.453932(age 1) ref: -97.934502(rank 21)
best: 28.433582(age 4) ref: -121.706337(rank 21)
best: 27.938528(age 1) ref: -44.681839(rank 21)
best: 26.743734(age 1) ref: -117.727440(rank 21)
best: 32.887238(age 1) ref: -118.119720(rank 21)
best: 31.815880(age 1) ref: -126.141380(rank 21)
best: 35.271561(age 1) ref: -160.575256(rank 21)
best: 39.056988(age 1) ref: -114.015266(rank 21)
best: 35.051537(age 1) ref: -172.867569(rank 21)
best: 33.369774(age 2) ref: -139.915665(rank 21)
best: 23.945967(age 1) ref: -160.053726(rank 21)
best: 28.880730(age 1) ref: -118.576210(rank 21)
best: 36.596848(age 1) ref: -126.771790(rank 21)
best: 40.642696(age 1) ref: -205.380783(rank 21)
best: 38.710934(age 1) ref: -119.274033(rank 21)
best: 32.663273(age 2) ref: -71.547211(rank 21)
best: 27.899593(age 1) ref: -128.230774(rank 21)
best: 35.756004(age 1) ref: -144.496521(rank 21)
best: 31.073360(age 2) ref: -46.526688(rank 20)
best: 28.740427(age 1) ref: -117.581848(rank 21)
best: 42.407894(age 2) ref: -91.168510(rank 21)
best: 22.859707(age 5) ref: -138.085449(rank 21)
best: 39.806992(age 1) ref: -75.063660(rank 21)
best: 30.126772(age 1) ref: -161.244186(rank 21)
```

```
best: 26.507477(age 1) ref: -138.023300(rank 21)
best: 23.815845(age 1) ref: -190.276886(rank 21)
best: 40.388985(age 1) ref: -124.716026(rank 21)
best: 36.726894(age 1) ref: -113.932503(rank 21)
best: 28.655504(age 1) ref: -161.943542(rank 21)
best: 32.068508(age 1) ref: -133.815598(rank 21)
best: 29.135687(age 1) ref: -147.955139(rank 21)
best: 40.737518(age 2) ref: -121.294418(rank 21)
best: 37.172047(age 1) ref: -197.387863(rank 21)
```

ELO rank of the best NeuraNet (blue) as evaluation function and ELO rank of the standard (red) evaluation function, and rank of the standard evaluation function against a pool of 21 NeuraNet: