GTree

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Contents

Introduction

GTree is a C library providing structures and functions to manipulate tree structures.

A GTree is a structure containing a pointer toward its parent, a void* pointer toward user's data and a GSet of subtrees. The GTree offers the same interface has a GSet to manipulate its subtrees. It also provides a function to cut the GTree from its parent.

The library provides also three iterators to run through the trees: GTreeIterDepth, GTreeIterBreadth, GTreeIterValue which step, respectively, in depth first order, breadth first order and value (sorting value of the GSet of subtrees) first order.

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

1 Interface

```
// ============ GTREE.H ================

#ifndef GTREE_H
#define GTREE_H

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

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include <stdbool.h>
#include "pberr.h"
#include "gset.h"

// ----------- GenTree

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

// ================= Data structure ===================
struct GenTree;
typedef struct GenTree {
  // Parent node
  struct GenTree* _parent;
  // Branches
  // Branch cannot be null, if the user tries to add a null branch
  // nothing happen
  GSetGenTree _subtrees;
  // User data
  void* _data;
} GenTree;

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

// Create a new GenTree
GenTree* GenTreeCreate(void);

// Create a new static GenTree
GenTree GenTreeCreateStatic(void);

// Create a new GenTree with user data 'data'
GenTree* GenTreeCreateData(void* const data);

// Free the memory used by the GenTree 'that'
// If 'that' is not a root node it is cut prior to be freed
// Subtrees are recursively freed
// User data must be freed by the user
void _GenTreeFree(GenTree** that);

// Free the memory used by the static GenTree 'that'
// If 'that' is not a root node it is cut prior to be freed
// Subtrees are recursively freed
// User data must be freed by the user
void _GenTreeFreeStatic(GenTree* that);
```

```
// Get the user data of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
void* _GenTreeData(const GenTree* const that);

// Set the user data of the GenTree 'that' to 'data'
#if BUILDMODE != 0
inline
#endif
void _GenTreeSetData(GenTree* const that, void* const data);

// Get the set of subtrees of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
GSetGenTree* _GenTreeSubtrees(const GenTree* const that);

// Disconnect the GenTree 'that' from its parent
// If it has no parent, do nothing
void _GenTreeCut(GenTree* const that);

// Return true if the GenTree 'that' is a root
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIsRoot(const GenTree* const that);

// Return true if the GenTree 'that' is a leaf
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIsLeaf(const GenTree* const that);

// Return the parent of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeParent(const GenTree* const that);

// Return the number of subtrees of the GenTree 'that' and their subtrees
// recursively
int _GenTreeGetSize(const GenTree* const that);

// Wrapping of GSet functions
inline GenTree* _GenTreeSubtree(const GenTree* const that, const int iSubtree) {
  return GSetGet(_GenTreeSubtrees(that), iSubtree);
}
inline GenTree* _GenTreeFirstSubtree(const GenTree* const that) {
  return GSetHead(_GenTreeSubtrees(that));
}
inline GenTree* _GenTreeLastSubtree(const GenTree* const that) {
  return GSetTail(_GenTreeSubtrees(that));
}
inline GenTree* _GenTreePopSubtree(GenTree* const that) {
  return GSetPop(_GenTreeSubtrees(that));
}
inline GenTree* _GenTreeDropSubtree(GenTree* const that) {
  return GSetDrop(_GenTreeSubtrees(that));
```

```
}
inline GenTree* _GenTreeRemoveSubtree(GenTree* const that, const int iSubtree) {
  return GSetRemove((GSet*)_GenTreeSubtrees(that), iSubtree);
}

inline void _GenTreePushSubtree(GenTree* const that, GenTree* const tree) {
  if (!tree) return;
  GSetPush(_GenTreeSubtrees(that), tree);
  tree->_parent = that;
}
inline void _GenTreeAddSortSubTree(GenTree* const that, GenTree* const tree,
  const float sortVal) {
  if (!tree) return;
  GSetAddSort(_GenTreeSubtrees(that), tree, sortVal);
  tree->_parent = that;
}
inline void _GenTreeInsertSubtree(GenTree* const that, GenTree* const tree,
  const int pos) {
  if (!tree) return;
  GSetInsert(_GenTreeSubtrees(that), tree, pos);
  tree->_parent = that;
}
inline void _GenTreeAppendSubtree(GenTree* const that, GenTree* const tree) {
  if (!tree) return;
  GSetAppend(_GenTreeSubtrees(that), tree);
  tree->_parent = that;
}

inline void _GenTreePushData(GenTree* const that, void* const data) {
  GenTree* tree = GenTreeCreateData(data);
  GSetPush(_GenTreeSubtrees(that), tree);
  tree->_parent = that;
}
inline void _GenTreeAddSortData(GenTree* const that, void* const data,
  const float sortVal) {
  GenTree* tree = GenTreeCreateData(data);
  GSetAddSort(_GenTreeSubtrees(that), tree, sortVal);
  tree->_parent = that;
}
inline void _GenTreeInsertData(GenTree* const that, void* const data,
  const int pos) {
  GenTree* tree = GenTreeCreateData(data);
  GSetInsert(_GenTreeSubtrees(that), tree, pos);
  tree->_parent = that;
}
inline void _GenTreeAppendData(GenTree* const that, void* const data) {
  GenTree* tree = GenTreeCreateData(data);
  GSetAppend(_GenTreeSubtrees(that), tree);
  tree->_parent = that;
}

// ----------- GenTreeIter

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

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

typedef struct GenTreeIter {
  // Attached tree
  GenTree* _tree;
  // Current position
  GSetElem* _curPos;
```

```
  // GSet to memorize nodes sequence
  // The node sequence doesn't include the root node of the attached tree
  GSetGenTree _seq;
} GenTreeIter;

typedef struct GenTreeIterDepth {GenTreeIter _iter;} GenTreeIterDepth;
typedef struct GenTreeIterBreadth {GenTreeIter _iter;} GenTreeIterBreadth;
typedef struct GenTreeIterValue {GenTreeIter _iter;} GenTreeIterValue;

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

// Create a new GenTreeIterDepth for the GenTree 'tree'
GenTreeIterDepth* _GenTreeIterDepthCreate(GenTree* const tree);

// Create a new static GenTreeIterDepth for the GenTree 'tree'
GenTreeIterDepth _GenTreeIterDepthCreateStatic(GenTree* const tree);

// Create a new GenTreeIterBreadth for the GenTree 'tree'
GenTreeIterBreadth* _GenTreeIterBreadthCreate(GenTree* const tree);

// Create a new static GenTreeIterBreadth for the GenTree 'tree'
GenTreeIterBreadth _GenTreeIterBreadthCreateStatic(GenTree* const tree);

// Create a new GenTreeIterValue for the GenTree 'tree'
GenTreeIterValue* _GenTreeIterValueCreate(GenTree* const tree);

// Create a new static GenTreeIterValue for the GenTree 'tree'
GenTreeIterValue _GenTreeIterValueCreateStatic(GenTree* const tree);

// Update the GenTreeIterDepth 'that' in case its attached GenTree has been
// modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterDepthUpdate(GenTreeIterDepth* const that);

// Update the GenTreeIterBreadth 'that' in case its attached GenTree has
// been modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterBreadthUpdate(GenTreeIterBreadth* const that);

// Update the GenTreeIterValue 'that' in case its attached GenTree has been
// modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterValueUpdate(GenTreeIterValue* const that);

// Free the memory used by the iterator 'that'
void _GenTreeIterFree(GenTreeIter** that);

// Free the memory used by the static iterator 'that'
void _GenTreeIterFreeStatic(GenTreeIter* const that);

// Reset the iterator 'that' at its start position
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterReset(GenTreeIter* const that);

// Reset the iterator 'that' at its end position
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterToEnd(GenTreeIter* const that);
```

```
// Step the iterator 'that' at its next position
// Return true if it could move to the next position
// Return false if it's already at the last position
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterStep(GenTreeIter* const that);

// Step back the iterator 'that' at its next position
// Return true if it could move to the previous position
// Return false if it's already at the first position
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterStepBack(GenTreeIter* const that);

// Apply a function to all elements' data of the GenTree of the iterator
// The iterator is first reset, then the function is apply sequencially
// using the Step function of the iterator
// The applied function takes to void* arguments: 'data' is the _data
// property of the nodes, 'param' is a hook to allow the user to pass
// parameters to the function through a user-defined structure
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterApply(GenTreeIter* const that,
  void(*fun)(void* const data, void* const param), void* const param);

// Return true if the iterator is at the start of the elements (from
// its point of view, not the order in the GenTree)
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterIsFirst(const GenTreeIter* const that);

// Return true if the iterator is at the end of the elements (from
// its point of view, not the order in the GenTree)
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterIsLast(const GenTreeIter* const that);

// Change the attached tree of the iterator, and reset it
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterDepthSetGenTree(GenTreeIterDepth* const that,
  GenTree* const tree);
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterBreadthSetGenTree(GenTreeIterBreadth* const that,
  GenTree* const tree);
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterValueSetGenTree(GenTreeIterValue* const that,
  GenTree* const tree);

// Return the user data of the tree currently pointed to by the iterator
```

```
#if BUILDMODE != 0
inline
#endif
void* _GenTreeIterGetData(const GenTreeIter* const that);

// Return the tree currently pointed to by the iterator
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeIterGetGenTree(const GenTreeIter* const that);

// Return the tree associated to the iterator 'that'
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeIterGenTree(const GenTreeIter* const that);

// Return the sequence of the iterator
#if BUILDMODE != 0
inline
#endif
GSetGenTree* _GenTreeIterSeq(const GenTreeIter* const that);

// ================= Typed GenTree ==================

typedef struct GenTreeStr {GenTree _tree;} GenTreeStr;
#define GenTreeStrCreate() ((GenTreeStr*)GenTreeCreate())
inline GenTreeStr GenTreeStrCreateStatic(void)
  {GenTreeStr ret = {._tree=GenTreeCreateStatic()}; return ret;}
#define GenTreeStrCreateData(Data) ((GenTreeStr*)GenTreeCreateData(Data))
inline char* _GenTreeStrData(const GenTreeStr* const that) {
  return (char*)_GenTreeData((const GenTree* const)that);
}
inline void _GenTreeStrSetData(GenTreeStr* const that, char* const data) {
  _GenTreeSetData((GenTree* const)that, (void* const)data);
}
inline GSetGenTreeStr* _GenTreeStrSubtrees(const GenTreeStr* const that) {
  return (GSetGenTreeStr*)_GenTreeSubtrees((const GenTree* const)that);
}
inline GenTreeStr* _GenTreeStrParent(const GenTreeStr* const that) {
  return (GenTreeStr*)_GenTreeParent((const GenTree* const)that);
}
inline void _GenTreeStrPushData(GenTreeStr* const that, char* const data) {
  _GenTreePushData((GenTree* const)that, (void* const)data);
}
inline void _GenTreeStrAddSortData(GenTreeStr* const that, char* const data,
  const float sortVal) {
  _GenTreeAddSortData((GenTree* const)that, (void* const)data, sortVal);
}
inline void _GenTreeStrInsertData(GenTreeStr* const that, char* const data,
  const int pos) {
  _GenTreeInsertData((GenTree* const)that, (void* const)data, pos);
}
inline void _GenTreeStrAppendData(GenTreeStr* const that, char* const data) {
  _GenTreeAppendData((GenTree* const)that, (void* const)data);
}
inline GenTreeStr* _GenTreeStrSubtree(const GenTreeStr* const that,
  const int iSubtree) {
  return (GenTreeStr*)_GenTreeSubtree((const GenTree* const)that, iSubtree);
}
inline GenTreeStr* _GenTreeStrFirstSubtree(const GenTreeStr* const that) {
  return (GenTreeStr*)_GenTreeFirstSubtree((const GenTree* const)that);
```

```
}
inline GenTreeStr* _GenTreeStrLastSubtree(const GenTreeStr* const that) {
  return (GenTreeStr*)_GenTreeLastSubtree((const GenTree* const)that);
}
inline GenTreeStr* _GenTreeStrPopSubtree(GenTreeStr* const that) {
  return (GenTreeStr*)_GenTreePopSubtree((GenTree* const)that);
}
inline GenTreeStr* _GenTreeStrDropSubtree(GenTreeStr* const that) {
  return (GenTreeStr*)_GenTreeDropSubtree((GenTree* const)that);
