

MiniFrame

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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 value for pruning during expansion
#define MF_PRUNINGDELTAVAL 1000.0
// Default maximum depth of expansion
#define MF_DEFAULTMAXDEPTHEXP 1000
// Expansion type
#define MF_EXPANSIONTYPE_BYVALUE 0
#define MF_EXPANSIONTYPE_BYWIDTH 1
#define MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK 2
#define MF_EXPANSIONTYPE_MONTECARLOTREESEARCH 3
#define MF_EXPANSIONTYPE MF_EXPANSIONTYPE_BYWIDTH
// Use of pruning
#define MF_USEPRUNING true
// Use telemetry
#define MF_USETELEMETRY true
// Reuse world
#define MF_REUSEWORLD true
// Use of depth limit
// TODO: Doesn't work, the world get dropped from teh set of worlds to
// expand but nothing is done, so the reference to the world is lost
#define MF_LIMITDEPTH true

// ===== 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 _worldsComputed;
    // Set of world waiting to be expanded
    GSet _worldsToExpand;
    // Time limit for expansion, in millisecond
    float _maxTimeExpansion;
    // Time unused during expansion, in millisecond
    float _timeUnusedExpansion;
    // 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;
    // The clock considered has start during expansion
    clock_t _startExpandClock;
    // Maximum depth during expansion, if -1 there is no limit
    int _maxDepthExp;
    // Value for pruning during expansion
    float _pruningDeltaVal;
    // Nb of world not found in MFSetCurWorld
    int _nbWorldNotFound;
    // Nb of tries in the MCTS
    int _nbTryMTCS;
    // Max depth reached during last MFExpand
    int _maxDepthExpReached;
#if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK
    // Internal flag
    int _expByDepthAppendPos;
#endif
} 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 MFWorld with a copy of the MFModelStatus 'status'
// Return the new MFWorld

```

```

MFWorld MFWorldCreateStatic(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* MFWorldsComputed(const MiniFrame* const that);

// Get the GSet of worlds to expand of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorldsToExpand(const MiniFrame* const that);

// Get the nb of world To expande of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldsToExpand(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);

#if MF_REUSEWORLD
// Set the flag 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);
#endif

// 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 MFAddWorldToComputed(MiniFrame* const that, \
    const MFWorld* const world);

// Add the MFWorld 'world' to the world to be expanded of the
// MiniFrame 'that'
void MFAddWorldToExpand(MiniFrame* const that, \
    const MFWorld* const world);

// 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 nb of computed worlds of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbComputedWorlds(const MiniFrame* const that);

// Get the percentage of resued world of the MiniFrame 'that' during
// the last MFEpxand()
#if BUILDMODE != 0
inline
#endif
float MFGetPercWorldReused(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 MFWorld 'that' has at least one transition to be
// expanded
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 MFModelState resulting from the 'iTrans' MFTransition
// of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
MFModelState 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 currenrt 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
// MFModelState 'status'
// If the world is in computed worlds reuse it, else create a new one
void MFSetCurWorld(MiniFrame* const that,
    const MFModelState* 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);

#if MF_LIMITDEPTH
// Set the max depth during expansion for the MiniFrame 'that' to 'depth'
// If depth is less than -1 it is converted to -1
// If the expansion type is not by width the max expansion depth is
// ignored during expansion
#if BUILDMODE != 0
inline
#endif
void MFSetMaxDepthExp(MiniFrame* const that, const int depth);
#endif

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

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

#if MF_USEPRUNING
// Set the pruning threshold during expansion for the MiniFrame 'that'
// to 'val'
#if BUILDMODE != 0
inline
#endif
void MFSetPruningDeltaVal(MiniFrame* const that, const float val);
#endif

// Get the pruning threshold during expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetPruningDeltaVal(const MiniFrame* const that);

// Get the nb of worlds not found during MFSetCurWorld
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldNotFound(const MiniFrame* const that);

// Get the max depth reached during last call of MFExpand
#if BUILDMODE != 0
inline
#endif
int MFGetMaxDepthExpReached(const MiniFrame* 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 =====

// Return true if the MFWorld 'that' should be pruned during search for
// worlds to expand when reaching it through transition 'trans',
// false else
bool MFWorldIsPrunedDuringExpansion(const MFWorld* const that,
    const MiniFrame* const mf, const MFTransition* const trans);

// Search in computed worlds of the MiniFrame 'that' if there is
// one with same status as the MFModelState 'status'
// If there is one return it, if not return null
MFWorld* MFSearchWorld(const MiniFrame* const that,
    const MFModelState* 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 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 by putting
// visited world in the set 'updatedWorld'
void MFUpdateForecastValues(MiniFrame* const that,
    const MFWorld* const world, int delayPenalty,
    GSet* const updatedWorld);

// Update the values of the MFTransition 'that' with 'val'
// Return true if the value has been updated, else false
bool MFTransitionUpdateValues(MFTransition* const that, 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);

// ===== 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->_worldsComputed = GSetCreateStatic();
    that->_worldsToExpand = GSetCreateStatic();
    MFAddWorldToExpand(that, MFCurWorld(that));
    that->_timeUnusedExpansion = 0.0;
    that->_reuseWorld = false;
    that->_percWorldReused = 0.0;
    that->_startExpandClock = 0;
    that->_maxDepthExp = MF_DEFAULTMAXDEPTHEXP;
    that->_pruningDeltaVal = MF_PRUNINGDELTAVAL;
    that->_maxDepthExpReached = 0;
    that->_nbWorldNotFound = 0;
    that->_nbTryMTCS = 0;
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK
        that->_expByDepthAppendPos = 0;
    #endif
    // 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
}

```

```

#endif
    // Allocate memory
    MFWorld *that = PBErrMalloc(MiniFrameErr, sizeof(MFWorld));
    // Set the status
    // Set the status
    MFModelStateCopy(status, &(that->_status));
    // Initialise the set of transitions reaching this world
    that->_sources = GSetCreateStatic();
    // Set the possible transitions from this world
    MFModelTransition transitions[MF_NBMAXTRANSITION];
    MFModelStateGetTrans(status, transitions, &(that->_nbTransition));
    MFTransition* thatTransitions = that->_transitions;
    for (int iTrans = that->_nbTransition; iTrans--;)
        thatTransitions[iTrans] =
            MFTransitionCreateStatic(that, transitions + iTrans);
#if MF_LIMITDEPTH == true
    // Init the depth
    that->_depth = 0;
#endif
    // Set the values
    float values[MF_NBMAXACTOR];
    for (int iActor = MF_NBMAXACTOR; iActor--;)
        values[iActor] = 0.0;
    MFModelStateGetValues(status, values);
    MFWorldSetValues(that, values);
    // Return the new MFWorld
    return that;
}

// Create a new static MFWorld with a copy of the MFModelState 'status'
// Return the new MFWorld
MFWorld MFWorldCreateStatic(const MFModelState* const status) {
#if BUILDMODE == 0
    if (status == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'status' is null");
        PBErrCatch(MiniFrameErr);
    }
#endif
    // Declare the new world
    MFWorld that;
    // Set the status
    MFModelStateCopy(status, &(that._status));
    // Initialise the set of transitions reaching this world
    that._sources = GSetCreateStatic();
    // Set the possible transitions from this world
    MFModelTransition transitions[MF_NBMAXTRANSITION];
    MFModelStateGetTrans(status, transitions, &(that._nbTransition));
    MFTransition* thatTransitions = that._transitions;
    for (int iTrans = that._nbTransition; iTrans--;)
        thatTransitions[iTrans] =
            MFTransitionCreateStatic(NULL, transitions + iTrans);
#if MF_LIMITDEPTH == true
    // Init the depth
    that._depth = 0;
#endif
    // Set the values
    float values[MF_NBMAXACTOR] = {0.0};
    MFWorldSetValues(&that, values);
    // 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 MF_EXPANSIONTYPE != MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
        if (world == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'world' is null");
            PErrCatch(MiniFrameErr);
        }
    #endif
    #endif
    // Declare a variable to memorize the new action
    MFTransition that;
    // Set properties
    that._transition = *transition;
    that._fromWorld = (MFWorld*)world;
    that._toWorld = NULL;
    float* thatValues = that._values;
    for (int iActor = MF_NBMAXACTOR; iActor--;)
        thatValues[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
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
        MFWorldFree(&((*that)->_curWorld));
    #else
        (*that)->_curWorld = NULL;
    #endif
    while(MFGetNbComputedWorlds(*that) > 0) {
        MFWorld* world = GSetPop((GSet*)MFWorldsComputed(*that));
        MFWorldFree(&world);
    }
    while(MFGetNbWorldsToExpand(*that) > 0) {
        MFWorld* world = GSetPop((GSet*)MFWorldsToExpand(*that));
        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;
    // Remove from sources and childs
    while (GSetNbElem(MFWorldSources(*that)) > 0) {
        MFTransition* transSource = MFWorldPopSource(*that);
        MFTransitionSetToWorld(transSource, NULL);
    }
    for (int iTrans = MFWorldGetNbTrans(*that); iTrans--;) {
        const MFTransition* trans = MFWorldTransition(*that, iTrans);
        MFWorld* toWorld = (MFWorld*)MFTransitionToWorld(trans);
    }
}

```

```

        if (toWorld != NULL)
            MFWorldRemoveSource(toWorld, trans);
    }
    // Free memory
    GSetFlush(&((*that)->_sources));
    MFModelStateFreeStatic(&((*that)->_status));
    MFTransition* thatTransitions = (*that)->_transitions;
    for (int iAct = (*that)->_nbTransition; iAct--;) {
        if (thatTransitions[iAct]._toWorld != NULL)
            MFTransitionFreeStatic(thatTransitions + 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
#if MF_EXPANSIONTYPE != MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
void MFExpand(MiniFrame* that) {
    #if BUILDMODE == 0
        if (that == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(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;
    #if MF_USETELEMETRY
        that->_maxDepthExpReached = that->_curWorld->_depth;
        // Declare a variable to memorize the number of reused worlds
        int nbReusedWorld = 0;
        // Declare a variable to memorize the number of worlds searched for
        // reuse
        int nbWorldSearchForReuse = 0;
    #endif
    // Declare a variable to memorize the time spent expanding
    double timeUsed =
        ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
    // Ensure the set of world to expand is not empty
    if (GSetNbElem(MFWorldsToExpand(that)) == 0) {
        #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK
            that->_expByDepthAppendPos = 0;
        #endif
        #if MF_LIMITDEPTH
            // Declare a variable to memorize the limit of expansion by depth
            int limitDepthExpansion =

```

```

    MFCurWorld(that)->_depth + MFGetMaxDepthExp(that);
#endif
    // 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 + maxTimeOneStep < MFGetMaxTimeExpansion(that) &&
        GSetNbElem(MFWorldsToExpand(that)) > 0 &&
        timeUsed >= 0.0) {
        // 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((GSet*)MFWorldsToExpand(that));
        // If this world is disposable
        if (worldToExpand != MFCurWorld(that) && (
            GSetNbElem(MFWorldSources(worldToExpand)) == 0 ||
            MFModelStatusIsDisposable(MFWorldStatus(worldToExpand),
            MFWorldStatus(MFCurWorld(that)))) {
            // Free this world
            MFWorldFree(&worldToExpand);
        } else, if this world is under the limit by depth of expansion
        // it needs to be expanded
        } else
    #if MF_LIMITDEPTH
        if (worldToExpand->_depth <= limitDepthExpansion)
    #endif
    {
        // 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 + maxTimeOneStep < MFGetMaxTimeExpansion(that) &&
            timeUsed >= 0.0;
            ++iTrans) {
            // If this transition is expandable
            const MFTransition* const trans =
                MFWorldTransition(worldToExpand, iTrans);
            if (MFTransitionIsExpandable(trans)) {
                // Expand through this transition
                MFModelStatus status =
                    MFWorldComputeTransition(worldToExpand, iTrans);
            #if MF_REUSEWORLD
                // Search if the resulting status has already been computed,
                // MFSearchWorld always return NULL if the reuse mode
                // is false
                MFWorld* sameWorld = MFSearchWorld(that, &status);
            #endif
            #if MF_USETELEMETRY
                // Increment the number of worlds searched for reuse
                ++nbWorldSearchForReuse;
            #endif
            #if MF_REUSEWORLD
                // If there is no world to reuse
                if (sameWorld == NULL) {
            #endif
                // Create a MFWorld for the new status
                MFWorld* expandedWorld = MFWorldCreate(&status);
                // Update the depth of the world
                expandedWorld->_depth = worldToExpand->_depth + 1;
            #if MF_USETELEMETRY
                if (that->_maxDepthExpReached < expandedWorld->_depth)
                    that->_maxDepthExpReached = expandedWorld->_depth;
            #endif
        }
    }

```

```

#endif
#if MF_USEPRUNING
    // If the expanded world is pruned
    if (MFCurWorld(that) != worldToExpand &&
        MFWorldIsPrunedDuringExpansion(
            expandedWorld, that, trans)) {
        // Add it to the computed worlds
        MFAddWorldToComputed(that, expandedWorld);
    } // Else, the world is not pruned
} else {

#endif
    // Add the world to the set of worlds to expand
#if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK
    that->_expByDepthAppendPos = iTrans;
#endif
    MFAddWorldToExpand(that, expandedWorld);
#if MF_USEPRUNING
}
#endif
    // Set the expanded world as the result of the transition
    MFWorldSetTransitionToWorld(
        worldToExpand, iTrans, expandedWorld);
#if MF_REUSEWORLD
} else {
#endif
#if MF_USETELEMETRY
    // Increment the number of reused world
    ++nbReusedWorld;
#endif
    // Set the already computed one as the result of the
    // transition
    MFWorldSetTransitionToWorld(worldToExpand, iTrans, sameWorld);
}
#endif
}
}
// Move the expanded world from the worlds to expands to the
// computed worlds
MFAddWorldToComputed(that, worldToExpand);
// Update the total time used from beginning of expansion
timeUsed =
    ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
// Update backward the forecast values for each transitions
// leading to the expanded world according to its new transitions
#if MF_REUSEWORLD == true
    GSet updatedWorld = GSetCreateStatic();
    MFUpdateForecastValues(that, worldToExpand, 0, &updatedWorld);
    GSetFlush(&updatedWorld);
#else
    MFUpdateForecastValues(that, worldToExpand, 0, NULL);
#endif
}
// 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;
    }
#endif MF_USETELEMETRY
    // 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;
    if (nbWorldSearchForReuse > 0)
        that->_percWorldReused =
            ((float)nbReusedWorld) / ((float)nbWorldSearchForReuse);
    else
        that->_percWorldReused = 0.0;
#endif
}
#else
void MFExpand(MiniFrame* that) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
    if (MFModelStateGetSente(MFWorldStatus(MFCurWorld(that))) == -1) {
        MiniFrameErr->_type = PBErrTypeInvalidArg;
        sprintf(MiniFrameErr->_msg,
            "MCTS doesn't work with undefined sente");
        PBErrCatch(MiniFrameErr);
    }
#endif
    // Declare a variable to memorize the time at beginning of the whole
    // expansion process
    clock_t clockStart = MFGetStartExpandClock(that);
    // Get the sente
    int sente = MFModelStateGetSente(MFWorldStatus(MFCurWorld(that)));
    // Declare variables to compute the MCTS
    float sumTrans[MF_NBMAXTRANSITION];
    for (int iTrans = MF_NBMAXTRANSITION; iTrans--;) {
        sumTrans[iTrans] = 0.0;
    }
    float values[MF_NBMAXACTOR];
    long nbTryTrans[MF_NBMAXTRANSITION] = {0};
    long nbTry = 0;
    int nbTrans = MFWorldGetNbTrans(MFCurWorld(that));
    // Declare a variable to memorize the maximum time used for one
    // step of expansion
    double maxTimeOneStep = 0.0;
    // Declare a variable to memorize the time spent expanding
    double timeUsed =
        ((double)(clock() - clockStart)) / MF_MILLISECTOCLOCKS;
    // 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 + maxTimeOneStep < MFGetMaxTimeExpansion(that) &&
        timeUsed >= 0.0) {
        // Declare a variable to memorize the time at the beginning of one
        // step of expansion
        clock_t clockStartLoop = clock();
        // Select the transition with the highest value so far
        int bestTrans = -1;

```

```

float valBestTrans = 0.0;
for (int iTrans = nbTrans; iTrans--;) {
    float val = 0.0;
    if (nbTryTrans[iTrans] > 0 && nbTry > 0) {
        val = sumTrans[iTrans] / (float)nbTryTrans[iTrans] +
            sqrt(2.0 * log(nbTry) / (float)nbTryTrans[iTrans]);
    }
    if (bestTrans < 0 || valBestTrans < val) {
        bestTrans = iTrans;
        valBestTrans = val;
    }
}
// Make a copy of the curWorld
MFWorld expandedWorld = *(MFWorld*)MFCurWorld(that);
// Loop until we reach an end world or a limit of step
int nbStep = 0;
int iTrans = bestTrans;
int nbNextTrans = MFWorldGetNbTrans(&expandedWorld);
while (!MFModelStatusIsEnd(MFWorldStatus(&expandedWorld)) &&
    nbStep < MFGetMaxDepthExp(that) && nbNextTrans > 0) {
    // Apply the transition
    MFModelStatus status =
        MFWorldComputeTransition(&expandedWorld, iTrans);
    expandedWorld = MFWorldCreateStatic(&status);
    // Select randomly the next transition
    nbNextTrans = MFWorldGetNbTrans(&expandedWorld);
    iTrans = (int)round(rnd() * (float)(nbNextTrans - 1));
    // Increment the number of step
    ++nbStep;
}
// Get the value of the reached world for the current player
// TODO: doesn't work for simultaneous game
for (int iActor = MF_NBMAXACTOR; iActor--;)
    values[iActor] = 0.0;
MFModelStatusGetValues(MFWorldStatus(&expandedWorld), values);
float val = values[sente];
// Update the variables for the MCTS
++nbTry;
++(nbTryTrans[bestTrans]);
sumTrans[bestTrans] += val;
// 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;
}
// Update the values of the transitions
// TODO: doesn't work for simultaneous game
for (int iTrans = nbTrans; iTrans--;) {
    MFTransition* trans =
        (MFTransition*)MFWorldTransition(MFCurWorld(that), iTrans);
    if (nbTryTrans[iTrans] > 0) {
        trans->_values[sente] =
            sumTrans[iTrans] / (float)nbTryTrans[iTrans];
    } else {

```

```

        trans->_values[sente] = 0.0;
    }
}

#if MF_USETELEMETRY
    // 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->_nbTryMTCS = nbTry;
#endif
}
#endif

// Return true if the MFWorld 'that' should be pruned during search for
// worlds to expand when reaching it through transition 'trans',
// false else
bool MFWorldIsPrunedDuringExpansion(const MFWorld* const that,
    const MiniFrame* const mf, const MFTransition* const trans) {
    #if BUILDMODE == 0
        if (that == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(MiniFrameErr);
        }
        if (mf == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'mf' is null");
            PErrCatch(MiniFrameErr);
        }
        if (trans == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'trans' is null");
            PErrCatch(MiniFrameErr);
        }
        if (MFTransitionFromWorld(trans) == NULL) {
            MiniFrameErr->_type = PErrTypeInvalidArg;
            sprintf(MiniFrameErr->_msg, "The transition has no origin");
            PErrCatch(MiniFrameErr);
        }
    #endif
    // Declare a variable to memorize the result
    bool ret = false;
    // Get the origin world of the transition
    const MFWorld* const fatherWorld = MFTransitionFromWorld(trans);
    // Get the sente of the father world
    int sente = MFModelStatusGetSente(MFWorldStatus(fatherWorld));
    // Variable to memorize the maximum forecast value
    float max = 0.0;
    // Variable to memorize the best brother
    const MFWorld* bestBrother = NULL;
    // Loop on transition
    for (int iTrans = MFWorldGetNbTrans(fatherWorld); iTrans--;) {
        // Get the brother
        const MFWorld* const brother =
            MFTransitionToWorld(MFWorldTransition(fatherWorld, iTrans));
        // If the brother is not itself and not null
        if (brother != that && brother != NULL) {
            // Get the value of the brother

```

```

        const float val = MFWorldGetForecastValue(brother, sente);
        // Update the best value
        if (bestBrother == NULL || max < val) {
            bestBrother = brother;
            max = val;
        }
    }
}
//If there was a best brother
if (bestBrother != NULL) {
    // Get the value of the world
    float val = MFWorldGetForecastValue(that, sente);
    // If the pruning condition is verified
    if (val < max - MFGetPruningDeltaVal(mf))
        ret = true;
}
// Return the result
return ret;
}

// 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 we are not at the end
    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 (MFIWorldReusable(that)) {
    if (MFGetNbComputedWorlds(that) > 0) {
        // Loop on computed worlds
        GSetIterForward iter =
            GSetIterForwardCreateStatic((GSet*)MFWorldsComputed(that));
        do {
            MFWorld* world = GSetIterGet(&iter);
            // If this world is the same as the searched one
            if (MFModelStateIsSame(status, MFWorldStatus(world))) {
                sameWorld = world;
            }
        } while (sameWorld == NULL && GSetIterStep(&iter));
    }
    if (sameWorld == NULL && MFGetNbWorldsToExpand(that) > 0) {
        // Loop on worlds to expand
        GSetIterForward iter =
            GSetIterForwardCreateStatic((GSet*)MFWorldsToExpand(that));
        do {
            MFWorld* world = GSetIterGet(&iter);
            // If this world is the same as the searched one
            if (MFModelStateIsSame(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,
            MFWorldGetForecastValue(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) {
#ifdef 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;
    }
}