}
inline GenTreeStr* _GenTreeStrRemoveSubtree(GenTreeStr* const that,
  const int iSubtree) {
  return (GenTreeStr*)_GenTreeRemoveSubtree((GenTree* const)that, iSubtree);
}
inline void _GenTreeStrPushSubtree(GenTreeStr* const that,
  GenTreeStr* const tree) {
  _GenTreePushSubtree((GenTree* const)that, (GenTree* const)tree);
}
inline void _GenTreeStrAddSortSubTree(GenTreeStr* const that,
  GenTreeStr* const tree, const float sortVal) {
  _GenTreeAddSortSubTree((GenTree* const)that, (GenTree* const)tree, sortVal);
}
inline void _GenTreeStrInsertSubtree(GenTreeStr* const that,
  GenTreeStr* const tree, const int pos) {
  _GenTreeInsertSubtree((GenTree* const)that, (GenTree* const)tree, pos);
}
inline void _GenTreeStrAppendSubtree(GenTreeStr* const that,
  GenTreeStr* const tree) {
  _GenTreeAppendSubtree((GenTree* const)that, (GenTree* const)tree);
}

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

#define GenTreeFree(RefTree) _Generic(RefTree, \
  GenTree**: _GenTreeFree, \
  GenTreeStr**: _GenTreeFree, \
  default: PBErrInvalidPolymorphism) ((GenTree**)(RefTree))

#define GenTreeFreeStatic(Tree) _Generic(Tree, \
  GenTree*: _GenTreeFreeStatic, \
  const GenTree*: _GenTreeFreeStatic, \
  GenTreeStr*: _GenTreeFreeStatic, \
  const GenTreeStr*: _GenTreeFreeStatic, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeParent(Tree) _Generic(Tree, \
  GenTree*: _GenTreeParent, \
  const GenTree*: _GenTreeParent, \
  GenTreeStr*: _GenTreeStrParent, \
  const GenTreeStr*: _GenTreeStrParent, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeSubtrees(Tree) _Generic(Tree, \
  GenTree*: _GenTreeSubtrees, \
  const GenTree*: _GenTreeSubtrees, \
  GenTreeStr*: _GenTreeStrSubtrees, \
  const GenTreeStr*: _GenTreeStrSubtrees, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeData(Tree) _Generic(Tree, \
  GenTree*: _GenTreeData, \
  const GenTree*: _GenTreeData, \
```

```
  GenTreeStr*: _GenTreeStrData, \
  const GenTreeStr*: _GenTreeStrData, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeSetData(Tree, Data) _Generic(Tree, \
  GenTree*: _GenTreeSetData, \
  GenTreeStr*: _GenTreeStrSetData, \
  default: PBErrInvalidPolymorphism) (Tree, Data)

#define GenTreeCut(Tree) _Generic(Tree, \
  GenTree*: _GenTreeCut, \
  GenTreeStr*: _GenTreeCut, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIsRoot(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIsRoot, \
  const GenTree*: _GenTreeIsRoot, \
  GenTreeStr*: _GenTreeIsRoot, \
  const GenTreeStr*: _GenTreeIsRoot, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIsLeaf(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIsLeaf, \
  const GenTree*: _GenTreeIsLeaf, \
  GenTreeStr*: _GenTreeIsLeaf, \
  const GenTreeStr*: _GenTreeIsLeaf, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeGetSize(Tree) _Generic(Tree, \
  GenTree*: _GenTreeGetSize, \
  const GenTree*: _GenTreeGetSize, \
  GenTreeStr*: _GenTreeGetSize, \
  const GenTreeStr*: _GenTreeGetSize, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreePushData(Tree, Data) _Generic(Tree, \
  GenTree*: _GenTreePushData, \
  GenTreeStr*: _GenTreeStrPushData, \
  default: PBErrInvalidPolymorphism) (Tree, Data);

#define GenTreeAddSortData(Tree, Data, SortVal) _Generic(Tree, \
  GenTree*: _GenTreeAddSortData, \
  GenTreeStr*: _GenTreeStrAddSortData, \
  default: PBErrInvalidPolymorphism) (Tree, Data, SortVal);

#define GenTreeInsertData(Tree, Data, Pos) _Generic(Tree, \
  GenTree*: _GenTreeInsertData, \
  GenTreeStr*: _GenTreeStrInsertData, \
  default: PBErrInvalidPolymorphism) (Tree, Data, Pos);

#define GenTreeAppendData(Tree, Data) _Generic(Tree, \
  GenTree*: _GenTreeAppendData, \
  GenTreeStr*: _GenTreeStrAppendData, \
  default: PBErrInvalidPolymorphism) (Tree, Data);

#define GenTreeSubtree(Tree, ISubtree) _Generic(Tree, \
  GenTree*: _GenTreeSubtree, \
  const GenTree*: _GenTreeSubtree, \
  GenTreeStr*: _GenTreeStrSubtree, \
  const GenTreeStr*: _GenTreeStrSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, ISubtree)
```

```
#define GenTreeFirstSubtree(Tree) _Generic(Tree, \
  GenTree*: _GenTreeFirstSubtree, \
  const GenTree*: _GenTreeFirstSubtree, \
  GenTreeStr*: _GenTreeStrFirstSubtree, \
  const GenTreeStr*: _GenTreeStrFirstSubtree, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeLastSubtree(Tree) _Generic(Tree, \
  GenTree*: _GenTreeLastSubtree, \
  const GenTree*: _GenTreeLastSubtree, \
  GenTreeStr*: _GenTreeStrLastSubtree, \
  const GenTreeStr*: _GenTreeStrLastSubtree, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreePopSubtree(Tree) _Generic(Tree, \
  GenTree*: _GenTreePopSubtree, \
  GenTreeStr*: _GenTreeStrPopSubtree, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeDropSubtree(Tree) _Generic(Tree, \
  GenTree*: _GenTreeDropSubtree, \
  GenTreeStr*: _GenTreeStrDropSubtree, \
  default: PBErrInvalidPolymorphism) (Tree)

#define GenTreeRemoveSubtree(Tree, ISubTree) _Generic(Tree, \
  GenTree*: _GenTreeRemoveSubtree, \
  GenTreeStr*: _GenTreeStrRemoveSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, ISubTree)

#define GenTreePushSubtree(Tree, SubTree) _Generic(Tree, \
  GenTree*: _GenTreePushSubtree, \
  GenTreeStr*: _GenTreeStrPushSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, SubTree)

#define GenTreeAddSortSubtree(Tree, SubTree, SortVal) _Generic(Tree, \
  GenTree*: _GenTreeAddSortSubtree, \
  GenTreeStr*: _GenTreeStrAddSortSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, SubTree, SortVal)

#define GenTreeInsertSubtree(Tree, SubTree, Pos) _Generic(Tree, \
  GenTree*: _GenTreeInsertSubtree, \
  GenTreeStr*: _GenTreeStrInsertSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, SubTree, Pos)

#define GenTreeAppendSubtree(Tree, SubTree) _Generic(Tree, \
  GenTree*: _GenTreeAppendSubtree, \
  GenTreeStr*: _GenTreeStrAppendSubtree, \
  default: PBErrInvalidPolymorphism) (Tree, SubTree)

#define GenTreeIterDepthCreate(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterDepthCreate, \
  const GenTree*: _GenTreeIterDepthCreate, \
  GenTreeStr*: _GenTreeIterDepthCreate, \
  const GenTreeStr*: _GenTreeIterDepthCreate, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIterDepthCreateStatic(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterDepthCreateStatic, \
  const GenTree*: _GenTreeIterDepthCreateStatic, \
  GenTreeStr*: _GenTreeIterDepthCreateStatic, \
  const GenTreeStr*: _GenTreeIterDepthCreateStatic, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))
```

```
#define GenTreeIterBreadthCreate(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterBreadthCreate, \
  const GenTree*: _GenTreeIterBreadthCreate, \
  GenTreeStr*: _GenTreeIterBreadthCreate, \
  const GenTreeStr*: _GenTreeIterBreadthCreate, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIterBreadthCreateStatic(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterBreadthCreateStatic, \
  const GenTree*: _GenTreeIterBreadthCreateStatic, \
  GenTreeStr*: _GenTreeIterBreadthCreateStatic, \
  const GenTreeStr*: _GenTreeIterBreadthCreateStatic, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIterValueCreate(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterValueCreate, \
  const GenTree*: _GenTreeIterValueCreate, \
  GenTreeStr*: _GenTreeIterValueCreate, \
  const GenTreeStr*: _GenTreeIterValueCreate, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIterValueCreateStatic(Tree) _Generic(Tree, \
  GenTree*: _GenTreeIterValueCreateStatic, \
  const GenTree*: _GenTreeIterValueCreateStatic, \
  GenTreeStr*: _GenTreeIterValueCreateStatic, \
  const GenTreeStr*: _GenTreeIterValueCreateStatic, \
  default: PBErrInvalidPolymorphism) ((GenTree*)(Tree))

#define GenTreeIterFree(RefIter) _Generic(RefIter, \
  GenTreeIter**: _GenTreeIterFree, \
  GenTreeIterDepth**: _GenTreeIterFree, \
  GenTreeIterBreadth**: _GenTreeIterFree, \
  GenTreeIterValue**: _GenTreeIterFree, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter**)(RefIter))

#define GenTreeIterFreeStatic(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterFreeStatic, \
  GenTreeIterDepth*: _GenTreeIterFreeStatic, \
  GenTreeIterBreadth*: _GenTreeIterFreeStatic, \
  GenTreeIterValue*: _GenTreeIterFreeStatic, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterReset(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterReset, \
  GenTreeIterDepth*: _GenTreeIterReset, \
  GenTreeIterBreadth*: _GenTreeIterReset, \
  GenTreeIterValue*: _GenTreeIterReset, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterToEnd(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterToEnd, \
  GenTreeIterDepth*: _GenTreeIterToEnd, \
  GenTreeIterBreadth*: _GenTreeIterToEnd, \
  GenTreeIterValue*: _GenTreeIterToEnd, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterStep(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterStep, \
  GenTreeIterDepth*: _GenTreeIterStep, \
  GenTreeIterBreadth*: _GenTreeIterStep, \
  GenTreeIterValue*: _GenTreeIterStep, \
```

```
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterStepBack(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterStepBack, \
  GenTreeIterDepth*: _GenTreeIterStepBack, \
  GenTreeIterBreadth*: _GenTreeIterStepBack, \
  GenTreeIterValue*: _GenTreeIterStepBack, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterApply(Iter, Fun, Param) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterApply, \
  GenTreeIterDepth*: _GenTreeIterApply, \
  GenTreeIterBreadth*: _GenTreeIterApply, \
  GenTreeIterValue*: _GenTreeIterApply, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter), Fun, Param)

#define GenTreeIterIsFirst(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterIsFirst, \
  const GenTreeIter*: _GenTreeIterIsFirst, \
  GenTreeIterDepth*: _GenTreeIterIsFirst, \
  const GenTreeIterDepth*: _GenTreeIterIsFirst, \
  GenTreeIterBreadth*: _GenTreeIterIsFirst, \
  const GenTreeIterBreadth*: _GenTreeIterIsFirst, \
  GenTreeIterValue*: _GenTreeIterIsFirst, \
  const GenTreeIterValue*: _GenTreeIterIsFirst, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterIsLast(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterIsLast, \
  const GenTreeIter*: _GenTreeIterIsLast, \
  GenTreeIterDepth*: _GenTreeIterIsLast, \
  const GenTreeIterDepth*: _GenTreeIterIsLast, \
  GenTreeIterBreadth*: _GenTreeIterIsLast, \
  const GenTreeIterBreadth*: _GenTreeIterIsLast, \
  GenTreeIterValue*: _GenTreeIterIsLast, \
  const GenTreeIterValue*: _GenTreeIterIsLast, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterSetGenTree(Iter, Tree) _Generic(Iter, \
  GenTreeIterDepth*: _GenTreeIterDepthSetGenTree, \
  GenTreeIterBreadth*: _GenTreeIterBreadthSetGenTree, \
  GenTreeIterValue*: _GenTreeIterValueSetGenTree, \
  default: PBErrInvalidPolymorphism) (Iter, Tree)

#define GenTreeIterGetData(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterGetData, \
  const GenTreeIter*: _GenTreeIterGetData, \
  GenTreeIterDepth*: _GenTreeIterGetData, \
  const GenTreeIterDepth*: _GenTreeIterGetData, \
  GenTreeIterBreadth*: _GenTreeIterGetData, \
  const GenTreeIterBreadth*: _GenTreeIterGetData, \
  GenTreeIterValue*: _GenTreeIterGetData, \
  const GenTreeIterValue*: _GenTreeIterGetData, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterGenTree(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterGenTree, \
  const GenTreeIter*: _GenTreeIterGenTree, \
  GenTreeIterDepth*: _GenTreeIterGenTree, \
  const GenTreeIterDepth*: _GenTreeIterGenTree, \
  GenTreeIterBreadth*: _GenTreeIterGenTree, \
  const GenTreeIterBreadth*: _GenTreeIterGenTree, \
```

```
  GenTreeIterValue*: _GenTreeIterGenTree, \
  const GenTreeIterValue*: _GenTreeIterGenTree, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterGetGenTree(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterGetGenTree, \
  const GenTreeIter*: _GenTreeIterGetGenTree, \
  GenTreeIterDepth*: _GenTreeIterGetGenTree, \
  const GenTreeIterDepth*: _GenTreeIterGetGenTree, \
  GenTreeIterBreadth*: _GenTreeIterGetGenTree, \
  const GenTreeIterBreadth*: _GenTreeIterGetGenTree, \
  GenTreeIterValue*: _GenTreeIterGetGenTree, \
  const GenTreeIterValue*: _GenTreeIterGetGenTree, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

#define GenTreeIterSeq(Iter) _Generic(Iter, \
  GenTreeIter*: _GenTreeIterSeq, \
  const GenTreeIter*: _GenTreeIterSeq, \
  GenTreeIterDepth*: _GenTreeIterSeq, \
  const GenTreeIterDepth*: _GenTreeIterSeq, \
  GenTreeIterBreadth*: _GenTreeIterSeq, \
  const GenTreeIterBreadth*: _GenTreeIterSeq, \
  GenTreeIterValue*: _GenTreeIterSeq, \
  const GenTreeIterValue*: _GenTreeIterSeq, \
  default: PBErrInvalidPolymorphism) ((GenTreeIter*)(Iter))

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

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


#endif
```

2 Code

2.1 pbmath.c

```
// ============ GTREE.C ================

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

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

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

// Free the memory used by 'subtrees' recursively
void GenTreeFreeRec(GSetGenTree* subtrees);

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

// Create a new GenTree
GenTree* GenTreeCreate(void) {
  // Declare the new tree
```

```
  GenTree *that = PBErrMalloc(GenTreeErr, sizeof(GenTree));
  // Set properties
  that->_parent = NULL;
  that->_subtrees = GSetGenTreeCreateStatic();
  that->_data = NULL;
  // Return the tree
  return that;
}

// Create a new static GenTree
GenTree GenTreeCreateStatic(void) {
  // Declare the new tree
  GenTree that;
  // Set properties
  that._parent = NULL;
  that._subtrees = GSetGenTreeCreateStatic();
  that._data = NULL;
  // Return the tree
  return that;
}

// Create a new GenTree with user data 'data'
GenTree* GenTreeCreateData(void* const data) {
  // Declare the new tree
  GenTree *that = PBErrMalloc(GenTreeErr, sizeof(GenTree));
  // Set properties
  that->_parent = NULL;
  that->_subtrees = GSetGenTreeCreateStatic();
  that->_data = data;
  // Return the tree
  return that;
}

// Free the memory used by the GenTree 'that'
// If 'that' is not a root node it is cut prior to be freed
// Subtrees are recursively freed
// User data must be freed by the user
void _GenTreeFree(GenTree** that) {
  // Check argument
  if (that == NULL || *that == NULL)
    // Nothing to do
    return;
  // If it's not a root node
  if (!GenTreeIsRoot(*that))
    // Cut the tree
    GenTreeCut(*that);
  // Free recursively the memory
  GenTreeFreeRec(GenTreeSubtrees(*that));
  free(*that);
  *that = NULL;
}

// Free the memory used by 'subtrees' recursively
void GenTreeFreeRec(GSetGenTree* subtrees) {
  while (GSetNbElem(subtrees) > 0) {
    GenTree* tree = GSetPop(subtrees);
    GenTreeFreeRec(GenTreeSubtrees(tree));
    free(tree);
  }
}

// Free the memory used by the static GenTree 'that'
```

```
// If 'that' is not a root node it is cut prior to be freed
// Subtrees are recursively freed
// User data must be freed by the user
void _GenTreeFreeStatic(GenTree* that) {
  // Check argument
  if (that == NULL)
    // Nothing to do
    return;
  // If it's not a root node
  if (!GenTreeIsRoot(that))
    // Cut the tree
    GenTreeCut(that);
  // Free memory
  GenTreeFreeRec(GenTreeSubtrees(that));
}

// Disconnect the GenTree 'that' from its parent
// If it has no parent, do nothing
void _GenTreeCut(GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // If there is no parent
  if (GenTreeParent(that) == NULL)
    // Nothing to do
    return;
  // Remove the tree from the parent's subtrees
  GSetRemoveAll(GenTreeSubtrees(GenTreeParent(that)), that);
  // Cut the link to the parent
  that->_parent = NULL;
}

// Return the number of subtrees of the GenTree 'that' and their subtrees
// recursively
int _GenTreeGetSize(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare a variable to memorize the result and initialize it with
  // the number of subtrees
  int nb = GSetNbElem(GenTreeSubtrees(that));
  // If there are subtrees
  if (nb > 0) {
    // Recursion on the subtrees
    GSetIterForward iter =
      GSetIterForwardCreateStatic(GenTreeSubtrees(that));
    do {
      GenTree* subtree = GSetIterGet(&iter);
      nb += GenTreeGetSize(subtree);
    } while (GSetIterStep(&iter));
  }
  // Return the result
  return nb;
}
```

```
// ----------- GenTreeIter

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

// Create recursively the sequence of an iterator for depth first
void GenTreeIterCreateSequenceDepthFirst(GSetGenTree* seq, GenTree* tree);

// Create recursively the sequence of an iterator for breadth first
void GenTreeIterCreateSequenceBreadthFirst(GSetGenTree* seq, GenTree* tree,
  int lvl);

// Create recursively the sequence of an iterator for value first
void GenTreeIterCreateSequenceValueFirst(GSetGenTree* seq, GenTree* tree,
  float val);

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

// Create a new GenTreeIterDepth for the GenTree 'tree'
GenTreeIterDepth* _GenTreeIterDepthCreate(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterDepth *iter = PBErrMalloc(GenTreeErr, sizeof(GenTreeIterDepth));
  // Set properties
  ((GenTreeIter*)iter)->_tree = tree;
  ((GenTreeIter*)iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterDepthUpdate(iter);
  GenTreeIterReset(iter);
  // Return the iterator
  return iter;
}

// Create a new static GenTreeIterDepth for the GenTree 'tree'
GenTreeIterDepth _GenTreeIterDepthCreateStatic(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterDepth iter;
  // Set properties
  ((GenTreeIter*)&iter)->_tree = tree;
  ((GenTreeIter*)&iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterDepthUpdate(&iter);
  GenTreeIterReset(&iter);
  // Return the iterator
  return iter;
}

// Create a new GenTreeIterBreadth for the GenTree 'tree'
GenTreeIterBreadth* _GenTreeIterBreadthCreate(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
```

```
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterBreadth *iter =
    PBErrMalloc(GenTreeErr, sizeof(GenTreeIterBreadth));
  // Set properties
  ((GenTreeIter*)iter)->_tree = tree;
  ((GenTreeIter*)iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterBreadthUpdate(iter);
  GenTreeIterReset(iter);
  // Return the iterator
  return iter;
}

// Create a new static GenTreeIterBreadth for the GenTree 'tree'
GenTreeIterBreadth _GenTreeIterBreadthCreateStatic(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterBreadth iter;
  // Set properties
  ((GenTreeIter*)&iter)->_tree = tree;
  ((GenTreeIter*)&iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterBreadthUpdate(&iter);
  GenTreeIterReset(&iter);
  // Return the iterator
  return iter;
}

// Create a new GenTreeIterValue for the GenTree 'tree'
GenTreeIterValue* _GenTreeIterValueCreate(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterValue *iter = PBErrMalloc(GenTreeErr, sizeof(GenTreeIterValue));
  // Set properties
  ((GenTreeIter*)iter)->_tree = tree;
  ((GenTreeIter*)iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterValueUpdate(iter);
  GenTreeIterReset(iter);
  // Return the iterator
  return iter;
}

// Create a new static GenTreeIterValue for the GenTree 'tree' with
// 'rootval' the value of its root node
GenTreeIterValue _GenTreeIterValueCreateStatic(GenTree* const tree) {
#if BUILDMODE == 0
  if (tree == NULL) {
```

```
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Declare the new iterator
  GenTreeIterValue iter;
  // Set properties
  ((GenTreeIter*)&iter)->_tree = tree;
  ((GenTreeIter*)&iter)->_seq = GSetGenTreeCreateStatic();
  GenTreeIterValueUpdate(&iter);
  GenTreeIterReset(&iter);
  // Return the iterator
  return iter;
}

// Update the GenTreeIterDepth 'that' in case its attached GenTree has been
// modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterDepthUpdate(GenTreeIterDepth* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Flush the sequence
  GSetFlush(GenTreeIterSeq(that));
  // Create the sequence with a Depth First run through nodes of the tree
  GenTreeIterCreateSequenceDepthFirst(GenTreeIterSeq(that),
    GenTreeIterGenTree(that));
  // Reset the current position
  GenTreeIterReset(that);
}

// Create recursively the sequence of an iterator for depth first
void GenTreeIterCreateSequenceDepthFirst(GSetGenTree* seq, GenTree* tree) {
  // Append the current tree to the sequence if it's not root
  if (!GenTreeIsRoot(tree)) GSetAppend(seq, tree);
  // If there are subtrees
  if (GSetNbElem(GenTreeSubtrees(tree)) > 0) {
    // Append the subtrees recursively
    GSetIterForward iter =
      GSetIterForwardCreateStatic(GenTreeSubtrees(tree));
    do {
      GenTree* subtree = GSetIterGet(&iter);
      GenTreeIterCreateSequenceDepthFirst(seq, subtree);
    } while (GSetIterStep(&iter));
  }
}

// Update the GenTreeIterBreadth 'that' in case its attached GenTree has
// been modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterBreadthUpdate(GenTreeIterBreadth* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
```

```
#endif
  // Flush the sequence
  GSetFlush(GenTreeIterSeq(that));
  // Create the sequence with a Breadth First run through nodes of
  // the tree
  GenTreeIterCreateSequenceBreadthFirst(GenTreeIterSeq(that),
    GenTreeIterGenTree(that), 0);
  // Reset the current position
  GenTreeIterReset(that);
}

// Create recursively the sequence of an iterator for breadth first
void GenTreeIterCreateSequenceBreadthFirst(GSetGenTree* seq, GenTree* tree,
  int lvl) {
  // Append the current tree to the sequence if it's not root
  if (!GenTreeIsRoot(tree)) GSetAddSort(seq, tree, lvl);
  // If there are subtrees
  if (GSetNbElem(GenTreeSubtrees(tree)) > 0) {
    // Declare a variable to memorize the next lvl
    int nextLvl = lvl + 1;
    // Append the subtrees recursively
    GSetIterForward iter =
      GSetIterForwardCreateStatic(GenTreeSubtrees(tree));
    do {
      GenTree* subtree = GSetIterGet(&iter);
      GenTreeIterCreateSequenceBreadthFirst(seq, subtree, nextLvl);
    } while (GSetIterStep(&iter));
  }
}

// Update the GenTreeIterValue 'that' in case its attached GenTree has been
// modified
// The node sequence doesn't include the root node of the attached tree
void GenTreeIterValueUpdate(GenTreeIterValue* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Flush the sequence
  GSetFlush(GenTreeIterSeq(that));
  // Create the sequence with a Value First run through nodes of the tree
  GenTreeIterCreateSequenceValueFirst(GenTreeIterSeq(that),
    GenTreeIterGenTree(that), 0.0);
  // Reset the current position
  GenTreeIterReset(that);
}

// Create recursively the sequence of an iterator for value first
void GenTreeIterCreateSequenceValueFirst(GSetGenTree* seq, GenTree* tree,
  float val) {
  // Append the current tree to the sequence if it's not root
  if (!GenTreeIsRoot(tree)) GSetAddSort(seq, tree, val);
  // If there are subtrees
  if (GSetNbElem(GenTreeSubtrees(tree)) > 0) {
    // Append the subtrees recursively
    GSetIterForward iter =
      GSetIterForwardCreateStatic(GenTreeSubtrees(tree));
    do {
      GenTree* subtree = GSetIterGet(&iter);
```

```
      GenTreeIterCreateSequenceValueFirst(seq, subtree,
        GSetIterGetSortVal(&iter));
    } while (GSetIterStep(&iter));
  }
}

// Free the memory used by the iterator 'that'
void _GenTreeIterFree(GenTreeIter** that) {
  // Check argument
  if (that == NULL || *that == NULL)
    // Nothing to do
    return;
  // Free memory
  GSetFlush(GenTreeIterSeq(*that));
  free(*that);
  *that = NULL;
}

// Free the memory used by the static iterator 'that'
void _GenTreeIterFreeStatic(GenTreeIter* const that) {
  // Check argument
  if (that == NULL)
    // Nothing to do
    return;
  // Free memory
  GSetFlush(GenTreeIterSeq(that));
}
```