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

```

```

    }
    if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
        MiniFrameErr->_type = PBErrTypeInvalidArg;
        sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
            iActor, MF_NBMAXACTOR);
        PBErrCatch(MiniFrameErr);
    }
#endif
    // Get the best transition
    const MFTransition* bestTrans =
        (const MFTransition*)MFWorldBestTransition(that, iActor);
    // If there is a best transition
    if (bestTrans != NULL) {
        // Return the value of the best transition
        return MFTransitionGetValue(bestTrans, iActor);
    }
    // Else, there was no transition from this world
    else {
        // Return the value of this world
        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 transition with highest value
const MFTransition* bestTrans = NULL;
// Get the sente
int sente = MFModelStatusGetSente(MFWorldStatus(that));
sente = (sente == -1 ? iActor : sente);
// Loop on transitions
for (int iTrans = MFWorldGetNbTrans(that); iTrans--;) {
    // Declare a variable to memorize the transition
    const MFTransition* const trans = MFWorldTransition(that, iTrans);
#if MF_EXPANSIONTYPE != MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
    // If this transitions has been expanded
    if (MFTransitionIsExpanded(trans)) {
#endif
        // Get the value of the transition from the point of view of
        // the sente
        float val = MFTransitionGetValue(trans, sente);
        // If it's the first considered transition
        if (bestTrans == NULL) {
            // Init the best value with the value of this transition
            valBestTrans = val;
            // Init the best transition
            bestTrans = trans;
        }
        // Else if the value is better
        else if (valBestTrans < val) {
            // Update the best transition
            valBestTrans = val;
            bestTrans = trans;
        }
    }
}
#if MF_EXPANSIONTYPE != MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
}
#endif
// Return the best transition
return (const MFModelTransition*)bestTrans;
}

// Update backward the forecast values 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 by putting
// visited world in the set 'setWorld'
void MFUpdateForecastValues(MiniFrame* const that,
    const MFWorld* const world, int delayPenalty,
    GSet* const updatedWorld) {
#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
#if MF_REUSEWORLD == true
    if (updatedWorld == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
    }
}

```



```

        sprintf(MiniFrameErr->_msg, "'updatedWorld' is null");
        PBErrCatch(MiniFrameErr);
    }
#endif
#endif
    // If the world has not been updated yet and has ancestor
    if (GSetNbElem(MFWorldSources(world)) > 0
#if MF_REUSEWORLD == true
        && GSetFirstElem(updatedWorld, world) == NULL
#endif
    ) {
#if MF_REUSEWORLD == true
        GSetAppend(updatedWorld, (void*)world);
#endif
        // Get the sente of the world
        int sente = MFModelStatusGetSente(MFWorldStatus(world));
        // Search the best transition of the world
        MFTransition* bestTrans =
            (MFTransition*)MFWorldBestTransition(world, sente);
        // Declare a variable to memorize the updated forecast values
        float updatedForecastValues[MF_NBMAXACTOR] = {0.0};
        // Declare a pointer toward the forecast values
        float* forecastValues = NULL;
        if (bestTrans == NULL)
            forecastValues = ((MFWorld*)world)->_values;
        else
            forecastValues = bestTrans->_values;
        // Calculate the updated forecast values
        for (int iActor = MF_NBMAXACTOR; iActor--;)
            updatedForecastValues[iActor] =
                forecastValues[iActor] - (float)delayPenalty * PBMATH_EPSILON;
        // For each transition to the world
        GSetIterForward iter =
            GSetIterForwardCreateStatic(MFWorldSources(world));
        do {
            // Get the transition
            MFTransition* const trans = GSetIterGet(&iter);
            // Update the values of the transition
            bool updated =
                MFTransitionUpdateValues(trans, updatedForecastValues);
            // If the values has been modified
            if (updated) {
                // Update recursively the source of the transition
                MFUpdateForecastValues(that, MFTransitionFromWorld(trans),
                    delayPenalty + 1, updatedWorld);
            }
        } while (GSetIterStep(&iter));
#if MF_REUSEWORLD == true
        // Remove the world for the set of visited world to allow
        // another path to reupdate it later
        GSetRemoveFirst(updatedWorld, (void*)world);
#endif
    }
}

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

```

```

        PBErriCatch(MiniFrameErr);
    }
    if (val == NULL) {
        MiniFrameErr->_type = PBErriTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'val' is null");
        PBErriCatch(MiniFrameErr);
    }
#endif
    // Declare a variable to memorize the returned flag
    bool updated = false;
    // Update values
    float* const thatValues = that->_values;
    for (int iActor = MF_NBMAXACTOR; iActor--;) {
        // If the new value is different from the current one
        if (!ISEQUALF(thatValues[iActor], val[iActor])) {
            thatValues[iActor] = val[iActor];
            updated = true;
        }
    }
    // 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 = PBErriTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PBErriCatch(MiniFrameErr);
        }
        if (stream == NULL) {
            MiniFrameErr->_type = PBErriTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'stream' is null");
            PBErriCatch(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 = PBErriTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");

```

```

        PBErCatch(MiniFrameErr);
    }
    if (stream == NULL) {
        MiniFrameErr->_type = PBErTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'stream' is null");
        PBErCatch(MiniFrameErr);
    }
#endif
    fprintf(stream, "transition from (");
    if (MFTransitionFromWorld(that) != NULL)
        MFModelStatePrint(
            MFWorldStatus(MFTransitionFromWorld(that)), stream);
    else
        fprintf(stream, "<null>");
    fprintf(stream, ") to (");
    if (MFTransitionToWorld(that) != NULL)
        MFModelStatePrint(
            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, "]\n");
}

// 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 = PBErTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErCatch(MiniFrameErr);
    }
    if (stream == NULL) {
        MiniFrameErr->_type = PBErTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'stream' is null");
        PBErCatch(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
// MFModelState 'status'
// If the world is in computed worlds reuse it, else create a new one
void MFSetCurWorld(MiniFrame* const that,
    const MFModelState* 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
#if MF_EXPANSIONTYPE != MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
    // Declare a flag to memorize if we have found the world
    bool flagFound = false;
    // If there are computed worlds
    if (MFGetNbComputedWorlds(that) > 0) {
        // Flag to manage removal of worlds from sets
        bool moved = false;
        // Loop on computed worlds
        GSetIterForward iter = GSetIterForwardCreateStatic(MFWorldsComputed(that));
        do {
            moved = false;
            MFWorld* world = GSetIterGet(&iter);
            // If this is the current world
            if (!flagFound &&
                MFModelStateIsSame(MFWorldStatus(world), status)) {
                // Ensure that the status is exactly the same by copying the
                // MFModelState struct, in case MFModelStateIsSame refers only
                // to a subset of properties of the MFModelState
                memcpy(world, status, sizeof(MFModelState));
                // Update the curWorld in MiniFrame
                that->_curWorld = world;
                flagFound = true;
            }
            // Else if this world is disposable
        } else if (world != MFCurWorld(that) &&
            (GSetNbElem(MFWorldSources(world)) == 0 ||
            MFModelStateIsDisposable(MFWorldStatus(world),
            MFWorldStatus(MFCurWorld(that)))) {
                // Remove it from the set of computed worlds
                moved = GSetIterRemoveElem(&iter);
                // Free this world
                MFWorldFree(&world);
            }
        } while (moved || GSetIterStep(&iter));
    }
    // If we haven't found the searched status
    if (!flagFound) {
        // If there are worlds to expand
        if (MFGetNbWorldsToExpand(that) > 0) {
            // Loop on worlds to expand
            GSetIterForward iter =
                GSetIterForwardCreateStatic(MFWorldsToExpand(that));
            do {
                MFWorld* world = GSetIterGet(&iter);
                // If this is the current world
                if (MFModelStateIsSame(MFWorldStatus(world), status)) {
                    // Ensure that the status is exactly the same by copying the
                    // MFModelState struct, in case MFModelStateIsSame refers only
                    // to a subset of properties of the MFModelState
                    memcpy(world, status, sizeof(MFModelState));
                    // Update the curWorld in MiniFrame
                    that->_curWorld = world;
                    flagFound = true;
                }
            } while (GSetIterStep(&iter));
        }
    }
}

```

```

        // Put the current world at the end of the worlds to expand
        // to be sure it will be the first expanded
        bool moved = GSetIterForwardRemoveElem(&iter);
        (void)moved;
        GSetAppend((GSet*)MFWorldsToExpand(that), world);
    }
    } while (!flagFound && GSetIterStep(&iter));
}
}
// If we haven't found the searched status
if (!flagFound) {
#ifdef MF_USETELEMETRY
    ++(that->_nbWorldNotFound);
#endif
    // Create a new MFWorld with the current status
    MFWorld* world = MFWorldCreate(status);
    // Set the depth of the new world to the depth of the current world
#ifdef MF_SIMULTANEOUS_PLAY
    world->_depth = that->_curWorld->_depth + 1;
#else
    world->_depth = that->_curWorld->_depth +
        MFModelStateGetNbActor(status);
#endif
    // Update the current world
    that->_curWorld = world;
    #if MF_REUSEWORLD == false
    // Flush all the worlds
    while(MFGetNbComputedWorlds(that) > 0) {
        world = GSetPop((GSet*)MFWorldsComputed(that));
        MFWorldFree(&world);
    }
    while(MFGetNbWorldsToExpand(that) > 0) {
        world = GSetPop((GSet*)MFWorldsToExpand(that));
        MFWorldFree(&world);
    }
    #endif
    // Add it to the worlds to expand
    GSetAppend((GSet*)MFWorldsToExpand(that), that->_curWorld);
}
#else
    // Update the current world with the status
    *(that->_curWorld) = MFWorldCreateStatic(status);
#endif
}

// Remove the MFTransition 'source' from the sources of the
// MFWorld 'that'
void MFWorldRemoveSource(MFWorld* const that,
    const MFTransition* const source) {
#ifdef 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
    // If the world has sources

```

```

    if (GSetNbElem(MFWorldSources(that)) > 0) {
        bool removed = false;
        // Loop on transitions
        GSetIterForward iter =
            GSetIterForwardCreateStatic(MFWorldSources(that));
        do {
            removed = false;
            MFTransition* trans = GSetIterGet(&iter);
            // If it's the transition to be removed
            if (trans == source) {
                removed = GSetIterRemoveElem(&iter);
            }
        } while (removed || GSetIterStep(&iter));
    }
}

// Pop a MFTransition from the sources of the MFWorld 'that'
#ifdef BUILDMODE != 0
inline
#endif
MFTransition* MFWorldPopSource(MFWorld* const that) {
#ifdef 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) {
#ifdef 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 (!MFModelStateIsEnd(MFWorldStatus(curWorld))) {
    // Get the sente for the current world
    int sente = MFModelStateGetSente(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 {
        // 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) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (values == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'values' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    float* thatValues = that->_values;
    for (int iActor = MF_NBMAXACTOR; iActor--;) {
        thatValues[iActor] = values[iActor];
    }
}
}

```