2.2 pbmath-inline.c

```
// ============ GTREE-INLINE.C ================

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

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

// Get the user data of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
void* _GenTreeData(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return that->_data;
}

// Get the parent of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeParent(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
```

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

// Set the user data of the GenTree 'that' to 'data'
#if BUILDMODE != 0
inline
#endif
void _GenTreeSetData(GenTree* const that, void* const data) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  that->_data = data;
}

// Get the set of subtrees of the GenTree 'that'
#if BUILDMODE != 0
inline
#endif
GSetGenTree* _GenTreeSubtrees(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (GSetGenTree*)&(that->_subtrees);
}

// Return true if the GenTree 'that' is a root
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIsRoot(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (that->_parent == NULL ? true : false);
}

// Return true if the GenTree 'that' is a leaf
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIsLeaf(const GenTree* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (GSetNbElem(&(that->_subtrees)) == 0 ? true : false);
}

// ----------- GenTreeIter

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

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

// Reset the iterator 'that' at its start position
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterReset(GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  that->_curPos = ((GSet*)&(that->_seq))->_head;
}

// Reset the iterator 'that' to its end position
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterToEnd(GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  that->_curPos = ((GSet*)&(that->_seq))->_tail;
}

// Step the iterator 'that' at its next position
// Return true if it could move to the next position
// Return false if it's already at the last position
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterStep(GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (that->_curPos == NULL) {
    GenTreeErr->_type = PBErrTypeInvalidArg;
    sprintf(GSetErr->_msg, "'that->_curPos' is null");
    PBErrCatch(GSetErr);
  }
#endif
```

```
  if (that->_curPos->_next != NULL) {
    that->_curPos = that->_curPos->_next;
    return true;
  }
  return false;
}

// Step back the iterator 'that' at its next position
// Return true if it could move to the previous position
// Return false if it's already at the first position
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterStepBack(GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (that->_curPos == NULL) {
    GenTreeErr->_type = PBErrTypeInvalidArg;
    sprintf(GSetErr->_msg, "'that->_curPos' is null");
    PBErrCatch(GSetErr);
  }
#endif
  if (that->_curPos->_prev != NULL) {
    that->_curPos = that->_curPos->_prev;
    return true;
  }
  return false;
}

// Apply a function to all elements' data of the GenTree of the iterator
// The iterator is first reset, then the function is apply sequencially
// using the Step function of the iterator
// The applied function takes to void* arguments: 'data' is the _data
// property of the nodes, 'param' is a hook to allow the user to pass
// parameters to the function through a user-defined structure
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterApply(GenTreeIter* const that,
  void(*fun)(void* const data, void* const param), void* const param) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (fun == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'fun' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Reset the iterator;
  GenTreeIterReset(that);
  // If the associated tree is not empty
  if (GSetNbElem(&(that->_seq)) > 0) {
    // For each node of the tree
    do {
```

```
      // Apply the user function
      fun(GenTreeIterGetData(that), param);
    } while (GenTreeIterStep(that));
  }
}

// Return true if the iterator is at the start of the elements (from
// its point of view, not the order in the GenTree)
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterIsFirst(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (that->_curPos == ((GSet*)&(that->_seq))->_head);
}

// Return true if the iterator is at the end of the elements (from
// its point of view, not the order in the GenTree)
// Return false else
#if BUILDMODE != 0
inline
#endif
bool _GenTreeIterIsLast(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (that->_curPos == ((GSet*)&(that->_seq))->_tail);
}

// Change the attached tree of the iterator, and reset it
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterDepthSetGenTree(GenTreeIterDepth* const that,
  GenTree* const tree) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Set the tree
  ((GenTreeIter*)that)->_tree = tree;
  // Update the sequence
  GenTreeIterDepthUpdate(that);
```

```
  // Reset the iterator
  GenTreeIterReset(that);
}
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterBreadthSetGenTree(GenTreeIterBreadth* const that,
  GenTree* tree) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Set the tree
  ((GenTreeIter*)that)->_tree = tree;
  // Update the sequence
  GenTreeIterBreadthUpdate(that);
  // Reset the iterator
  GenTreeIterReset(that);
}
#if BUILDMODE != 0
inline
#endif
void _GenTreeIterValueSetGenTree(GenTreeIterValue* const that,
  GenTree* const tree) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
  if (tree == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'tree' is null");
    PBErrCatch(GSetErr);
  }
#endif
  // Set the tree
  ((GenTreeIter*)that)->_tree = tree;
  // Update the sequence
  GenTreeIterValueUpdate(that);
  // Reset the iterator
  GenTreeIterReset(that);
}

// Return the user data of the tree currently pointed to by the iterator
#if BUILDMODE != 0
inline
#endif
void* _GenTreeIterGetData(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
```

```
  }
  if (that->_curPos == NULL) {
    GenTreeErr->_type = PBErrTypeInvalidArg;
    sprintf(GSetErr->_msg, "'that->_curPos' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return ((GenTree*)(that->_curPos->_data))->_data;
}

// Return the tree currently pointed to by the iterator
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeIterGetGenTree(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (GenTree*)(that->_curPos->_data);
}

// Return the tree associated to the iterator 'that'
#if BUILDMODE != 0
inline
#endif
GenTree* _GenTreeIterGenTree(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return that->_tree;
}

// Return the sequaence of the iterator 'that'
#if BUILDMODE != 0
inline
#endif
GSetGenTree* _GenTreeIterSeq(const GenTreeIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    GenTreeErr->_type = PBErrTypeNullPointer;
    sprintf(GSetErr->_msg, "'that' is null");
    PBErrCatch(GSetErr);
  }
#endif
  return (GSetGenTree*)&(that->_seq);
}
```

3 Makefile

```
# Build mode
```

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

all: main

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

# Rules to make the executable
repo=gtree
$($(repo)_EXENAME): \
$($(repo)_EXENAME).o \
$($(repo)_EXE_DEP) \
$($(repo)_DEP)
$(COMPILER) `echo "$($(repo)_EXE_DEP) $($(repo)_EXENAME).o" | tr ' ' '\n' | sort -u` $(LINK_ARG) $($(repo)_LINK_ARG)

$($(repo)_EXENAME).o: \
$($(repo)_DIR)/$($(repo)_EXENAME).c \
$($(repo)_INC_H_EXE) \
$($(repo)_EXE_DEP)
$(COMPILER) $(BUILD_ARG) $($(repo)_BUILD_ARG) `echo "$($(repo)_INC_DIR)" | tr ' ' '\n' | sort -u` -c $($(repo)_DIR)/$
```

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 "gtree.h"

#define RANDOMSEED 0

void UnitTestGenTreeCreateFree() {
  GenTree* tree = GenTreeCreate();
  if (tree == NULL ||
    tree->_parent != NULL ||
    GSetNbElem(&(tree->_subtrees)) != 0 ||
    tree->_data != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeCreate failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeFree(&tree);
  if (tree != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeFree failed");
    PBErrCatch(GenTreeErr);
  }
  int data = 1;
  tree = GenTreeCreateData(&data);
  if (tree == NULL ||
```

```
    tree->_parent != NULL ||
    GSetNbElem(&(tree->_subtrees)) != 0 ||
    tree->_data != &data) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeCreateData failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeFree(&tree);
  GenTree treeStatic = GenTreeCreateStatic();
  if (treeStatic._parent != NULL ||
    GSetNbElem(&(treeStatic._subtrees)) != 0 ||
    treeStatic._data != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeCreateStatic failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeFreeStatic(&treeStatic);
  printf("UnitTestGenTreeCreateFree OK\n");
}

void UnitTestGenTreeGetSet() {
  GenTree tree = GenTreeCreateStatic();
  int data = 1;
  tree._data = &data;
  if (GenTreeData(&tree) != &data) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeData failed");
    PBErrCatch(GenTreeErr);
  }
  int data2 = 1;
  GenTreeSetData(&tree, &data2);
  if (GenTreeData(&tree) != &data2) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeSetData failed");
    PBErrCatch(GenTreeErr);
  }
  if (GenTreeSubtrees(&tree) != &(tree._subtrees)) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeSubTrees failed");
    PBErrCatch(GenTreeErr);
  }
  if (GenTreeIsRoot(&tree) == false) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIsRoot failed");
    PBErrCatch(GenTreeErr);
  }
  tree._parent = &tree;
  if (GenTreeIsRoot(&tree) == true) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIsRoot failed");
    PBErrCatch(GenTreeErr);
  }
  if (GenTreeParent(&tree) != &tree) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeParent failed");
    PBErrCatch(GenTreeErr);
  }
  tree._parent = NULL;
  if (GenTreeIsLeaf(&tree) == false) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIsLeaf failed");
    PBErrCatch(GenTreeErr);
```

```
  }
  GenTreeAppendData(&tree, &data);
  if (GenTreeIsLeaf(&tree) == true) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIsLeaf failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeFreeStatic(&tree);
  printf("UnitTestGenTreeGetSet OK\n");
}

void UnitTestGenTreeCutGetSize() {
  GenTree tree = GenTreeCreateStatic();
  int data = 1;
  GenTreeAppendData(&tree, &data);
  GenTreeAppendData(&tree, &data);
  GenTreeAppendData(GenTreeSubtree(&tree, 1), &data);
  if (GenTreeGetSize(&tree) != 3) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeGetSize failed");
    PBErrCatch(GenTreeErr);
  }
  GenTree* cuttree = GenTreeSubtree(&tree, 1);
  GenTreeCut(cuttree);
  if (GenTreeGetSize(&tree) != 1 ||
    GenTreeGetSize(cuttree) != 1) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeCut failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeFreeStatic(&tree);
  GenTreeFree(&cuttree);
  printf("UnitTestGenTreeCutGetSize OK\n");
}

void UnitTestGenTree() {
  UnitTestGenTreeCreateFree();
  UnitTestGenTreeGetSet();
  UnitTestGenTreeCutGetSize();
  printf("UnitTestGenTree OK\n");
}

int dataExampleTree[10] = {0,1,2,3,4,5,6,7,8,9};
GenTree* GetExampleTree() {
  GenTree* tree = GenTreeCreate();
  GenTreeAddSortData(tree, dataExampleTree + 0, 0);
  GenTreeAddSortData(tree, dataExampleTree + 9, 9);
  GenTree* subtree = GenTreeSubtree(tree, 0);
  GenTreeAddSortData(subtree, dataExampleTree + 1, 1);
  GenTreeAddSortData(subtree, dataExampleTree + 2, 2);
  subtree = GenTreeSubtree(tree, 1);
  GenTreeAddSortData(subtree, dataExampleTree + 3, 3);
  GenTreeAddSortData(subtree, dataExampleTree + 4, 4);
  subtree = GenTreeSubtree(subtree, 0);
  GenTreeAddSortData(subtree, dataExampleTree + 8, 8);
  GenTreeAddSortData(subtree, dataExampleTree + 6, 6);
  subtree = GenTreeSubtree(subtree, 1);
  GenTreeAddSortData(subtree, dataExampleTree + 7, 7);
  GenTreeAddSortData(subtree, dataExampleTree + 5, 5);
  return tree;
}
```

```
void funApply(void* data, void* param) {
  printf("%d%c", *(int*)data,*(char*)param);
}

void UnitTestGenTreeIterDepth() {
  GenTree* tree = GetExampleTree();
  GenTreeIterDepth* iter = GenTreeIterDepthCreate(tree);
  if (iter == NULL ||
    iter->_iter._tree != tree ||
    GSetNbElem(&(iter->_iter._seq)) != 10 ||
    iter->_iter._curPos != iter->_iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterDepthCreate failed");
    PBErrCatch(GenTreeErr);
  }
  int check[10] = {0,1,2,9,3,6,8,5,7,4};
  int iCheck = 0;
  do {
    int* data = GenTreeIterGetData(iter);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterDepth failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
  } while (GenTreeIterStep(iter));
  GenTreeIterFree(&iter);
  if (iter != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterFree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterDepth iterstatic = GenTreeIterDepthCreateStatic(tree);
  if (iterstatic._iter._tree != tree ||
    GSetNbElem(&(iterstatic._iter._seq)) != 10 ||
    iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterDepthCreateStatic failed");
    PBErrCatch(GenTreeErr);
  }
  iCheck = 0;
  do {
    int* data = GenTreeIterGetData(&iterstatic);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterDepth failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
  } while (GenTreeIterStep(&iterstatic));
  check[3] = 12;
  dataExampleTree[9] = 12;
  GenTreeIterDepthUpdate(&iterstatic);
  iCheck = 0;
  do {
    int* data = GenTreeIterGetData(&iterstatic);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterUpdate failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
```

```
} while (GenTreeIterStep(&iterstatic));
dataExampleTree[9] = 9;
GenTreeIterReset(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterReset failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGetGenTree(&iterstatic) != GenTreeSubtree(tree, 0)) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterGetGenTree failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterToEnd(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterToEnd failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterStepBack(&iterstatic);
if (iterstatic._iter._curPos->_next !=
  iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterStepBack failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGenTree(&iterstatic) != tree) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterGenTree failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterSeq(&iterstatic) != &(iterstatic._iter._seq)) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterSeq failed");
  PBErrCatch(GenTreeErr);
}
char c = ',';
GenTreeIterApply(&iterstatic, &funApply, &c);
printf("\n");
GenTree* treeB = GenTreeCreate();
GenTreeIterSetGenTree(&iterstatic, treeB);
if (GenTreeIterGenTree(&iterstatic) != treeB ||
```

```
    GSetNbElem(&(iterstatic._iter._seq)) != 0) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterSetGenTree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterFreeStatic(&iterstatic);
  GenTreeFree(&tree);
  GenTreeFree(&treeB);
  printf("UnitTestGenTreeIterDepth OK\n");
}

void UnitTestGenTreeIterBreadth() {
  GenTree* tree = GetExampleTree();
  GenTreeIterBreadth* iter = GenTreeIterBreadthCreate(tree);
  if (iter == NULL ||
    iter->_iter._tree != tree ||
    GSetNbElem(&(iter->_iter._seq)) != 10 ||
    iter->_iter._curPos != iter->_iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterBreadthCreate failed");
    PBErrCatch(GenTreeErr);
  }
  int check[10] = {0,9,1,2,3,4,6,8,5,7};
  int iCheck = 0;
  do {
    int* data = GenTreeIterGetData(iter);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterBreadth failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
  } while (GenTreeIterStep(iter));
  GenTreeIterFree(&iter);
  if (iter != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterFree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterBreadth iterstatic = GenTreeIterBreadthCreateStatic(tree);
  if (iterstatic._iter._tree != tree ||
    GSetNbElem(&(iterstatic._iter._seq)) != 10 ||
    iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterBreadthCreateStatic failed");
    PBErrCatch(GenTreeErr);
  }
  iCheck = 0;
  do {
    int* data = GenTreeIterGetData(&iterstatic);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterBreadth failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
  } while (GenTreeIterStep(&iterstatic));
  check[1] = 12;
  dataExampleTree[9] = 12;
  GenTreeIterBreadthUpdate(&iterstatic);
  iCheck = 0;
  do {
```

```
  int* data = GenTreeIterGetData(&iterstatic);
  if (*data != check[iCheck]) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterUpdate failed");
    PBErrCatch(GenTreeErr);
  }
  ++iCheck;
} while (GenTreeIterStep(&iterstatic));
dataExampleTree[9] = 9;
GenTreeIterReset(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterReset failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGetGenTree(&iterstatic) != GenTreeSubtree(tree, 0)) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterGetGenTree failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterToEnd(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterToEnd failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterStepBack(&iterstatic);
if (iterstatic._iter._curPos->_next !=
  iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterStepBack failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGenTree(&iterstatic) != tree) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterGenTree failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterSeq(&iterstatic) != &(iterstatic._iter._seq)) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterSeq failed");
  PBErrCatch(GenTreeErr);
```

```
  }
  char c = ',';
  GenTreeIterApply(&iterstatic, &funApply, &c);
  printf("\n");
  GenTree* treeB = GenTreeCreate();
  GenTreeIterSetGenTree(&iterstatic, treeB);
  if (GenTreeIterGenTree(&iterstatic) != treeB ||
    GSetNbElem(&(iterstatic._iter._seq)) != 0) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterSetGenTree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterFreeStatic(&iterstatic);
  GenTreeFree(&tree);
  GenTreeFree(&treeB);
  printf("UnitTestGenTreeIterBreadth OK\n");
}

void UnitTestGenTreeIterValue() {
  GenTree* tree = GetExampleTree();
  GenTreeIterValue* iter = GenTreeIterValueCreate(tree);
  if (iter == NULL ||
    iter->_iter._tree != tree ||
    GSetNbElem(&(iter->_iter._seq)) != 10 ||
    iter->_iter._curPos != iter->_iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterValueCreate failed");
    PBErrCatch(GenTreeErr);
  }
  int check[10] = {0,1,2,3,4,5,6,7,8,9};
  int iCheck = 0;
  do {
    int* data = GenTreeIterGetData(iter);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterValue failed");
      PBErrCatch(GenTreeErr);
    }
    ++iCheck;
  } while (GenTreeIterStep(iter));
  GenTreeIterFree(&iter);
  if (iter != NULL) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterFree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterValue iterstatic = GenTreeIterValueCreateStatic(tree);
  if (iterstatic._iter._tree != tree ||
    GSetNbElem(&(iterstatic._iter._seq)) != 10 ||
    iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterValueCreateStatic failed");
    PBErrCatch(GenTreeErr);
  }
  iCheck = 0;
  do {
    int* data = GenTreeIterGetData(&iterstatic);
    if (*data != check[iCheck]) {
      GenTreeErr->_type = PBErrTypeUnitTestFailed;
      sprintf(GenTreeErr->_msg, "GenTreeIterValue failed");
      PBErrCatch(GenTreeErr);
    }
```

```
  ++iCheck;
} while (GenTreeIterStep(&iterstatic));
check[9] = 12;
dataExampleTree[9] = 12;
GenTreeIterValueUpdate(&iterstatic);
iCheck = 0;
do {
  int* data = GenTreeIterGetData(&iterstatic);
  if (*data != check[iCheck]) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterUpdate failed");
    PBErrCatch(GenTreeErr);
  }
  ++iCheck;
} while (GenTreeIterStep(&iterstatic));
dataExampleTree[9] = 9;
GenTreeIterReset(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._head) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterReset failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGetGenTree(&iterstatic) != GenTreeSubtree(tree, 0)) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterGetGenTree failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterToEnd(&iterstatic);
if (iterstatic._iter._curPos != iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterToEnd failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsFirst(&iterstatic) == true) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsFirst failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterIsLast(&iterstatic) == false) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterIsLast failed");
  PBErrCatch(GenTreeErr);
}
GenTreeIterStepBack(&iterstatic);
if (iterstatic._iter._curPos->_next !=
  iterstatic._iter._seq._set._tail) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
  sprintf(GenTreeErr->_msg, "GenTreeIterStepBack failed");
  PBErrCatch(GenTreeErr);
}
if (GenTreeIterGenTree(&iterstatic) != tree) {
  GenTreeErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(GenTreeErr->_msg, "GenTreeIterGenTree failed");
    PBErrCatch(GenTreeErr);
  }
  if (GenTreeIterSeq(&iterstatic) != &(iterstatic._iter._seq)) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterSeq failed");
    PBErrCatch(GenTreeErr);
  }
  char c = ',';
  GenTreeIterApply(&iterstatic, &funApply, &c);
  printf("\n");
  GenTree* treeB = GenTreeCreate();
  GenTreeIterSetGenTree(&iterstatic, treeB);
  if (GenTreeIterGenTree(&iterstatic) != treeB ||
    GSetNbElem(&(iterstatic._iter._seq)) != 0) {
    GenTreeErr->_type = PBErrTypeUnitTestFailed;
    sprintf(GenTreeErr->_msg, "GenTreeIterSetGenTree failed");
    PBErrCatch(GenTreeErr);
  }
  GenTreeIterFreeStatic(&iterstatic);
  GenTreeFree(&tree);
  GenTreeFree(&treeB);
  printf("UnitTestGenTreeIterValue OK\n");
}

void UnitTestGenTreeIter() {
  UnitTestGenTreeIterDepth();
  UnitTestGenTreeIterBreadth();
  UnitTestGenTreeIterValue();
  printf("UnitTestGenTreeIter OK\n");
}

void UnitTestAll() {
  UnitTestGenTree();
  UnitTestGenTreeIter();
  printf("UnitTestAll OK\n");
}

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

5 Unit tests output

```
UnitTestGTreeCreateFree OK
UnitTestGTreeGetSet OK
UnitTestGTreeCutGetSize OK
UnitTestGTree OK
0,1,2,9,3,6,8,5,7,4,
UnitTestGTreeIterDepth OK
0,9,1,2,3,4,6,8,5,7,
UnitTestGTreeIterBreadth OK
0,1,2,3,4,5,6,7,8,9,
UnitTestGTreeIterValue OK
UnitTestGTreeIter OK
UnitTestAll OK
```