```

// Get the number of expandable transition for the MFWorld 'that'
int MFWorldGetNbTransExpandable(const MFWorld* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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;
}

// Add the MFWorld 'world' to the world to be expanded of the
// MiniFrame 'that'
void MFAddWorldToExpand(MiniFrame* const that, \
    const MFWorld* const world) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (world == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'world' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    #endif
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYVALUE
        GSetAddSort(&(that->_worldsToExpand), (MFWorld*)world,
            MFWorldGetValue(world,
                MFModelStateGetSente(MFWorldStatus(world))));
    #endif
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYWIDTH
        GSetPush(&(that->_worldsToExpand), (MFWorld*)world);
    #endif
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_BYDEPTH_RANDOMWALK
        if (that->_expByDepthAppendPos == 0)
            GSetAppend(&(that->_worldsToExpand), (MFWorld*)world);
        else
            GSetPush(&(that->_worldsToExpand), (MFWorld*)world);
    #endif
    #if MF_EXPANSIONTYPE == MF_EXPANSIONTYPE_MONTECARLOTREESEARCH
        (void)that; (void)world;
    #endif
}

```


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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    return that->_timeUnusedExpansion;
}

// Get the nb of world To expande of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbWorldsToExpand(const MiniFrame* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    return GSetNbElem(MFWorldsToExpand(that));
}

// 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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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* MFWorldsComputed(const MiniFrame* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
#endif
}

```

```

    }
#endif
    return &(that->_worldsComputed);
}

// Get the GSet of worlds to expand of the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
const GSet* MFWorldsToExpand(const MiniFrame* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    return &(that->_worldsToExpand);
}

// Add the MFWorld 'world' to the computed MFWorlds of the
// MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
void MFAddWorldToComputed(MiniFrame* const that, const MFWorld* const world) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (world == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'world' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    GSetAppend((GSet*)MFWorldsComputed(that), world);
}

// Return the MFModelState of the MFWorld 'that'
#if BUILDMODE != 0
inline
#endif
const MFModelState* MFWorldStatus(const MFWorld* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    return (const MFModelState*)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 MFGetPercWorldReused(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;
        }
    #endif
}

```

```

        sprintf(MiniFrameErr->_msg, "'iTrans' is invalid (0<=%d<%d)",
            iTrans, that->_nbTransition);
        PBErrCatch(MiniFrameErr);
    }
#endif
    // Return the resulting MFModelState
    MFModelState res = MFModelStateStepEnd(MFWorldStatus(that));
    res = MFModelStateStep(&res,
        (const MFModelTransition* const)MFWorldTransition(that, iTrans));
    return MFModelStateStepInit(&res);
}

// 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;
}

#if MF_REUSEWORLD
// Set the flag 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;
}
#endif

// 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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
        MiniFrameErr->_type = PErrTypeInvalidArg;
        sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<%d)",
            iActor, MF_NBMAXACTOR);
        PErrCatch(MiniFrameErr);
    }
#endif
    that->_values[iActor] = val;
}

// Return the number of computed worlds in the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
int MFGetNbComputedWorlds(const MiniFrame* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
    }
#endif
}

```

```

        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
#endif
    return GSetNbElem(MFWorldsComputed(that));
}

// 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);
        }
    )
    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);
        }
    )
    return that->_maxDepthExp;
}

#if MF_LIMITDEPTH
// Set the max depth during expansion for the MiniFrame 'that' to 'depth'
// If depth is less than -1 it is converted to -1
// If the expansion type is not by width the max expansion depth is
// ignored during expansion
#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);
        }
    )
    that->_maxDepthExp = MAX(-1, depth);
}
#endif

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

```



```

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

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

#if MF_USEPRUNING
// Set the pruning threshold during expansion for the MiniFrame 'that'
// to 'val'
#if BUILDMODE != 0
inline
#endif
void MFSetPruningDeltaVal(MiniFrame* const that, const float val) {
    if (that == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
    #endif
    that->_pruningDeltaVal = val;
}
#endif

// Get the pruning threshold during expansion for the MiniFrame 'that'
#if BUILDMODE != 0
inline
#endif
float MFGetPruningDeltaVal(const MiniFrame* const that) {
    if (that == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
    #endif
    return that->_pruningDeltaVal;
}

// Get the nb of worlds not found during MFSetCurWorld
#if BUILDMODE != 0
inline

```

```

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

// Get the max depth reached during last call of MFExpand
#if BUILDMODE != 0
inline
#endif
int MFGetMaxDepthExpReached(const MiniFrame* const that) {
#if BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PBErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PBErrCatch(MiniFrameErr);
    }
#endif
    return that->_maxDepthExpReached;
}

```

3 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: pbmake_wget main

# Automatic installation of the repository PBMake in the parent folder
pbmake_wget:
if [ ! -d ../PBMake ]; then wget https://github.com/BayashiPascal/PBMake/archive/master.zip; unzip master.zip; rm -f

# 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-in-

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 = {._step = 0, ._pos = 0, ._tgt = 1};
    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 = {._step = 0, ._pos = 0, ._tgt = 1};
    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() {
    MFModelState 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() {
    MFModelState 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() {
    MFModelState modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
    MFWorld* world = MFWorldCreate(&modelWorld);
    MFModelState statusA = {._step = 1, ._pos = -1, ._tgt = 1};
    MFModelState statusB = {._step = 1, ._pos = 0, ._tgt = 1};
    MFModelState statusC = {._step = 1, ._pos = 1, ._tgt = 1};
    MFModelState status = MFWorldComputeTransition(world, 0);
    if (memcmp(&status, &statusA, sizeof(MFModelState)) != 0) {
        MiniFrameErr->_type = PBErrTypeUnitTestFailed;
        sprintf(MiniFrameErr->_msg, "MFWorldComputeTransition failed");
        PBErrCatch(MiniFrameErr);
    }
    status = MFWorldComputeTransition(world, 1);
    if (memcmp(&status, &statusB, sizeof(MFModelState)) != 0) {
        MiniFrameErr->_type = PBErrTypeUnitTestFailed;
        sprintf(MiniFrameErr->_msg, "MFWorldComputeTransition failed");
        PBErrCatch(MiniFrameErr);
    }
    status = MFWorldComputeTransition(world, 2);
    if (memcmp(&status, &statusC, sizeof(MFModelState)) != 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() {
    MFModelState initStatus = {._step = 0, ._pos = 0, ._tgt = 1};
    MiniFrame* mf = MiniFrameCreate(&initStatus);
    if (mf == NULL ||
        mf->_nbStep != 0 ||
        ISEQUALF(mf->_maxTimeExpansion, MF_DEFAULTTIMEEXPANSION) == false ||
        MFModelStateIsSame(&initStatus, &(MFCurWorld(mf)->_status)) == false ||
        GSetNbElem(MFWorldsToExpand(mf)) != 1 ||
        MFCurWorld(mf) != GSetGet(MFWorldsToExpand(mf), 0) ||
        ISEQUALF(mf->_timeUnusedExpansion, 0.0) == false ||
        ISEQUALF(mf->_percWorldReused, 0.0) == false ||
        mf->_maxDepthExp != MF_DEFAULTMAXDEPTHEXP ||
        mf->_pruningDeltaVal != MF_PRUNINGDELTAVAL ||
        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() {
    MFModelState 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);
    }
    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 (MFCurWorld(mf) != mf->_curWorld) {
        MiniFrameErr->_type = PBErrTypeUnitTestFailed;
        sprintf(MiniFrameErr->_msg, "MFCurWorld failed");
    }
}

```

```

    PBErriCatch(MiniFrameErr);
}
if (MFWorldsComputed(mf) != &(mf->_worldsComputed)) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorlds failed");
    PBErriCatch(MiniFrameErr);
}
if (MFIsWorldReusable(mf) != mf->_reuseWorld) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFIsWorldReusable failed");
    PBErriCatch(MiniFrameErr);
}
bool reuse = !MFIsWorldReusable(mf);
MFSetWorldReusable(mf, reuse);
if (MFIsWorldReusable(mf) != reuse) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetWorldReusable failed");
    PBErriCatch(MiniFrameErr);
}
mf->_percWorldReused = 1.0;
if (ISEQUALF(MFGetPercWorldReused(mf), 1.0) == false) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetPercWorldReused failed");
    PBErriCatch(MiniFrameErr);
}
MFModelStatus modelWorld = {._step = 0, ._pos = 0, ._tgt = 1};
MFWorld* world = MFWorldCreate(&modelWorld);
MFAddWorldToComputed(mf, world);
if (GSetNbElem(MFWorldsComputed(mf)) != 1 ||
    MFModelStatusIsSame(MFWorldStatus(world),
        (MFModelStatus*)GSetGet(MFWorldsComputed(mf), 0)) == false) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFAddWorldToComputed failed");
    PBErriCatch(MiniFrameErr);
}
MFWorld* worldToExpand = MFWorldCreate(&modelWorld);
MFAddWorldToExpand(mf, worldToExpand);
if (GSetNbElem(MFWorldsToExpand(mf)) != 2) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFAddWorldToExpand failed");
    PBErriCatch(MiniFrameErr);
}
mf->_timeUnusedExpansion = 3.0;
if (ISEQUALF(MFGetTimeUnusedExpansion(mf),
    mf->_timeUnusedExpansion) == false) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetTimeUnusedExpansion failed");
    PBErriCatch(MiniFrameErr);
}
mf->_percWorldReused = 4.0;
if (ISEQUALF(MFGetPercWorldReused(mf),
    mf->_percWorldReused) == false) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetPercWorldReused failed");
    PBErriCatch(MiniFrameErr);
}
clock_t now = clock();
MFSetStartExpandClock(mf, now);
if (mf->_startExpandClock != now) {
    MiniFrameErr->_type = PBErriTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetStartExpandClock failed");
    PBErriCatch(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 (MFGetPruningDeltaVal(mf) != mf->_pruningDeltaVal) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetPruningDeltaVal failed");
    PBErrCatch(MiniFrameErr);
}
MFSetPruningDeltaVal(mf, 10.0);
if (!ISEQUALF(MFGetPruningDeltaVal(mf), 10.0)) {
    MiniFrameErr->_type = PBErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetPruningDeltaVal failed");
    PBErrCatch(MiniFrameErr);
}
MiniFrameFree(&mf);
printf("UnitTestMiniFrameGetSet OK\n");
}

void UnitTestMiniFrameExpandSetCurWorld() {
    MFModelState 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("Nb computed worlds: %d\n", MFGetNbComputedWorlds(mf));
    printf("Nb worlds to expand: %d\n", MFGetNbWorldsToExpand(mf));
    printf("Perc world reused: %f\n", MFGetPercWorldReused(mf));
    printf("Computed worlds:\n");
    GSetIterForward iter =
        GSetIterForwardCreateStatic(MFWorldsComputed(mf));
    do {
        MFWorld* world = GSetIterGet(&iter);
        MFWorldTransPrintln(world, stdout);
    } while (GSetIterStep(&iter));
    if (mf->_timeUnusedExpansion < 0.0 ||
        MFGetNbComputedWorlds(mf) != 13 ||
        MFGetNbWorldsToExpand(mf) != 0 ||
        ISEQUALF(MFGetPercWorldReused(mf), 0.666667) == 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 = PErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFGetBestTransition failed");
    PErrCatch(MiniFrameErr);
}
if (ISEQUALF(MFWorldGetForecastValue(MFCurWorld(mf), 0), 0.0) == false) {
    MiniFrameErr->_type = PErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetPOVValue failed");
    PErrCatch(MiniFrameErr);
}
if (ISEQUALF(
    MFWorldGetForecastValue(MFCurWorld(mf), 0), 0.0) == false) {
    MiniFrameErr->_type = PErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFWorldGetForecastValue failed");
    PErrCatch(MiniFrameErr);
}
MFModelState nextWorld = {._pos = -1, ._tgt = 2};
MFSetCurWorld(mf, &nextWorld);
if (MFCurWorld(mf) != GSetGet(MFWorldsComputed(mf), 1)) {
    MiniFrameErr->_type = PErrTypeUnitTestFailed;
    sprintf(MiniFrameErr->_msg, "MFSetCurWorld failed");
    PErrCatch(MiniFrameErr);
}
MiniFrameFree(&mf);
printf("UnitTestMiniFrameExpandSetCurWorld OK\n");
}

void UnitTestMiniFrameFullExample() {
    // Initial world
    MFModelState curWorld = {._step = 0, ._pos = 0, ._tgt = 2};
    // Create the MiniFrame
    MiniFrame* mf = MiniFrameCreate(&curWorld);
    MFSetWorldReusable(mf, false);
    // Loop until end of game
    int tgt[7] = {2,2,-1,-1,-1,-1,-1};
    while (!MFModelStateIsEnd(&curWorld)) {
        // Set the start clock
        MFSetStartExpandClock(mf, clock());
        // Correct the current world in the MiniFrame
        MFSetCurWorld(mf, &curWorld);
        // Expand
        MFExpand(mf);
        // Display the current world
        printf("mf(");
        MFModelStatePrint(MFWorldStatus(MFCurWorld(mf)), stdout);
        printf(") real(");
        MFModelStatePrint(&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");
        // Get best transition
        const MFModelTransition* bestTrans = MFBestTransition(mf, 0);
        if (bestTrans != NULL) {
            // Step with best transition
            curWorld = MFModelStateStep(&curWorld, bestTrans);
        }
    }
}

```

```

        // Apply external forces to the world
        curWorld._tgt = tgt[curWorld._step];
    }
    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: 99.960999
Nb computed worlds: 13
Nb worlds to expand: 0
Perc world reused: 0.666667
Computed worlds:
(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[-0.000010]
  1) transition from (step:0 pos:0 tgt:2) to (step:1 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[-3.000000] forecast[-0.000000]
  0) transition from (step:1 pos:-1 tgt:2) to (step:2 pos:-2 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:1 pos:-1 tgt:2) to (step:2 pos:-1 tgt:2) through (move:0) values[-0.000000]
  2) transition from (step:1 pos:-1 tgt:2) to (step:0 pos:0 tgt:2) through (move:1) values[-0.000010]
(step:1 pos:0 tgt:2) values[-2.000000] forecast[-0.000000]
  0) transition from (step:1 pos:0 tgt:2) to (step:1 pos:-1 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:1 pos:0 tgt:2) to (step:0 pos:0 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:1 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:2 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[-4.000000] forecast[-0.000000]
  0) transition from (step:2 pos:-2 tgt:2) to (step:3 pos:-3 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:2 pos:-2 tgt:2) to (step:3 pos:-2 tgt:2) through (move:0) values[-0.000000]
  2) transition from (step:2 pos:-2 tgt:2) to (step:1 pos:-1 tgt:2) through (move:1) values[-0.000010]
(step:2 pos:-1 tgt:2) values[-3.000000] forecast[-0.000010]
  0) transition from (step:2 pos:-1 tgt:2) to (step:2 pos:-2 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:2 pos:-1 tgt:2) to (step:1 pos:-1 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:2 pos:-1 tgt:2) to (step:0 pos:0 tgt:2) through (move:1) values[-0.000020]
(step:2 pos:1 tgt:2) values[-1.000000] forecast[-0.000000]
  0) transition from (step:2 pos:1 tgt:2) to (step:0 pos:0 tgt:2) through (move:-1) values[-0.000000]
  1) transition from (step:2 pos:1 tgt:2) to (step:1 pos:1 tgt:2) through (move:0) values[-0.000000]
  2) transition from (step:2 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]
(step:3 pos:-3 tgt:2) values[-5.000000] forecast[-0.000000]
  0) transition from (step:3 pos:-3 tgt:2) to (step:4 pos:-4 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:3 pos:-3 tgt:2) to (step:4 pos:-3 tgt:2) through (move:0) values[-0.000000]
  2) transition from (step:3 pos:-3 tgt:2) to (step:2 pos:-2 tgt:2) through (move:1) values[-0.000010]
(step:3 pos:-2 tgt:2) values[-4.000000] forecast[-0.000000]
  0) transition from (step:3 pos:-2 tgt:2) to (step:3 pos:-3 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:3 pos:-2 tgt:2) to (step:2 pos:-2 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:3 pos:-2 tgt:2) to (step:1 pos:-1 tgt:2) through (move:1) values[-0.000000]
(step:4 pos:-4 tgt:2) values[-6.000000] forecast[-0.000000]
  0) transition from (step:4 pos:-4 tgt:2) to (step:5 pos:-4 tgt:2) through (move:-1) values[-0.000000]
  1) transition from (step:4 pos:-4 tgt:2) to (step:5 pos:-3 tgt:2) through (move:0) values[-0.000000]
  2) transition from (step:4 pos:-4 tgt:2) to (step:3 pos:-3 tgt:2) through (move:1) values[-0.000010]
(step:4 pos:-3 tgt:2) values[-5.000000] forecast[-0.000000]
  0) transition from (step:4 pos:-3 tgt:2) to (step:4 pos:-4 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:4 pos:-3 tgt:2) to (step:3 pos:-3 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:4 pos:-3 tgt:2) to (step:2 pos:-2 tgt:2) through (move:1) values[-0.000000]
(step:5 pos:-4 tgt:2) values[-6.000000] forecast[-0.000000]
  0) transition from (step:5 pos:-4 tgt:2) to (step:4 pos:-4 tgt:2) through (move:-1) values[-0.000010]
  1) transition from (step:5 pos:-4 tgt:2) to (step:4 pos:-3 tgt:2) through (move:0) values[-0.000010]
  2) transition from (step:5 pos:-4 tgt:2) to (step:3 pos:-3 tgt:2) through (move:1) values[-0.000000]
Best action: 1
UnitTestMiniFrameExpandSetCurWorld OK
mf(step:0 pos:0 tgt:2) real(step:0 pos:0 tgt:2)
(step:0 pos:0 tgt:2) values[-2.000000] forecast[-2.000000]
  0) transition from (step:0 pos:0 tgt:2) to (<null>) through (move:-1) values[0.000000]
  1) transition from (step:0 pos:0 tgt:2) to (<null>) through (move:0) values[0.000000]
  2) transition from (step:0 pos:0 tgt:2) to (<null>) through (move:1) values[0.000000]
mf(step:1 pos:1 tgt:2) real(step:1 pos:1 tgt:2)
(step:1 pos:1 tgt:2) values[-1.000000] forecast[-0.000000]
  0) transition from (step:1 pos:1 tgt:2) to (step:2 pos:0 tgt:2) through (move:-1) values[-0.000150]
  1) transition from (step:1 pos:1 tgt:2) to (step:2 pos:1 tgt:2) through (move:0) values[-0.000070]
  2) transition from (step:1 pos:1 tgt:2) to (step:2 pos:2 tgt:2) through (move:1) values[-0.000000]
mf(step:2 pos:2 tgt:-1) real(step:2 pos:2 tgt:-1)
(step:2 pos:2 tgt:-1) values[-3.000000] forecast[-3.000000]
  0) transition from (step:2 pos:2 tgt:-1) to (<null>) through (move:-1) values[0.000000]
  1) transition from (step:2 pos:2 tgt:-1) to (<null>) through (move:0) values[0.000000]
  2) transition from (step:2 pos:2 tgt:-1) to (<null>) through (move:1) values[0.000000]
mf(step:3 pos:1 tgt:-1) real(step:3 pos:1 tgt:-1)
(step:3 pos:1 tgt:-1) values[-2.000000] forecast[-0.000000]
  0) transition from (step:3 pos:1 tgt:-1) to (step:4 pos:0 tgt:-1) through (move:-1) values[-0.000000]
  1) transition from (step:3 pos:1 tgt:-1) to (step:4 pos:1 tgt:-1) through (move:0) values[-0.000050]
  2) transition from (step:3 pos:1 tgt:-1) to (step:4 pos:2 tgt:-1) through (move:1) values[-0.000070]
mf(step:4 pos:0 tgt:-1) real(step:4 pos:0 tgt:-1)
(step:4 pos:0 tgt:-1) values[-1.000000] forecast[-0.000000]
  0) transition from (step:4 pos:0 tgt:-1) to (step:5 pos:-1 tgt:-1) through (move:-1) values[-0.000000]

```

```

    1) transition from (step:4 pos:0 tgt:-1) to (<null>) through (move:0) values[0.000000]
    2) transition from (step:4 pos:0 tgt:-1) to (<null>) through (move:1) values[0.000000]
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
// MFModelState to another
typedef struct MFModelTransition {
    int _move;
} MFModelTransition;

// Structure describing the status of the world at one instant
typedef struct MFModelState {
    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);

// Preprocess of one turn of the game
// Return the game as it is if nothing to do

```

```

MFModelState MFModelStateStepInit(const MFModelState* const that);

// Postprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelState MFModelStateStepEnd(const MFModelState* const that);

// Print the MFModelState 'that' on the stream 'stream'
void MFModelStatePrint(const MFModelState* 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 should
// 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 MFModelStateIsDisposable(const MFModelState* const that,
    const MFModelState* const curStatus);

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

// Init the board
void MFModelStateInit(MFModelState* 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 MFModelStateGetNbActor(const MFModelState* const that) {
    (void)that;
    return MF_NBMAXACTOR;
}

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

// Free memory used by the properties of the MFModelState 'that'
// The memory used by the MFModelState itself is managed by MiniFrame
void MFModelStateFreeStatic(MFModelState* 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 MFModelStateIsSame(const MFModelState* const that,
    const MFModelState* 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
}

```



```

#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) {
#ifdef 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) {
#ifdef 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) {
#ifdef 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);
    }
#endif
}

```

```

    }
    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) {
#ifdef 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) {
#ifdef 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 = 4;
    if (status._pos < -limit) status._pos = -limit;

```

```

    if (status._pos > limit) status._pos = limit;
    // Return the status
    return status;
}

// Preprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelState MFModelStateStepInit(const MFModelState* const that) {
    return *that;
}

// Postprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelState MFModelStateStepEnd(const MFModelState* const that) {
    return *that;
}

// Print the MFModelState 'that' on the stream 'stream'
void MFModelStatePrint(const MFModelState* 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 should
// 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 MFModelStateIsDisposable(const MFModelState* const that,

```

```

    const MFModelState* const curStatus) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (curStatus == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'curStatus' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    if (abs(that->_pos - curStatus->_pos) > 4)
        return true;
    else
        return false;
}

// Return true if the MFModelState 'that' is the end of the
// game/simulation, else false
bool MFModelStateIsEnd(const MFModelState* const that) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
#endif
    if (that->_step >= 7 || that->_pos == that->_tgt) {
        return true;
    } else {
        return false;
    }
}
}

```

6.1.3 miniframe-inline-model.c

```

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

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

#ifdef 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
// MFModelState 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 MFModelState {
    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];
} MFModelState;

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

// Get the number of active actors
int MFModelStateGetNbActor(const MFModelState* 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);

// Preprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelStatus MFModelStatusStepInit(const MFModelStatus* const that);

// Postprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelStatus MFModelStatusStepEnd(const MFModelStatus* const that);

// 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 should
// 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);

// 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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (iActor < 0 || iActor >= MF_NBMAXACTOR) {
        MiniFrameErr->_type = PErrTypeInvalidArg;
        sprintf(MiniFrameErr->_msg, "'iActor' is invalid (0<=%d<=%d)", \
            iActor, MF_NBMAXACTOR);
        PErrCatch(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 = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(MiniFrameErr);
    }
    if (transitions == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'transitions' is null");
        PErrCatch(MiniFrameErr);
    }
    if (nbTrans == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'nbTrans' is null");
        PErrCatch(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 MFModelState '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 MFModelStateGetValues(const MFModelState* const that,
    float* const values) {
    #if BUILDMODE == 0
        if (that == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(MiniFrameErr);
        }
        if (values == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'values' is null");
            PErrCatch(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 MFModelState resulting from applying the
// MFModelTransition 'trans' to the MFModelState 'that'
MFModelState MFModelStateStep(const MFModelState* const that,
    const MFModelTransition* const trans) {
    #if BUILDMODE == 0
        if (that == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(MiniFrameErr);
        }
    #endif
}

```

```

if (trans == NULL) {
    MiniFrameErr->_type = PBErrTypeNullPointer;
    sprintf(MiniFrameErr->_msg, "'trans' is null");
    PBErrCatch(MiniFrameErr);
}
#endif
// Declare a variable to memorize the resulting status
MFModelState status;
// Apply the transition

MFModelStateCopy(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 loses.
        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;
}

// Preprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelState MFModelStateStepInit(const MFModelState* const that) {
    return *that;
}

// Postprocess of one turn of the game
// Return the game as it is if nothing to do
MFModelState MFModelStateStepEnd(const MFModelState* const that) {
    return *that;
}

// Print the MFModelState 'that' on the stream 'stream'
void MFModelStatePrint(const MFModelState* const that,
    FILE* const stream) {
    #if BUILDMODE == 0
        if (that == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(MiniFrameErr);
        }
        if (stream == NULL) {
            MiniFrameErr->_type = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'stream' is null");
            PErrCatch(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 == MFModelStateGetSente(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 = PErrTypeNullPointer;
            sprintf(MiniFrameErr->_msg, "'that' is null");
            PErrCatch(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 should
// 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 MFModelStateIsDisposable(const MFModelState* const that,
    const MFModelState* const curStatus) {
    #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
    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 MFModelState 'that' is the end of the
// game/simulation, else false
bool MFModelStateIsEnd(const MFModelState* 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) {
#ifdef BUILDMODE == 0
    if (that == NULL) {
        MiniFrameErr->_type = PErrTypeNullPointer;
        sprintf(MiniFrameErr->_msg, "'that' is null");
        PErrCatch(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 =====

#ifdef 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);
        // Display info
        printf("computed: %d, ", MFGetNbComputedWorlds(mf));
        printf("to expand: %d, ", MFGetNbWorldsToExpand(mf));
        printf("reused: %f, ", MFGetPercWorldReused(mf));
        printf("unused: %fms\n", MFGetTimeUnusedExpansion(mf));
        // 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");*/
        if (MFGetTimeUnusedExpansion(mf) < -2.0) {
            fprintf(stderr, "time out: %f !!\n", MFGetTimeUnusedExpansion(mf));
            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) < -2.0) {
        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();
// 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);
ELORankSetIsMilestone(eloRank, (GenAlgAdn*)GABestAdn(genAlg), true);
ELORankSetIsMilestone(eloRank, (void*)1, true);
// Declare a variable to memorize the current epoch
int iEpoch = 0;
// Loop on epochs
while (iEpoch < nbEpoch) {
    // Declare a variable to memorize the current game
    int iGame = 0;
    // Loop on games
    while (iGame < nbGameEpoch) {
        // Display some info
        float eloPretender = 0.0;
        float eloSoftPretender = 0.0;
        long int idPretender = 0;
        float eloBest = 0.0;
        float eloSoftBest = 0.0;
        long int idBest = 0;
        int iBest = 0;
        int iPretender = 1;
        if (ELORankGetRanked(eloRank, iBest)->_data == (void*)1) {
            ++iBest;
            ++iPretender;
        }
        if (ELORankGetRanked(eloRank, iPretender)->_data == (void*)1) {
            ++iPretender;
        }
        eloBest = ELORankGetELO(eloRank,
            ELORankGetRanked(eloRank, iBest)->_data);
        eloSoftBest = ELORankGetSoftELO(eloRank,
            ELORankGetRanked(eloRank, iBest)->_data);
        idBest = GAAdnGetId(ELORankGetRanked(eloRank, iBest)->_data);
        eloPretender = ELORankGetELO(eloRank,
            ELORankGetRanked(eloRank, iPretender)->_data);
        eloSoftPretender = ELORankGetSoftELO(eloRank,
            ELORankGetRanked(eloRank, iPretender)->_data);
        idPretender = GAAdnGetId(ELORankGetRanked(eloRank,
            iPretender)->_data);
        fprintf(stderr, "Epoch %05d/%05d Game %03d/%03d (bestelo(%ld) %f[%f], pretender(%ld) %f[%f]) \r",
            iEpoch + 1, nbEpoch, iGame + 1, nbGameEpoch, idBest, eloBest, eloSoftBest, idPretender, eloPretender, eloSoftBest);
        fflush(stderr);
        // Select randomly two adns
        GenAlgAdn* adns[NBPLAYER] = {NULL};
        GSet setPlayers = GSetCreateStatic();
        GSetAddSort(&setPlayers, (void*)1, rnd());
        for (int iAdn = sizePool; iAdn--;)
            GSetAddSort(&setPlayers, GSetGet(GAAdns(genAlg), iAdn), rnd());
        while (GSetNbElem(&setPlayers) > 2)
            (void)GSetDrop(&setPlayers);
        adns[0] = GSetGet(&setPlayers, 0);
        adns[1] = GSetGet(&setPlayers, 1);
    }
    iEpoch++;
}

```

```

    GSetFlush(&setPlayers);
    // 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 = ELORankGetSoftELO(eloRank, adn);
    GSetAdnValue(genAlg, adn, elo);
}
// Step the GenAlg
GAStep(genAlg);
// Display the elo of the best of all, best and pretender
GenAlgAdn* bestAdn = (GenAlgAdn*)GABestAdn(genAlg);
float eloSoftBest = GAAdnGetVal(bestAdn);
float eloSoftPretender = 0.0;
float eloSoftBestElo = 0.0;
int iBest = 0;
int iPretender = 1;
if (ELORankGetRanked(eloRank, iBest)->_data == (void*)1) {
    ++iBest;
    ++iPretender;
}
if (ELORankGetRanked(eloRank, iPretender)->_data == (void*)1) {
    ++iPretender;
}
eloSoftBestElo = ELORankGetSoftELO(eloRank,
    ELORankGetRanked(eloRank, iBest)->_data);
eloSoftPretender = ELORankGetSoftELO(eloRank,
    ELORankGetRanked(eloRank, iPretender)->_data);
printf("best(%ld): [%f] (age %ld) bestelo: [%f] pretender: [%f]\n",
    GAAdnGetId(bestAdn), eloSoftBest,
    GAAdnGetAge(bestAdn), eloSoftBestElo, eloSoftPretender);
fflush(stdout);
// Update the milestone (block the best and the ref)
ELORankResetAllMilestone(eloRank);
ELORankSetIsMilestone(eloRank, GAAdn(genAlg, 0), true);
ELORankSetIsMilestone(eloRank, (void*)1, true);
// Save the result
fprintf(streamRes, "%ld %f %f %f\n",
    GAGetCurEpoch(genAlg), eloSoftBest,
    eloSoftBestElo, eloSoftPretender);
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);
// Reset the ELO of the non elite adn
for (int iAdn = 0; iAdn < sizePool; ++iAdn) {
    GenAlgAdn* adn = GSetGet(GAAdns(genAlg), iAdn);
    int rank = ELORankGetRank(eloRank, adn);
    if (rank >= nbElite)
        ELORankResetELO(eloRank, adn);
}
// 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 = nbElite * 4;
    int nbGameEpoch = sizePool * sizePool;
    // 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?=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/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 elorank.o

```

```

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 -n'

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

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

automail:
while true; do tail -n 100 ~/GitHub/MiniFrame/Examples/Oware/res.txt | mail -s "oware" pascalbayashi@docomo.ne.jp; sleep 10; done

trainNN:
main -train -nbEpoch 200 -nbElite 10 -sizePool 50 -nbGameEpoch 1500 -expTime 2.0

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

```

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:

```

main -train -nbEpoch 200 -nbElite 10 -sizePool 50 -nbGameEpoch 1500 -expTime 2.0
Will train with following parameters:
nbEpoch: 200
sizePool: 50
nbElite: 10
nbGameEpoch: 1500
expansionTime: 2.000000ms
Epoch 00001/00200 Game 1500/1500 (bestelo(13) 122.146553[81.111359], pretender(14) 99.085320[59.684116])
best(13): [81.111359](age 1) bestelo: [81.111359] pretender: [59.684115]
Epoch 00002/00200 Game 1500/1500 (bestelo(14) 132.238266[92.006256], pretender(13) 122.146553[100.888786])
best(13): [100.888786](age 2) bestelo: [92.006256] pretender: [100.888789]
Epoch 00003/00200 Game 1500/1500 (bestelo(14) 128.846130[108.057419], pretender(13) 122.146553[110.515205])
best(13): [110.515205](age 3) bestelo: [108.057419] pretender: [110.515205]
Epoch 00004/00200 Game 1500/1500 (bestelo(55) 158.441742[101.968292], pretender(154) 153.004211[89.834274])
best(14): [115.722374](age 4) bestelo: [101.968292] pretender: [90.694162]
Epoch 00005/00200 Game 1500/1500 (bestelo(13) 212.469742[141.901993], pretender(154) 194.512772[130.011948])
best(13): [141.901993](age 5) bestelo: [141.901993] pretender: [130.011943]
Epoch 00006/00200 Game 1500/1500 (bestelo(13) 212.469742[170.625549], pretender(154) 176.528778[152.843689])
best(13): [170.625549](age 6) bestelo: [170.625549] pretender: [152.843682]
Epoch 00007/00200 Game 1500/1500 (bestelo(13) 212.469742[188.151657], pretender(243) 208.470062[136.641449])
best(13): [188.151657](age 7) bestelo: [188.151657] pretender: [136.641455]
Epoch 00008/00200 Game 1500/1500 (bestelo(13) 212.469742[199.297424], pretender(243) 175.513336[165.571426])
best(13): [199.297424](age 8) bestelo: [199.297424] pretender: [165.571426]
Epoch 00009/00200 Game 1500/1500 (bestelo(243) 213.357773[180.427261], pretender(13) 212.469742[205.546875])
best(13): [205.546875](age 9) bestelo: [180.427261] pretender: [205.546875]
Epoch 00010/00200 Game 1500/1500 (bestelo(13) 212.469742[209.009842], pretender(243) 206.147369[196.499161])
best(13): [209.009842](age 10) bestelo: [209.009842] pretender: [196.499160]
Epoch 00011/00200 Game 1500/1500 (bestelo(13) 212.469742[210.459351], pretender(243) 207.487030[197.235703])
best(13): [210.459351](age 11) bestelo: [210.459351] pretender: [197.235703]

```

Epoch 00012/00200 Game 1500/1500 (bestelo(330) 216.395081[159.325104], pretender(13) 212.469742[211.402878])
 best(13): [211.402878](age 12) bestelo: [159.325104] pretender: [211.402871]
 Epoch 00013/00200 Game 1500/1500 (bestelo(13) 212.469742[211.856293], pretender(346) 195.739639[164.121933])
 best(13): [211.856293](age 13) bestelo: [211.856293] pretender: [164.121934]
 Epoch 00014/00200 Game 1500/1500 (bestelo(13) 212.469742[212.169662], pretender(330) 192.361740[178.079391])
 best(13): [212.169662](age 14) bestelo: [212.169662] pretender: [178.079395]
 Epoch 00015/00200 Game 1500/1500 (bestelo(13) 212.469742[212.302612], pretender(243) 188.059555[181.082581])
 best(13): [212.302612](age 15) bestelo: [212.302612] pretender: [181.082578]
 Epoch 00016/00200 Game 1500/1500 (bestelo(13) 212.469742[212.373047], pretender(243) 172.111313[179.831268])
 best(13): [212.373047](age 16) bestelo: [212.373047] pretender: [179.831270]
 Epoch 00017/00200 Game 1500/1500 (bestelo(13) 212.469742[212.417252], pretender(243) 177.903946[179.042343])
 best(13): [212.417252](age 17) bestelo: [212.417252] pretender: [179.042344]
 Epoch 00018/00200 Game 1500/1500 (bestelo(13) 212.469742[212.439926], pretender(243) 212.137985[184.109634])
 best(13): [212.439926](age 18) bestelo: [212.439926] pretender: [184.109629]
 Epoch 00019/00200 Game 1500/1500 (bestelo(13) 212.469742[212.455780], pretender(588) 190.197067[159.970459])
 best(13): [212.455780](age 19) bestelo: [212.455780] pretender: [159.970459]
 Epoch 00020/00200 Game 1500/1500 (bestelo(13) 212.469742[212.461655], pretender(767) 190.128540[102.954498])
 best(13): [212.461655](age 20) bestelo: [212.461655] pretender: [102.954502]
 Epoch 00021/00200 Game 1500/1500 (bestelo(13) 212.469742[212.465729], pretender(767) 173.281555[138.470306])
 best(13): [212.465729](age 21) bestelo: [212.465729] pretender: [138.470313]
 Epoch 00022/00200 Game 1500/1500 (bestelo(13) 212.469742[212.468079], pretender(767) 162.882065[157.949875])
 best(13): [212.468079](age 22) bestelo: [212.468079] pretender: [157.949873]
 Epoch 00023/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469284], pretender(767) 160.066147[154.043991])
 best(13): [212.469284](age 23) bestelo: [212.469284] pretender: [154.043984]
 Epoch 00024/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(850) 159.305618[135.047058])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [135.047051]
 Epoch 00025/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(850) 163.542587[148.359497])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [148.359492]
 Epoch 00026/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(970) 140.878983[103.932953])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [103.932949]
 Epoch 00027/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(767) 168.376816[156.557953])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [156.557959]
 Epoch 00028/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(767) 160.293274[162.335175])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [162.335176]
 Epoch 00029/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1050) 151.816498[115.795792])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [115.795791]
 Epoch 00030/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(767) 174.624161[162.007263])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [162.088184]
 Epoch 00031/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(767) 175.773056[164.110138])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [164.110137]
 Epoch 00032/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1171) 175.312347[134.694519])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [134.694512]
 Epoch 00033/00200 Game 1500/1500 (bestelo(1171) 213.460297[160.059586], pretender(13) 212.469742[212.469727])
 best(13): [212.469727](age 24) bestelo: [160.059586] pretender: [212.469727]
 Epoch 00034/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1171) 180.805161[171.735779])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [171.735781]
 Epoch 00035/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1303) 179.550095[127.008919])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [127.008916]
 Epoch 00036/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1303) 178.595383[151.845703])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [151.845703]
 Epoch 00037/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1303) 175.319733[157.591614])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [157.591611]
 Epoch 00038/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(970) 147.775299[121.016525])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [121.016523]
 Epoch 00039/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1369) 139.033997[134.641968])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [134.641963]
 Epoch 00040/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1538) 151.039322[101.181198])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [101.181201]
 Epoch 00041/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1535) 168.711304[113.761696])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [113.761699]
 Epoch 00042/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 143.278732[104.563934])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [104.563936]

Epoch 00043/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1303) 155.163742[119.594902])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [119.594902]
 Epoch 00044/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 144.583191[121.916214])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [121.916211]
 Epoch 00045/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 136.143341[128.964249])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [128.964248]
 Epoch 00046/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 163.350449[133.744827])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [133.744824]
 Epoch 00047/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 129.967361[138.585617])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [138.585615]
 Epoch 00048/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 116.885513[131.981216])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [131.981211]
 Epoch 00049/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 143.321136[134.531113])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [134.531113]
 Epoch 00050/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1890) 157.214447[98.509590])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [98.509590]
 Epoch 00051/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1890) 127.422508[113.054451])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [113.054453]
 Epoch 00052/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1303) 146.832291[128.515442])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [128.515449]
 Epoch 00053/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 126.790443[126.263489])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [126.263486]
 Epoch 00054/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1883) 163.820618[117.960648])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [117.960645]
 Epoch 00055/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1604) 186.651398[151.566879])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [151.566875]
 Epoch 00056/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1883) 184.797455[143.656555])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [143.656563]
 Epoch 00057/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(1883) 129.223572[147.557785])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [147.557783]
 Epoch 00058/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(2307) 133.546722[74.773773])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [75.897381]
 Epoch 00059/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(2307) 155.578720[113.293015])
 best(13): [212.469727](age 24) bestelo: [212.469727] pretender: [113.293018]
 Epoch 00060/00200 Game 1500/1500 (bestelo(2307) 234.640701[154.071945], pretender(13) 212.469742[212.469727])
 best(13): [212.469727](age 24) bestelo: [154.071945] pretender: [212.469727]
 Epoch 00061/00200 Game 1500/1500 (bestelo(2307) 254.356491[200.947906], pretender(13) 212.469742[212.469727])
 best(13): [212.469727](age 24) bestelo: [200.947906] pretender: [212.469727]
 Epoch 00062/00200 Game 1500/1500 (bestelo(13) 212.469742[212.469727], pretender(2307) 209.752319[204.443832])
 best(13): [212.469727](age 24) bestelo: [204.526291] pretender: [212.469727]
 Epoch 00063/00200 Game 1500/1500 (bestelo(2307) 225.512222[208.331818], pretender(13) 212.469742[212.469727])
 best(13): [212.469727](age 24) bestelo: [208.331818] pretender: [212.469727]
 Epoch 00064/00200 Game 1500/1500 (bestelo(2307) 229.594940[213.094849], pretender(13) 212.469742[212.469727])
 best(2307): [213.094849](age 7) bestelo: [213.094849] pretender: [212.469727]
 Epoch 00065/00200 Game 1500/1500 (bestelo(2307) 229.594940[220.657455], pretender(2411) 153.968964[171.523727])
 best(2307): [220.657455](age 8) bestelo: [220.657455] pretender: [171.523730]
 Epoch 00066/00200 Game 1500/1500 (bestelo(2307) 229.594940[224.242126], pretender(2411) 176.953949[174.953384])
 best(2307): [224.242126](age 9) bestelo: [224.242126] pretender: [174.953379]
 Epoch 00067/00200 Game 1500/1500 (bestelo(2307) 229.594940[226.452942], pretender(2411) 195.070663[183.530609])
 best(2307): [226.452942](age 10) bestelo: [226.452942] pretender: [183.530605]
 Epoch 00068/00200 Game 1500/1500 (bestelo(2307) 229.594940[227.841171], pretender(2624) 169.804047[108.043030])
 best(2307): [227.841171](age 11) bestelo: [227.841171] pretender: [108.043027]
 Epoch 00069/00200 Game 1500/1500 (bestelo(2307) 229.594940[228.709869], pretender(2411) 182.433365[178.716187])
 best(2307): [228.709869](age 12) bestelo: [228.709869] pretender: [178.716191]
 Epoch 00070/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.148422], pretender(2411) 190.621567[181.187637])
 best(2307): [229.148422](age 13) bestelo: [229.148422] pretender: [181.187637]
 Epoch 00071/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.333099], pretender(2411) 176.667191[181.081253])
 best(2307): [229.333099](age 14) bestelo: [229.333099] pretender: [181.081250]
 Epoch 00072/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.449127], pretender(2732) 127.159004[108.255768])
 best(2307): [229.449127](age 15) bestelo: [229.449127] pretender: [108.255771]
 Epoch 00073/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.517868], pretender(2796) 136.555954[97.438477])
 best(2307): [229.517868](age 16) bestelo: [229.517868] pretender: [97.438477]

Epoch 00074/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.555603], pretender(2411) 133.402206[137.798279])
 best(2307): [229.555603] (age 17) bestelo: [229.555603] pretender: [137.798271]
 Epoch 00075/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.573959], pretender(2411) 130.179108[130.538025])
 best(2307): [229.573959] (age 18) bestelo: [229.573959] pretender: [113.977100]
 Epoch 00076/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.584259], pretender(2796) 167.501862[126.438347])
 best(2307): [229.584259] (age 19) bestelo: [229.584259] pretender: [126.438350]
 Epoch 00077/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.588867], pretender(2796) 172.951096[148.022949])
 best(2307): [229.588867] (age 20) bestelo: [229.588867] pretender: [148.022949]
 Epoch 00078/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.591370], pretender(3073) 144.086990[85.926750])
 best(2307): [229.591370] (age 21) bestelo: [229.591370] pretender: [85.926748]
 Epoch 00079/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.593353], pretender(3113) 139.090790[88.162521])
 best(2307): [229.593353] (age 22) bestelo: [229.593353] pretender: [88.162520]
 Epoch 00080/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594467], pretender(3165) 129.224243[80.136253])
 best(2307): [229.594467] (age 23) bestelo: [229.594467] pretender: [80.136255]
 Epoch 00081/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3200) 130.987717[104.633377])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [104.633379]
 Epoch 00082/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3200) 145.494568[117.391510])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [117.391514]
 Epoch 00083/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3291) 148.171722[96.267471])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [96.267471]
 Epoch 00084/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3291) 158.115646[118.438255])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [118.438252]
 Epoch 00085/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3330) 127.314415[85.482155])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [85.482158]
 Epoch 00086/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3364) 130.244797[88.868240])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [88.868242]
 Epoch 00087/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3442) 140.396194[84.085625])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [84.085625]
 Epoch 00088/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3442) 125.610229[105.224457])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [105.224453]
 Epoch 00089/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3442) 134.305176[116.018456])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [116.018457]
 Epoch 00090/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3364) 115.431946[111.120255])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [111.120254]
 Epoch 00091/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3604) 129.116135[69.046219])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [69.046216]
 Epoch 00092/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3604) 213.887390[119.508904])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [119.508906]
 Epoch 00093/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3604) 198.357285[165.089539])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [165.089531]
 Epoch 00094/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3712) 158.153961[112.506683])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [112.506680]
 Epoch 00095/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3712) 189.909714[139.493256])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [139.493262]
 Epoch 00096/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3712) 173.811462[153.367096])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [153.367100]
 Epoch 00097/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3712) 172.187851[161.217453])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [161.217451]
 Epoch 00098/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3712) 185.443405[168.188568])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [168.188574]
 Epoch 00099/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3863) 189.458664[139.999451])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [139.999443]
 Epoch 00100/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(3845) 164.358765[150.134827])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [150.134834]
 Epoch 00101/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4007) 162.456879[109.399933])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [109.873047]
 Epoch 00102/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4007) 210.174881[145.782898])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [145.782900]
 Epoch 00103/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4065) 180.069168[98.112381])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [98.112383]
 Epoch 00104/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4065) 171.172577[126.982468])
 best(2307): [229.594727] (age 24) bestelo: [229.594727] pretender: [126.982471]

Epoch 00105/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4057) 179.249252[136.584869])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [136.584863]
 Epoch 00106/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4057) 225.231689[171.806107])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [172.352656]
 Epoch 00107/00200 Game 1500/1500 (bestelo(4057) 236.670853[203.361832], pretender(2307) 229.594940[229.594727])
 best(2307): [229.594727](age 24) bestelo: [203.361832] pretender: [229.594727]
 Epoch 00108/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4171) 192.201263[149.860626])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [149.860625]
 Epoch 00109/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4171) 196.451492[166.330307])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [166.330312]
 Epoch 00110/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4372) 162.936630[88.812630])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [88.812627]
 Epoch 00111/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4331) 164.808975[132.673492])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [132.673486]
 Epoch 00112/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 190.523529[120.807716])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [120.807715]
 Epoch 00113/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 170.596527[149.054382])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [149.054385]
 Epoch 00114/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 157.847687[154.250107])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [154.250107]
 Epoch 00115/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4541) 154.107986[96.406273])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [96.406270]
 Epoch 00116/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 163.034180[144.912506])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [144.912500]
 Epoch 00117/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 154.988449[156.048828])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [156.048828]
 Epoch 00118/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4541) 130.235748[126.946022])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [126.946025]
 Epoch 00119/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4541) 159.103775[131.293167])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [131.293164]
 Epoch 00120/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 168.708435[149.241028])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [149.241025]
 Epoch 00121/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4644) 154.840424[144.853638])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [144.853633]
 Epoch 00122/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4850) 149.681992[102.686829])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [102.686826]
 Epoch 00123/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4851) 141.986816[106.447868])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [106.447871]
 Epoch 00124/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 176.288589[137.016907])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [137.016904]
 Epoch 00125/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4427) 173.833740[156.292572])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [156.292578]
 Epoch 00126/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4851) 147.194748[141.632202])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [141.632207]
 Epoch 00127/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(4596) 171.032883[148.276154])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [148.276152]
 Epoch 00128/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 191.360794[112.583534])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [112.583535]
 Epoch 00129/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 216.581512[152.897736])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [152.897734]
 Epoch 00130/00200 Game 1500/1500 (bestelo(5081) 230.059052[187.892700], pretender(2307) 229.594940[229.594727])
 best(2307): [229.594727](age 24) bestelo: [187.892700] pretender: [229.594727]
 Epoch 00131/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 219.557602[196.371307])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [196.371309]
 Epoch 00132/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 214.988571[210.757370])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [210.757363]
 Epoch 00133/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 184.410309[202.170547])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [202.170547]
 Epoch 00134/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 161.146667[187.444031])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [187.444023]
 Epoch 00135/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5081) 165.353973[176.106216])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [176.106211]

Epoch 00136/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5308) 187.812531[137.062103])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [137.062100]
 Epoch 00137/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5308) 177.949844[151.278275])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [151.278271]
 Epoch 00138/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5423) 173.656403[129.033493])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [129.033496]
 Epoch 00139/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5423) 224.629578[160.044495])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [160.044492]
 Epoch 00140/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5423) 225.403442[186.906204])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [186.906211]
 Epoch 00141/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5402) 139.014297[114.284004])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [114.284004]
 Epoch 00142/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5402) 161.865311[132.785858])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [132.785859]
 Epoch 00143/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5402) 135.672302[138.035034])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [138.035029]
 Epoch 00144/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5641) 100.938713[106.269104])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [106.269102]
 Epoch 00145/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5747) 127.169022[80.913391])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [80.913389]
 Epoch 00146/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5637) 130.032135[111.537155])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [111.537158]
 Epoch 00147/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5637) 129.518341[120.467484])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [120.467480]
 Epoch 00148/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5896) 116.596016[60.837269])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [60.837267]
 Epoch 00149/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 147.222153[77.182739])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [77.182736]
 Epoch 00150/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 157.859589[112.000374])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [112.000371]
 Epoch 00151/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 173.183319[129.113083])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [129.113076]
 Epoch 00152/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5637) 138.006424[116.607689])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [116.607686]
 Epoch 00153/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 116.528847[121.720177])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [121.720176]
 Epoch 00154/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6050) 119.725487[89.852989])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [89.852988]
 Epoch 00155/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 159.909561[126.024521])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [126.024521]
 Epoch 00156/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6130) 141.332779[90.983673])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [90.983672]
 Epoch 00157/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6200) 129.929092[95.940018])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [95.940020]
 Epoch 00158/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6211) 121.571198[89.469749])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [89.469746]
 Epoch 00159/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6294) 143.281509[80.063751])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [80.063755]
 Epoch 00160/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6294) 137.398575[112.564903])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [112.564902]
 Epoch 00161/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6130) 128.446335[116.906494])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [116.906494]
 Epoch 00162/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6294) 143.559616[115.460129])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [115.460127]
 Epoch 00163/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6050) 134.307297[120.124260])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [120.124258]
 Epoch 00164/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 143.657745[92.872375])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [92.872373]
 Epoch 00165/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(5936) 121.251556[114.471298])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [114.471299]
 Epoch 00166/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6050) 137.009415[119.594040])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [119.789561]

Epoch 00167/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6561) 121.406502[99.650978])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [99.650977]
 Epoch 00168/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 153.608337[90.125031])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [90.125029]
 Epoch 00169/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 147.808243[112.006447])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [112.006445]
 Epoch 00170/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 173.949753[131.342880])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [131.797988]
 Epoch 00171/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 169.093506[154.313675])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [154.488525]
 Epoch 00172/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 156.216721[158.283127])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [158.283125]
 Epoch 00173/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 182.966461[163.647995])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [163.647988]
 Epoch 00174/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 148.670059[163.312668])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [163.312666]
 Epoch 00175/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6937) 154.270020[99.693573])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [99.693574]
 Epoch 00176/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(6659) 142.389664[142.683640])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [142.683643]
 Epoch 00177/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7007) 181.218079[106.915565])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [106.915566]
 Epoch 00178/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7007) 183.978027[137.465836])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [137.465840]
 Epoch 00179/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7007) 200.221313[161.175064])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [161.175068]
 Epoch 00180/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7003) 165.031036[152.916840])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [152.981719]
 Epoch 00181/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7003) 185.869003[162.471863])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [162.471865]
 Epoch 00182/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7007) 146.999634[157.248032])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [157.248027]
 Epoch 00183/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7210) 121.389427[84.785156])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [84.785156]
 Epoch 00184/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7210) 124.043358[101.436806])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [101.436807]
 Epoch 00185/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7210) 136.366104[109.805344])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [109.805342]
 Epoch 00186/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7349) 103.748123[85.813446])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [85.813447]
 Epoch 00187/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7349) 136.704315[96.895050])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [96.895049]
 Epoch 00188/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7349) 156.676254[118.672890])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [118.672891]
 Epoch 00189/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7530) 119.269569[68.456085])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [68.456084]
 Epoch 00190/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7567) 120.979630[97.268562])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [97.268564]
 Epoch 00191/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7567) 121.066910[105.909737])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [106.009873]
 Epoch 00192/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7605) 121.054131[94.868477])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [94.868477]
 Epoch 00193/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7605) 152.173492[114.742744])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [114.742744]
 Epoch 00194/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7654) 153.577209[104.191124])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [104.191123]
 Epoch 00195/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7721) 144.222076[99.021721])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [99.021719]
 Epoch 00196/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7654) 152.314148[141.608002])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [141.607998]
 Epoch 00197/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7831) 155.080200[105.475250])
 best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [105.475254]

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Epoch 00198/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7831) 150.140503[127.012932])
best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [127.012930]
Epoch 00199/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7831) 150.507187[132.258820])
best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [132.258818]
Epoch 00200/00200 Game 1500/1500 (bestelo(2307) 229.594940[229.594727], pretender(7831) 142.231277[136.350327])
best(2307): [229.594727](age 24) bestelo: [229.594727] pretender: [136.350332]

```

Soft ELO of the best of all NeuraNet (blue), the current best NeuraNet (red) and the current second best NeuraNet (green) as evaluation function in a pool of 50 NeuraNet, plus a milestone with elo set at 0.0 using the default (no NeuraNet) evaluation function as a reference:

