Shapoid

P. Baillehache

May 13, 2020

Contents

Introduction

Shapoid is a C library providing the `Shapoid` structure and its functions which can be used to manipulate Shapoid objects (see next section for details).

It also provides the `ShapoidIter` structure and its functions which can be used to sequantially loop through the surface/volume/... of a `Shapoid`.

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

1 Definitions

A Shapoid is a geometry defined by its dimension $D \in \mathbb{N}_+^*$ equals to the number of dimensions of the space it exists in, its position $\overrightarrow{P}$, and its axis $(\overrightarrow{A_0}, \overrightarrow{A_1}, ..., \overrightarrow{A_{D-1}})$. A_i and P are vectors of dimension D. In what follows I'll use I as notation for the interval $[0, D-1]$ for simplification.

Shapoids are classified in three groups: Facoid, Pyramidoid and Spheroid. The volume of a Shapoid is defined by, for a Facoid:

$$\left\{\sum_{i \in I} v_i \overrightarrow{A_i} + \overrightarrow{P}\right\}, v_i \in [0.0, 1.0] \tag{1}$$

for a Pyramidoid:

$$\left\{\sum_{i \in I} v_i \overrightarrow{A_i} + \overrightarrow{P}\right\}, v_i \in [0.0, 1.0], \sum_{i \in I} v_i \leq 1.0 \tag{2}$$

and for a Spheroid:

$$\begin{array}{c}\left\{\sum_{i \in I} v_i \overrightarrow{A_i} + \overrightarrow{P}\right\}, \\ v_i \in [-0.5, 0.5], \quad \sum_{i \in I} v_i^2 \leq 0.25\end{array} \tag{3}$$

1.1 Transformation

A translation of a Shapoid by $\overrightarrow{T}$ is obtained as follow:

$$\left(\overrightarrow{P}, \left\{\overrightarrow{A_i}\right\}_{i \in I}\right) \mapsto \left(\overrightarrow{P} + \overrightarrow{T}, \left\{\overrightarrow{A_i}\right\}_{i \in I}\right) \tag{4}$$

A scale of a Shapoid by $\overrightarrow{S}$ is obtained as follow:

$$\left(\overrightarrow{P}, \left\{\overrightarrow{A_i}\right\}_{i \in I}\right) \mapsto \left(\overrightarrow{P}, \left\{\overrightarrow{A_i'}\right\}_{i \in I}\right) \tag{5}$$

where

$$\overrightarrow{A_i'} = S_i \overrightarrow{A_i} \tag{6}$$

For Shapoid whose dimension D is equal to 2, a rotation by angle θ is obtained as follow:

$$\left(\overrightarrow{P}, \overrightarrow{A_0}, \overrightarrow{A_1}\right) \mapsto \left(\overrightarrow{P}, \overrightarrow{A_0'}, \overrightarrow{A_1'}\right) \tag{7}$$

where

$$\overrightarrow{A_i'} = \left[\begin{array}{cc} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{array}\right] \overrightarrow{A_i} \tag{8}$$

1.2 Shapoid's coordinate system

The Shapoid's coordinate system is the system having $\overrightarrow{P}$ as origin and $\overrightarrow{A_i}$ as axis. One can change from the Shapoid's coordinate system ($\overrightarrow{X^S}$) to the standard coordinate system ($\overrightarrow{X}$) as follow:

$$\overrightarrow{X} = \left[\left(\overrightarrow{A_0}\right)\left(\overrightarrow{A_1}\right)...\left(\overrightarrow{A_{D-1}}\right)\right]\overrightarrow{X^S} + \overrightarrow{P} \tag{9}$$

and reciprocally, from the standard coordinate system to the Shapoid's coordinate system:

$$\overrightarrow{X^S} = \left[\left(\overrightarrow{A_0}\right)\left(\overrightarrow{A_1}\right)...\left(\overrightarrow{A_{D-1}}\right)\right]^{-1}\left(\overrightarrow{X} - \overrightarrow{P}\right) \tag{10}$$

1.3 Insideness

$\overrightarrow{X}$ is inside the Shapoid S if, for a Facoid:

$$\forall i \in I, 0.0 \leq X_i^S \leq 1.0 \tag{11}$$

for a Pyramidoid:

$$\left\{\begin{array}{l} \forall i \in I, 0.0 \leq X_i^S \leq 1.0 \\ \sum_{i\in I} X_i^S \leq 1.0 \end{array}\right. \tag{12}$$

for a Spheroid:

$$\left|\left|\overrightarrow{X^S}\right|\right| \leq 0.5 \tag{13}$$

1.4 Bounding box

A bounding box of a Shapoid is a Facoid whose axis are colinear to axis of the standard coordinate system, and including the Shapoid in its volume. While the smallest possible bounding box can be easily obtained for Facoid and Pyramidoid, it's more complicate for Spheroid. Then we

will consider for the Spheroid the bounding box of the equivalent Facoid $\left(\overrightarrow{P} - \sum_{i\in I}\left(0.5 * \overrightarrow{A_i}\right), \left\{\overrightarrow{A_i}\right\}_{i\in I}\right)$ which gives the smallest bounding box when axis of the Spheroid are colinear to axis of the standard coordinate system and a bounding box slightly too large when not colinear.
The bounding box is defined as follow, for a Facoid:

$$\left(\overrightarrow{P'}, \left\{\overrightarrow{A'_i}\right\}_{i\in I}\right) \tag{14}$$

where

$$\begin{cases} P'_i = P_i + \sum_{j\in I^-} A_{ji} \\ A'_{ij} = 0.0, i \neq j \\ A'_{ij} = \sum_{k\in I^+} A_{kj} - \sum_{k\in I^-} A_{kj}, i = j \end{cases} \tag{15}$$

and, I^+ and I^- are the subsets of I such as $\forall j \in I^+, A_{ij} \geq 0.0$ and $\forall j \in I^-, A_{ij} < 0.0$.

for a Pyramidoid:

$$\left(\overrightarrow{P'}, \left\{\overrightarrow{A'_i}\right\}_{i\in I}\right) \tag{16}$$

where

$$\begin{cases} P'_i = P_i + Min\left(Min_{j\in I}(A_{ji}), 0.0\right) \\ A'_{ij} = 0.0, i \neq j \\ A'_{ij} = Max_{k\in I}(A_{kj}) - Min_{k\in I}(A_{kj}), i = j \end{cases} \tag{17}$$

1.5 Depth and Center

Depth $\mathbf{D}_S(\overrightarrow{X})$ of position $\overrightarrow{X}$ a Shapoid S is a value ranging from 0.0 if $\overrightarrow{X}$ is on the surface of the Shapoid, to 1.0 if $\overrightarrow{X}$ is at the farthest location from the surface inside the Shapoid. Depth is by definition equal to 0.0 if $\overrightarrow{X}$ is outside the Shapoid. Depth is continuous and derivable on the volume of the Shapoid. It is defined by, for a Facoid:

$$\mathbf{D}_S(\overrightarrow{X}) = \prod_{i\in I}\left(1.0 - 4.0 * (0.5 - X_i^S)^2\right) \tag{18}$$

for a Pyramidoid:

$$\mathbf{D}_S(\overrightarrow{X}) = \prod_{i\in I}\left(1.0 - 4.0 * \left(0.5 - \frac{X_i^S}{1.0 - \sum_{j\in I-\{i\}} X_j^S}\right)^2\right) \tag{19}$$

and for a Spheroid:

$$\mathbf{D}_S(\overrightarrow{X}) = 1.0 - 2.0 * \left|\left|\overrightarrow{X^S}\right|\right| \tag{20}$$

The maximum depth is obtained at $\overrightarrow{C}$ such as, for a Facoid:

$$\forall i \in I, C_i^S = 0.5 \tag{21}$$

for a Pyramidoid:

$$\forall i \in I, C_i^S = \frac{1}{D+1} \tag{22}$$

for a Spheroid:

$$\forall i \in I, C_i^S = 0.0 \tag{23}$$

$\overrightarrow{C}$ is called the center of the Shapoid.

1.6 Iterator on Spheroid

While a sequential path through a Facoid and a Pyramidoid is obvious, path through a Spheroid is more complex. The solution implemented is described below.

Given a Spheroid of dimension N we start from an arbitrary position: $< 0, 0, ..., -0.5 >$. From there we step the axis starting from the first one. If we could step an axis the step algorithm stops and return the new position as it could successfully step. However, if we could step on an axis other than the first one, it means we have modified the constraint for previous axis, the constraint being "is inside the spheroid". Then we reposition the axis before the stepped one to its lower possible value. It will allow it to step again at the next iteration on a new boundary defined by other axis values, and this scale up naturally to any dimension. Care must be care to the case when an axis reaches its upper value: the delta given by the user and the influence of other axis value make it jumps "over" the boundary in most cases. To keep things neat and clean we recalculate the exact value of the axis for its last step instead of using the delta given by the user.

The calculation of the lower and upper values of an axis given the values of other axis can be performed as follow:

Lets note $\overrightarrow{P} =< p_0, p_1, ..., p_{N-1} >$ the position in a Spheroid of dimension N. A position will be on the boundary of the Spheroid if and only if $||\overrightarrow{P}|| = 0.5$. We want to calculate α which bring a position $\overrightarrow{P'}$ inside the Spheroid to a position $\overrightarrow{P}$ on the boundary of the Spheroid by modifying the axis i (i.e. $p_i = p'_i + \alpha$ and $p_j = p'_j, j \neq i$). Lets note $n = ||\overrightarrow{P'}||$. We have:

$$p_0'^2 + p_1'^2 + ... + p_i'^2 + ... + p_{N-1}'^2 = n^2 \tag{24}$$

and

$$p_0^2 + p_1^2 + ... + p_i^2 + ... + p_{N-1}^2 = 0.25 \tag{25}$$

equivalent to

$$p_0'^2 + p_1'^2 + ... + (p'_i + \alpha)^2 + ... + p_{N-1}'^2 = 0.25 \tag{26}$$

by substracting (24) and (26) we have

$$p_i'^2 - (p'_i + \alpha)^2 = n^2 - 0.25 \tag{27}$$

equivalent to

$$p_i'^2 - (p_i'^2 + \alpha^2 + 2p'_i\alpha) = n^2 - 0.25 \tag{28}$$

equivalent to

$$-\alpha^2 - 2p'_i\alpha - (n^2 - 0.25) = 0 \tag{29}$$

simplified to

$$\alpha^2 + 2p'_i\alpha + (n^2 - 0.25) = 0 \tag{30}$$

This quadratic equation can be solved directly to obtain α:

$$\alpha = \frac{-2p'_i \pm \sqrt{4p_i'^2 - 4(n^2 - 0.25)}}{2} \tag{31}$$

Which gives the two solutions defining the lower and upper boundaries of the Spheroid on the axis i.

This result can then be used to solve our problem with what I'll call the "Wormy Algorithm":

```
flag := true
norm := Norm(P)
iDim := 0
loop until (iDim < N and flag == true)
  prevNorm := norm
  P_iDim := P_iDim + delta
  norm := Norm(P)
  if (prevNorm < 0.5 and norm > 0.5)
    P_iDim := 0
    norm := Norm(P)
    val :=  0.5 * Sqrt(-4.0 * (norm^2 - 0.25))
    P_iDim := val
    norm := 0.5
    flag := false
    iDim := iDim - 1
  else
    if (norm > 0.5)
      P_iDim := 0
    else
      flag := false
      iDim := iDim - 1
    end if
  end if
  iDim := iDim + 1
end loop
if (flag == false)
  iDim := iDim - 1
  if (iDim >= 0)
    P_iDim := P_iDim + 0.5 * (-2.0 * P_iDim -
      Sqrt(4.0 * (P_iDim)^2 - 4.0 * (norm^2 - 0.25)))
  end if
end if
return Not(flag)
```

This algorithm step P to the next position in the path by *delta* and returns true if we haven't reached the end of the path, or false if we have reached the end of the path (i.e. if we have iterated through all the surface/volume/... of the Spheroid). Remember that P must be initialised to $< 0, 0, ..., -0.5 >$ as the beginning of the path, and that `ShapoidIter` iterates coordinates in the Shapoid's coordinate system.

1.7 Collision detection of Spheroid

The detection of collision between two Spheroids is done as follow. One of the spheroid is converted into the coordinates system of the other and checked against a circle of radius 0.5 centered at the origin of the system. By checking that the position of the converted Spheroid is less than its minor radius plus 0.5 or more than its major radius plus 0.5, the trivial cases of, respectively, interesection and non intersection can be performed. In other cases an incremental search from the center of the converted Spheroid toward the nearest point to the origin inside this Spheroid is performed. The intersection can then be checked by testing if the distance of this point to the origin is less or equal than 0.5.

1.8 Collision detection between Facoid and Pyramidoid

The intersection detection is impletemented for 2D and 3D static cases only. For optimal performance, in 2D the SAT algorithm is used, in 3D the FMB algorithm is used.

2 Interface

```
// ============ SHAPOID.H ================

#ifndef SHAPOID_H
#define SHAPOID_H

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

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

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

#define CloneShapoidType(T) typedef struct T {Shapoid _s;} T

#define SpheroidCreate(Dim) \
  (Spheroid*)ShapoidCreate(Dim, ShapoidTypeSpheroid)
#define FacoidCreate(Dim) \
  (Facoid*)ShapoidCreate(Dim, ShapoidTypeFacoid)
#define PyramidoidCreate(Dim) \
  (Pyramidoid*)ShapoidCreate(Dim, ShapoidTypePyramidoid)

#define ShapoidGetCoverage(ShapoidA, ShapoidB) \
  _ShapoidGetCoverageDelta((Shapoid* const)ShapoidA, \
  (Shapoid* const)ShapoidB, 0.1)
#define ShapoidGetCoverageDelta(ShapoidA, ShapoidB, Prec) \
  _ShapoidGetCoverageDelta((Shapoid* const)ShapoidA, \
  (Shapoid* const)ShapoidB, Prec)

#define ShapoidIterCreateStatic(Shap, Delta) \
  _ShapoidIterCreateStatic((Shapoid* const)(Shap), (VecFloat*)(Delta))

#define ShapoidIterSetShapoid(Iter, Shap) \
  _ShapoidIterSetShapoid(Iter, (Shapoid* const)(Shap))
```

```
#define ShapoidIterSetDelta(Iter, Delta) \
  _ShapoidIterSetDelta(Iter, (VecFloat* const)(Delta))

extern const char* ShapoidTypeString[3];

// -------------- ShapoidIter

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

typedef enum ShapoidType {
  ShapoidTypeFacoid, ShapoidTypeSpheroid,
  ShapoidTypePyramidoid
} ShapoidType;
// Don't forget to update ShapoidTypeString in shapoid.c when adding
// new type

typedef struct Shapoid {
  // Position of origin
  VecFloat* _pos;
  // Dimension
  const int _dim;
  // Vectors defining axes
  VecFloat** _axis;
  // Type of Shapoid
  const ShapoidType _type;
  // Linear sytem used to import coordinates
  SysLinEq* _sysLinEqImport;
} Shapoid;

CloneShapoidType(Facoid);
CloneShapoidType(Pyramidoid);
typedef struct Spheroid {
  Shapoid _s;
  // Major and minor axis for optimization
  int _majAxis;
  int _minAxis;
} Spheroid;
//CloneShapoidType(Spheroid);

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

// Create a Shapoid of dimension 'dim' and type 'type', default values:
// _pos = null vector
// _axis[d] = unit vector along dimension d
Shapoid* ShapoidCreate(const int dim, const ShapoidType type);

// Clone a Shapoid
Shapoid* _ShapoidClone(const Shapoid* const that);
static inline Facoid* FacoidClone(const Facoid* const that) {
  return (Facoid*)_ShapoidClone((const Shapoid*)that);
}
static inline Pyramidoid* PyramidoidClone(const Pyramidoid* const that) {
  return (Pyramidoid*)_ShapoidClone((const Shapoid*)that);
}
static inline Spheroid* SpheroidClone(const Spheroid* const that) {
  return (Spheroid*)_ShapoidClone((const Shapoid*)that);
}

// Free memory used by a Shapoid
void _ShapoidFree(Shapoid** that);

// Function which return the JSON encoding of 'that'
```

```
JSONNode* _ShapoidEncodeAsJSON(const Shapoid* const that);

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

// Load the Shapoid of type 'type' from the stream
// If the Shapoid is already allocated, it is freed before loading
// Return true upon success else false
bool _ShapoidLoad(Shapoid** that, FILE* const stream);
#if BUILDMODE != 0
static inline
#endif
bool FacoidLoad(Facoid** that, FILE* const stream);
#if BUILDMODE != 0
static inline
#endif
bool PyramidoidLoad(Pyramidoid** that, FILE* const stream);
#if BUILDMODE != 0
static inline
#endif
bool SpheroidLoad(Spheroid** that, FILE* const stream);

// Save the Shapoid to the stream
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true upon success else false
bool _ShapoidSave(const Shapoid* const that, FILE* const stream,
  const bool compact);

// Print the Shapoid on 'stream'
void _ShapoidPrintln(const Shapoid* const that, FILE* const stream);

// Get the dimension of the Shapoid
#if BUILDMODE != 0
static inline
#endif
int _ShapoidGetDim(const Shapoid* const that);

// Get the type of the Shapoid
#if BUILDMODE != 0
static inline
#endif
ShapoidType _ShapoidGetType(const Shapoid* const that);

// Get the type of the Shapoid as a string
// Return a pointer to a constant string (not to be freed)
#if BUILDMODE != 0
static inline
#endif
const char* _ShapoidGetTypeAsString(const Shapoid* const that);

// Return a VecFloat equals to the position of the Shapoid
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetPos(const Shapoid* const that);

// Return a VecFloat equals to the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetAxis(const Shapoid* const that, const int dim);
```

```
// Return the position of the Shapoid
#if BUILDMODE != 0
static inline
#endif
const VecFloat* _ShapoidPos(const Shapoid* const that);

// Return the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
const VecFloat* _ShapoidAxis(const Shapoid* const that, const int dim);

// Set the position of the Shapoid to 'pos'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetPos(Shapoid* const that, const VecFloat* const pos);

// Set the 'iElem'-th value of the position of the Shapoid to 'val'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidPosSet(Shapoid* const that, const int iElem,
  const float val);

// Set the 'iElem'-th value of the position of the Shapoid to 'val'
// added to its current value
#if BUILDMODE != 0
static inline
#endif
void _ShapoidPosSetAdd(Shapoid* const that, const int iElem,
  const float val);

// Get the 'iElem'-th value of the position of the Shapoid
#if BUILDMODE != 0
static inline
#endif
float _ShapoidPosGet(const Shapoid* const that, const int iElem);

// Set the position of the Shapoid such as its center is at 'pos'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetCenterPos(Shapoid* const that,
  const VecFloat* const pos);

// Set the 'dim'-th axis of the Shapoid to 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetAxis(Shapoid* const that, const int dim,
  const VecFloat* const v);

// Set all the axis of the Shapoid to vectors in 'set' (axis in
// dimensions order
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetAllAxis(Shapoid* const that, GSetVecFloat* const set);

// Set the 'iElem'-th element of the 'dim'-th axis of the Shapoid to 'v'
```

```
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisSet(Shapoid* const that, const int dim,
  const int iElem, const float v);

// Set the 'iElem'-th element of the 'dim'-th axis of the Shapoid to
// 'v' added to its current value
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisSetAdd(Shapoid* const that, const int dim,
  const int iElem, const float v);

// Get the 'iElem'-th element of the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
float _ShapoidAxisGet(const Shapoid* const that, const int dim,
  const int iElem);

// Scale the 'dim'-th axis of the Shapoid by 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisScale(Shapoid* const that, const int dim,
  const float v);

// Translate the Shapoid by 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidTranslate(Shapoid* const that, const VecFloat* const v);

// Scale the Shapoid by 'v' (each axis is multiplied by v[iAxis])
#if BUILDMODE != 0
static inline
#endif
void _ShapoidScaleVector(Shapoid* const that, const VecFloat* const v);

// Scale the Shapoid by 'c'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidScaleScalar(Shapoid* const that, const float c);

// Scale the Shapoid by 'v' (each axis is multiplied by v[iAxis])
// and translate the Shapoid such as its center after scaling
// is at the same position than before scaling
#if BUILDMODE != 0
static inline
#endif
void _ShapoidGrowVector(Shapoid* const that, const VecFloat* const v);

// Scale the Shapoid by 'c'
// and translate the Shapoid such as its center after scaling
// is at the same position than before scaling
#if BUILDMODE != 0
static inline
#endif
void _ShapoidGrowScalar(Shapoid* const that, const float c);
```

```
// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to its center
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotCenter(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to its position
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotStart(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotOrigin(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisCenter(Shapoid* const that,
  const VecFloat3D* const axis, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisStart(Shapoid* const that,
  const VecFloat3D* const axis, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisOrigin(Shapoid* const that,
  const VecFloat3D* const axis, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXCenter(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXStart(Shapoid* const that, const float theta);
```

```
// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXOrigin(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYCenter(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYStart(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYOrigin(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZCenter(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZStart(Shapoid* const that, const float theta);

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZOrigin(Shapoid* const that, const float theta);

// Convert the coordinates of 'pos' from standard coordinate system
// toward the Shapoid coordinates system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidImportCoord(const Shapoid* const that,
  const VecFloat* const pos);

// Convert the coordinates of 'pos' from the Shapoid coordinates system
// toward standard coordinate system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidExportCoord(const Shapoid* const that,
  const VecFloat* const pos);

// Return true if 'pos' (in standard coordinates system) is inside the
// Shapoid
// Else return false
#if BUILDMODE != 0
static inline
#endif
bool _ShapoidIsPosInside(const Shapoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
static inline
#endif
bool FacoidIsPosInside(const Facoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
static inline
#endif
bool PyramidoidIsPosInside(const Pyramidoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
static inline
#endif
bool SpheroidIsPosInside(const Spheroid* const that,
  const VecFloat* const pos);

// Get a bounding box of the Shapoid. The bounding box is aligned
// on the standard coordinate system (its axis are colinear with
// the axis of the standard coordinate system).
// The bounding box is returned as a Facoid, which position is
// at the minimum value along each axis.
Facoid* _ShapoidGetBoundingBox(const Shapoid* const that);
Facoid* FacoidGetBoundingBox(const Facoid* const that);
Facoid* PyramidoidGetBoundingBox(const Pyramidoid* const that);
Facoid* SpheroidGetBoundingBox(const Spheroid* const that);

// Get the bounding box of a set of Facoid. The bounding box is aligned
// on the standard coordinate system (its axis are colinear with
// the axis of the standard coordinate system).
// The bounding box is returned as a Facoid, which position is
// at the minimum value along each axis.
Facoid* ShapoidGetBoundingBoxSet(const GSetShapoid* const set);

// Get the depth value in the Shapoid of 'pos' in standard coordinate
// system
// The depth is defined as follow: the point with depth equals 1.0 is
// the farthest point from the surface of the Shapoid (inside it),
// points with depth equals to 0.0 are point on the surface of the
// Shapoid. Depth is continuous and derivable over the volume of the
// Shapoid
// Return 0.0 if pos is outside the Shapoid
#if BUILDMODE != 0
static inline
#endif
float _ShapoidGetPosDepth(const Shapoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
```

```
static inline
#endif
float FacoidGetPosDepth(const Facoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
static inline
#endif
float PyramidoidGetPosDepth(const Pyramidoid* const that,
  const VecFloat* const pos);
#if BUILDMODE != 0
static inline
#endif
float SpheroidGetPosDepth(const Spheroid* const that,
  const VecFloat* const pos);

// Get the center of the shapoid in standard coordinate system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetCenter(const Shapoid* const that);
#if BUILDMODE != 0
static inline
#endif
VecFloat* FacoidGetCenter(const Facoid* const that);
#if BUILDMODE != 0
static inline
#endif
VecFloat* PyramidoidGetCenter(const Pyramidoid* const that);
#if BUILDMODE != 0
static inline
#endif
VecFloat* SpheroidGetCenter(const Spheroid* const that);

// Get the percentage of 'tho' included into 'that' (in [0.0, 1.0])
// 0.0 -> 'tho' is completely outside of 'that'
// 1.0 -> 'tho' is completely inside of 'that'
// 'that' and 'tho' must me of same dimensions
// delta is the step of the algorithm (in ]0.0, 1.0])
// small -> slow but precise
// big -> fast but rough
float _ShapoidGetCoverageDelta(const Shapoid* const that,
  const Shapoid* const tho, const float delta);

// Update the system of linear equation used to import coordinates
#if BUILDMODE != 0
static inline
#endif
void ShapoidUpdateSysLinEqImport(Shapoid* const that);

// Check if shapoid 'that' and 'tho' are equals
#if BUILDMODE != 0
static inline
#endif
bool _ShapoidIsEqual(const Shapoid* const that,
  const Shapoid* const tho);

// Add a copy of the Facoid 'that' to the GSet 'set' (containing
// other Facoid), taking care to avoid overlaping Facoid
// The copy of 'that' may be resized or divided
// The Facoid in the set and 'that' must be aligned with the
// coordinates system axis and have
// same dimensions
```

```
void FacoidAlignedAddClippedToSet(const Facoid* const that,
  GSetShapoid* const set);

// Check if the Facoid 'that' is completely included into the Facoid
// 'facoid'
// Both Facoid must be aligned with the coordinates system and have
// same dimensions
// Return true if it is included, false else
bool FacoidAlignedIsInsideFacoidAligned(const Facoid* const that,
  const Facoid* const facoid);

// Check if the Facoid 'that' is completely excluded from the Facoid
// 'facoid'
// Both Facoid must be aligned with the coordinates system and have
// same dimensions
// Return true if it is excluded, false else
bool FacoidAlignedIsOutsideFacoidAligned(const Facoid* const that,
  const Facoid* const facoid);

// Get a GSet of Facoid aligned with coordinates system covering the
// Facoid 'that' except for area in the Facoid 'facoid'
// Both Facoid must be aligned with the coordinates system and have
// same dimensions
GSetShapoid* FacoidAlignedSplitExcludingFacoidAligned(
  const Facoid* const that, const Facoid* const facoid);

// Return true if 'that' intersects 'tho'
// Return false else
// 'that' and 'tho' must have same dimension
bool _SpheroidIsInterSpheroid(const Spheroid* const that,
  const Spheroid* const tho);
bool _FacoidIsInterFacoid(const Facoid* const that,
  const Facoid* const tho);
bool _FacoidIsInterPyramidoid(const Facoid* const that,
  const Pyramidoid* const tho);
bool _PyramidoidIsInterFacoid(const Pyramidoid* const that,
  const Facoid* const tho);
bool _PyramidoidIsInterPyramidoid(const Pyramidoid* const that,
  const Pyramidoid* const tho);

// Update the major and minor axis of the Spheroid 'that'
void SpheroidUpdateMajMinAxis(Spheroid* const that);

// Get the maximum distance from the center of the Shapoid 'that' and
// its surface
// Currenty only defined for spheroid, return 0.0 else
float _ShapoidGetBoundingRadius(const Shapoid* const that);

// -------------- ShapoidIter

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

typedef struct ShapoidIter {
  // Attached shapoid
  const Shapoid* _shap;
  // Delta step
  VecFloat* _delta;
  // Current position (in internal coordinates of the shapoid)
  VecFloat* _pos;
} ShapoidIter;

// ================ Functions declaration ====================
// Create a new iterator on the Shapoid 'shap' with a step of 'delta'
// (step on the internal coordinates of the Shapoid)
// The iterator is initialized and ready to be stepped
ShapoidIter _ShapoidIterCreateStatic(const Shapoid* const shap,
  const VecFloat* const delta);

// Free the memory used by the ShapoidIter 'that'
void ShapoidIterFreeStatic(ShapoidIter* const that);

// Reinitialise the ShapoidIter 'that' to its starting position
void ShapoidIterInit(ShapoidIter* const that);

// Step the ShapoidIter 'that'
// Return false if the iterator is at its end and couldn't be stepped
bool ShapoidIterStep(ShapoidIter* const that);

// Return the current position in Shapoid coordinates of the
// ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
VecFloat* ShapoidIterGetInternalPos(const ShapoidIter* const that);

// Return the current position in standard coordinates of the
// ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
VecFloat* ShapoidIterGetExternalPos(const ShapoidIter* const that);

// Set the attached Shapoid of the ShapoidIter 'that' to 'shap'
// The iterator is reset to its initial position
#if BUILDMODE != 0
static inline
#endif
void _ShapoidIterSetShapoid(ShapoidIter* const that,
  const Shapoid* const shap);

// Get the Shapoid of the ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
const Shapoid* ShapoidIterShapoid(const ShapoidIter* const that);

// Set the delta of the ShapoidIter 'that' to a copy of 'delta'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidIterSetDelta(ShapoidIter* const that,
  const VecFloat* const delta);

// Get the delta of the ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
const VecFloat* ShapoidIterDelta(const ShapoidIter* const that);

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

#define ShapoidClone(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidClone, \
  Facoid*: FacoidClone, \
  Pyramidoid*: PyramidoidClone, \
  Spheroid*: SpheroidClone, \
  const Shapoid*: _ShapoidClone, \
  const Facoid*: FacoidClone, \
  const Pyramidoid*: PyramidoidClone, \
  const Spheroid*: SpheroidClone, \
  default: PBErrInvalidPolymorphism)(Shap)

#define ShapoidFree(ShapRef) _Generic(ShapRef, \
  Shapoid**: _ShapoidFree, \
  Facoid**: _ShapoidFree, \
  Pyramidoid**: _ShapoidFree, \
  Spheroid**: _ShapoidFree, \
  default: PBErrInvalidPolymorphism)((Shapoid**)(ShapRef))

#define ShapoidEncodeAsJSON(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidEncodeAsJSON, \
  Facoid*: _ShapoidEncodeAsJSON, \
  Pyramidoid*: _ShapoidEncodeAsJSON, \
  Spheroid*: _ShapoidEncodeAsJSON, \
  const Shapoid*: _ShapoidEncodeAsJSON, \
  const Facoid*: _ShapoidEncodeAsJSON, \
  const Pyramidoid*: _ShapoidEncodeAsJSON, \
  const Spheroid*: _ShapoidEncodeAsJSON, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)Shap)

#define ShapoidDecodeAsJSON(ShapRef, Json) _Generic(ShapRef, \
  Shapoid**: _ShapoidDecodeAsJSON, \
  Facoid**: _ShapoidDecodeAsJSON, \
  Pyramidoid**: _ShapoidDecodeAsJSON, \
  Spheroid**: _ShapoidDecodeAsJSON, \
  default: PBErrInvalidPolymorphism)((Shapoid**)ShapRef, Json)

#define ShapoidLoad(ShapRef, Stream) _Generic(ShapRef, \
  Shapoid**: _ShapoidLoad, \
  Facoid**: FacoidLoad, \
  Pyramidoid**: PyramidoidLoad, \
  Spheroid**: SpheroidLoad, \
  default: PBErrInvalidPolymorphism)(ShapRef, Stream)

#define ShapoidSave(Shap, Stream, Compact) _Generic(Shap, \
  Shapoid*: _ShapoidSave, \
  Facoid*: _ShapoidSave, \
  Pyramidoid*: _ShapoidSave, \
  Spheroid*: _ShapoidSave, \
  const Shapoid*: _ShapoidSave, \
  const Facoid*: _ShapoidSave, \
  const Pyramidoid*: _ShapoidSave, \
  const Spheroid*: _ShapoidSave, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), \
    Stream, Compact)

#define ShapoidPrintln(Shap, Stream) _Generic(Shap, \
  Shapoid*: _ShapoidPrintln, \
  Facoid*: _ShapoidPrintln, \
  Pyramidoid*: _ShapoidPrintln, \
  Spheroid*: _ShapoidPrintln, \
  const Shapoid*: _ShapoidPrintln, \
  const Facoid*: _ShapoidPrintln, \
  const Pyramidoid*: _ShapoidPrintln, \
  const Spheroid*: _ShapoidPrintln, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), Stream)

#define ShapoidGetType(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetType, \
  Facoid*: _ShapoidGetType, \
  Pyramidoid*: _ShapoidGetType, \
  Spheroid*: _ShapoidGetType, \
  const Shapoid*: _ShapoidGetType, \
  const Facoid*: _ShapoidGetType, \
  const Pyramidoid*: _ShapoidGetType, \
  const Spheroid*: _ShapoidGetType, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap))

#define ShapoidGetTypeAsString(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetTypeAsString, \
  Facoid*: _ShapoidGetTypeAsString, \
  Pyramidoid*: _ShapoidGetTypeAsString, \
  Spheroid*: _ShapoidGetTypeAsString, \
  const Shapoid*: _ShapoidGetTypeAsString, \
  const Facoid*: _ShapoidGetTypeAsString, \
  const Pyramidoid*: _ShapoidGetTypeAsString, \
  const Spheroid*: _ShapoidGetTypeAsString, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap))

#define ShapoidGetDim(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetDim, \
  Facoid*: _ShapoidGetDim, \
  Pyramidoid*: _ShapoidGetDim, \
  Spheroid*: _ShapoidGetDim, \
  const Shapoid*: _ShapoidGetDim, \
  const Facoid*: _ShapoidGetDim, \
  const Pyramidoid*: _ShapoidGetDim, \
  const Spheroid*: _ShapoidGetDim, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap))

#define ShapoidGetPos(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetPos, \
  Facoid*: _ShapoidGetPos, \
  Pyramidoid*: _ShapoidGetPos, \
  Spheroid*: _ShapoidGetPos, \
  const Shapoid*: _ShapoidGetPos, \
  const Facoid*: _ShapoidGetPos, \
  const Pyramidoid*: _ShapoidGetPos, \
  const Spheroid*: _ShapoidGetPos, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap))

#define ShapoidPos(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidPos, \
  Facoid*: _ShapoidPos, \
  Pyramidoid*: _ShapoidPos, \
  Spheroid*: _ShapoidPos, \
  const Shapoid*: _ShapoidPos, \
  const Facoid*: _ShapoidPos, \
  const Pyramidoid*: _ShapoidPos, \
  const Spheroid*: _ShapoidPos, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap))

#define ShapoidSetAxis(Shap, Index, Vec) _Generic(Shap, \
  Shapoid*: _ShapoidSetAxis, \
  Facoid*: _ShapoidSetAxis, \
  Pyramidoid*: _ShapoidSetAxis, \
  Spheroid*: _ShapoidSetAxis, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Index, \
    (VecFloat*)Vec)

#define ShapoidSetAllAxis(Shap, Set) _Generic(Shap, \
  Shapoid*: _ShapoidSetAllAxis, \
  Facoid*: _ShapoidSetAllAxis, \
  Pyramidoid*: _ShapoidSetAllAxis, \
  Spheroid*: _ShapoidSetAllAxis, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Set)

#define ShapoidSetPos(Shap, Vec) _Generic(Shap, \
  Shapoid*: _ShapoidSetPos, \
  Facoid*: _ShapoidSetPos, \
  Pyramidoid*: _ShapoidSetPos, \
  Spheroid*: _ShapoidSetPos, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), (VecFloat*)Vec)

#define ShapoidPosSet(Shap, Index, Val) _Generic(Shap, \
  Shapoid*: _ShapoidPosSet, \
  Facoid*: _ShapoidPosSet, \
  Pyramidoid*: _ShapoidPosSet, \
  Spheroid*: _ShapoidPosSet, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Index, Val)

#define ShapoidPosSetAdd(Shap, Index, Val) _Generic(Shap, \
  Shapoid*: _ShapoidPosSetAdd, \
  Facoid*: _ShapoidPosSetAdd, \
  Pyramidoid*: _ShapoidPosSetAdd, \
  Spheroid*: _ShapoidPosSetAdd, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Index, Val)

#define ShapoidPosGet(Shap, Index) _Generic(Shap, \
  Shapoid*: _ShapoidPosGet, \
  Facoid*: _ShapoidPosGet, \
  Pyramidoid*: _ShapoidPosGet, \
  Spheroid*: _ShapoidPosGet, \
  const Shapoid*: _ShapoidPosGet, \
  const Facoid*: _ShapoidPosGet, \
  const Pyramidoid*: _ShapoidPosGet, \
  const Spheroid*: _ShapoidPosGet, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Index)

#define ShapoidSetCenterPos(Shap, Vec) _Generic(Shap, \
  Shapoid*: _ShapoidSetCenterPos, \
  Facoid*: _ShapoidSetCenterPos, \
  Pyramidoid*: _ShapoidSetCenterPos, \
  Spheroid*: _ShapoidSetCenterPos, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), (VecFloat*)Vec)

#define ShapoidGetAxis(Shap, Index) _Generic(Shap, \
  Shapoid*: _ShapoidGetAxis, \
  Facoid*: _ShapoidGetAxis, \
  Pyramidoid*: _ShapoidGetAxis, \
  Spheroid*: _ShapoidGetAxis, \
  const Shapoid*: _ShapoidGetAxis, \
  const Facoid*: _ShapoidGetAxis, \
  const Pyramidoid*: _ShapoidGetAxis, \
  const Spheroid*: _ShapoidGetAxis, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), Index)

#define ShapoidAxis(Shap, Index) _Generic(Shap, \
  Shapoid*: _ShapoidAxis, \
  Facoid*: _ShapoidAxis, \
  Pyramidoid*: _ShapoidAxis, \
  Spheroid*: _ShapoidAxis, \
  const Shapoid*: _ShapoidAxis, \
  const Facoid*: _ShapoidAxis, \
  const Pyramidoid*: _ShapoidAxis, \
  const Spheroid*: _ShapoidAxis, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), Index)

#define ShapoidAxisSet(Shap, Dim, Index, Val) _Generic(Shap, \
  Shapoid*: _ShapoidAxisSet, \
  Facoid*: _ShapoidAxisSet, \
  Pyramidoid*: _ShapoidAxisSet, \
  Spheroid*: _ShapoidAxisSet, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Dim, Index, Val)

#define ShapoidAxisSetAdd(Shap, Dim, Index, Val) _Generic(Shap, \
  Shapoid*: _ShapoidAxisSetAdd, \
  Facoid*: _ShapoidAxisSetAdd, \
  Pyramidoid*: _ShapoidAxisSetAdd, \
  Spheroid*: _ShapoidAxisSetAdd, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Dim, Index, Val)

#define ShapoidAxisGet(Shap, Dim, Index) _Generic(Shap, \
  Shapoid*: _ShapoidAxisGet, \
  Facoid*: _ShapoidAxisGet, \
  Pyramidoid*: _ShapoidAxisGet, \
  Spheroid*: _ShapoidAxisGet, \
  const Shapoid*: _ShapoidAxisGet, \
  const Facoid*: _ShapoidAxisGet, \
  const Pyramidoid*: _ShapoidAxisGet, \
  const Spheroid*: _ShapoidAxisGet, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Dim, Index)

#define ShapoidAxisScale(Shap, Dim, Val) _Generic(Shap, \
  Shapoid*: _ShapoidAxisScale, \
  Facoid*: _ShapoidAxisScale, \
  Pyramidoid*: _ShapoidAxisScale, \
  Spheroid*: _ShapoidAxisScale, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Dim, Val)

#define ShapoidTranslate(Shap, Vec) _Generic(Shap, \
  Shapoid*: _ShapoidTranslate, \
  Facoid*: _ShapoidTranslate, \
  Pyramidoid*: _ShapoidTranslate, \
  Spheroid*: _ShapoidTranslate, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), (VecFloat*)Vec)

#define ShapoidIsEqual(ShapA, ShapB) _Generic(ShapA, \
  Shapoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  Facoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  Pyramidoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  Spheroid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  const Shapoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  const Facoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  const Pyramidoid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  const Spheroid*: _Generic(ShapB, \
    Shapoid*: _ShapoidIsEqual, \
    Facoid*: _ShapoidIsEqual, \
    Pyramidoid*: _ShapoidIsEqual, \
    Spheroid*: _ShapoidIsEqual, \
    const Shapoid*: _ShapoidIsEqual, \
    const Facoid*: _ShapoidIsEqual, \
    const Pyramidoid*: _ShapoidIsEqual, \
    const Spheroid*: _ShapoidIsEqual, \
    default: PBErrInvalidPolymorphism), \
  default: PBErrInvalidPolymorphism)((const Shapoid* const)(ShapA), \
    (const Shapoid* const)(ShapB))

#define ShapoidGetBoundingBox(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetBoundingBox, \
  Facoid*: FacoidGetBoundingBox, \
  Pyramidoid*: PyramidoidGetBoundingBox, \
  Spheroid*: SpheroidGetBoundingBox, \
  const Shapoid*: _ShapoidGetBoundingBox, \
  const Facoid*: FacoidGetBoundingBox, \
  const Pyramidoid*: PyramidoidGetBoundingBox, \
  const Spheroid*: SpheroidGetBoundingBox, \
  GSetShapoid*: ShapoidGetBoundingBoxSet, \
  const GSetShapoid*: ShapoidGetBoundingBoxSet, \
  default: PBErrInvalidPolymorphism)(Shap)

#define ShapoidScale(Shap, Scale) _Generic(Scale, \
  VecFloat*: _ShapoidScaleVector, \
  VecFloat2D*: _ShapoidScaleVector, \
  VecFloat3D*: _ShapoidScaleVector, \
  float: _ShapoidScaleScalar, \
  const VecFloat*: _ShapoidScaleVector, \
  const VecFloat2D*: _ShapoidScaleVector, \
  const VecFloat3D*: _ShapoidScaleVector, \
  const float: _ShapoidScaleScalar, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Scale)

#define ShapoidGrow(Shap, Scale) _Generic(Shap, \
  Shapoid*: _Generic(Scale, \
    VecFloat*: _ShapoidGrowVector, \
    float: _ShapoidGrowScalar, \
    default: PBErrInvalidPolymorphism), \
  Facoid*: _Generic(Scale, \
    VecFloat*: _ShapoidGrowVector, \
    float: _ShapoidGrowScalar, \
    default: PBErrInvalidPolymorphism), \
  Pyramidoid*: _Generic(Scale, \
    VecFloat*: _ShapoidGrowVector, \
    float: _ShapoidGrowScalar, \
    default: PBErrInvalidPolymorphism), \
  Spheroid*: _Generic(Scale, \
    VecFloat*: _ShapoidGrowVector, \
    float: _ShapoidGrowScalar, \
    default: PBErrInvalidPolymorphism), \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Scale)

#define ShapoidGetCenter(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetCenter, \
  Facoid*: FacoidGetCenter, \
  Pyramidoid*: PyramidoidGetCenter, \
  Spheroid*: SpheroidGetCenter, \
  const Shapoid*: _ShapoidGetCenter, \
  const Facoid*: FacoidGetCenter, \
  const Pyramidoid*: PyramidoidGetCenter, \
  const Spheroid*: SpheroidGetCenter, \
  default: PBErrInvalidPolymorphism)(Shap)
```

```
#define ShapoidRotCenter(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotCenter, \
  Facoid*: _ShapoidRotCenter, \
  Pyramidoid*: _ShapoidRotCenter, \
  Spheroid*: _ShapoidRotCenter, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotOrigin(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotOrigin, \
  Facoid*: _ShapoidRotOrigin, \
  Pyramidoid*: _ShapoidRotOrigin, \
  Spheroid*: _ShapoidRotOrigin, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotStart(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotStart, \
  Facoid*: _ShapoidRotStart, \
  Pyramidoid*: _ShapoidRotStart, \
  Spheroid*: _ShapoidRotStart, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotAxisCenter(Shap, Axis, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotAxisCenter, \
  Facoid*: _ShapoidRotAxisCenter, \
  Pyramidoid*: _ShapoidRotAxisCenter, \
  Spheroid*: _ShapoidRotAxisCenter, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Axis, Theta)

#define ShapoidRotAxisOrigin(Shap, Axis, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotAxisOrigin, \
  Facoid*: _ShapoidRotAxisOrigin, \
  Pyramidoid*: _ShapoidRotAxisOrigin, \
  Spheroid*: _ShapoidRotAxisOrigin, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Axis, Theta)

#define ShapoidRotAxisStart(Shap, Axis, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotAxisStart, \
  Facoid*: _ShapoidRotAxisStart, \
  Pyramidoid*: _ShapoidRotAxisStart, \
  Spheroid*: _ShapoidRotAxisStart, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Axis, Theta)

#define ShapoidRotXCenter(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotXCenter, \
  Facoid*: _ShapoidRotXCenter, \
  Pyramidoid*: _ShapoidRotXCenter, \
  Spheroid*: _ShapoidRotXCenter, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotXOrigin(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotXOrigin, \
  Facoid*: _ShapoidRotXOrigin, \
  Pyramidoid*: _ShapoidRotXOrigin, \
  Spheroid*: _ShapoidRotXOrigin, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotXStart(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotXStart, \
  Facoid*: _ShapoidRotXStart, \
  Pyramidoid*: _ShapoidRotXStart, \
  Spheroid*: _ShapoidRotXStart, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)
```

```
#define ShapoidRotYCenter(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotYCenter, \
  Facoid*: _ShapoidRotYCenter, \
  Pyramidoid*: _ShapoidRotYCenter, \
  Spheroid*: _ShapoidRotYCenter, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotYOrigin(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotYOrigin, \
  Facoid*: _ShapoidRotYOrigin, \
  Pyramidoid*: _ShapoidRotYOrigin, \
  Spheroid*: _ShapoidRotYOrigin, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotYStart(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotYStart, \
  Facoid*: _ShapoidRotYStart, \
  Pyramidoid*: _ShapoidRotYStart, \
  Spheroid*: _ShapoidRotYStart, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotZCenter(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotZCenter, \
  Facoid*: _ShapoidRotZCenter, \
  Pyramidoid*: _ShapoidRotZCenter, \
  Spheroid*: _ShapoidRotZCenter, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotZOrigin(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotZOrigin, \
  Facoid*: _ShapoidRotZOrigin, \
  Pyramidoid*: _ShapoidRotZOrigin, \
  Spheroid*: _ShapoidRotZOrigin, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidRotZStart(Shap, Theta) _Generic(Shap, \
  Shapoid*: _ShapoidRotZStart, \
  Facoid*: _ShapoidRotZStart, \
  Pyramidoid*: _ShapoidRotZStart, \
  Spheroid*: _ShapoidRotZStart, \
  default: PBErrInvalidPolymorphism)((Shapoid*)(Shap), Theta)

#define ShapoidImportCoord(Shap, VecPos) _Generic(Shap, \
  Shapoid*: _ShapoidImportCoord, \
  Facoid*: _ShapoidImportCoord, \
  Pyramidoid*: _ShapoidImportCoord, \
  Spheroid*: _ShapoidImportCoord, \
  const Shapoid*: _ShapoidImportCoord, \
  const Facoid*: _ShapoidImportCoord, \
  const Pyramidoid*: _ShapoidImportCoord, \
  const Spheroid*: _ShapoidImportCoord, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), \
    (const VecFloat*)VecPos)

#define ShapoidExportCoord(Shap, VecPos) _Generic(Shap, \
  Shapoid*: _ShapoidExportCoord, \
  Facoid*: _ShapoidExportCoord, \
  Pyramidoid*: _ShapoidExportCoord, \
  Spheroid*: _ShapoidExportCoord, \
  const Shapoid*: _ShapoidExportCoord, \
  const Facoid*: _ShapoidExportCoord, \
  const Pyramidoid*: _ShapoidExportCoord, \
  const Spheroid*: _ShapoidExportCoord, \
  default: PBErrInvalidPolymorphism)((const Shapoid*)(Shap), \
    (const VecFloat*)VecPos)

#define ShapoidIsPosInside(Shap, VecPos) _Generic(Shap, \
  Shapoid*: _ShapoidIsPosInside, \
  Facoid*: FacoidIsPosInside, \
  Pyramidoid*: PyramidoidIsPosInside, \
  Spheroid*: SpheroidIsPosInside, \
  const Shapoid*: _ShapoidIsPosInside, \
  const Facoid*: FacoidIsPosInside, \
  const Pyramidoid*: PyramidoidIsPosInside, \
  const Spheroid*: SpheroidIsPosInside, \
  default: PBErrInvalidPolymorphism)(Shap, VecPos)

#define ShapoidGetPosDepth(Shap, VecPos) _Generic(Shap, \
  Shapoid*: _ShapoidGetPosDepth, \
  Facoid*: FacoidGetPosDepth, \
  Pyramidoid*: PyramidoidGetPosDepth, \
  Spheroid*: SpheroidGetPosDepth, \
  const Shapoid*: _ShapoidGetPosDepth, \
  const Facoid*: FacoidGetPosDepth, \
  const Pyramidoid*: PyramidoidGetPosDepth, \
  const Spheroid*: SpheroidGetPosDepth, \
  default: PBErrInvalidPolymorphism)(Shap, (VecFloat*)VecPos)

#define ShapoidIsInter(ShapA, ShapB) _Generic(ShapA, \
  Spheroid*: _Generic(ShapB, \
    Spheroid*: _SpheroidIsInterSpheroid, \
    const Spheroid*: _SpheroidIsInterSpheroid, \
    default: PBErrInvalidPolymorphism), \
  const Spheroid*: _Generic(ShapB, \
    Spheroid*: _SpheroidIsInterSpheroid, \
    const Spheroid*: _SpheroidIsInterSpheroid, \
    default: PBErrInvalidPolymorphism), \
  Pyramidoid*: _Generic(ShapB, \
    Pyramidoid*: _PyramidoidIsInterPyramidoid, \
    const Pyramidoid*: _PyramidoidIsInterPyramidoid, \
    Facoid*: _PyramidoidIsInterFacoid, \
    const Facoid*: _PyramidoidIsInterFacoid, \
    default: PBErrInvalidPolymorphism), \
  const Pyramidoid*: _Generic(ShapB, \
    Pyramidoid*: _PyramidoidIsInterPyramidoid, \
    const Pyramidoid*: _PyramidoidIsInterPyramidoid, \
    Facoid*: _PyramidoidIsInterFacoid, \
    const Facoid*: _PyramidoidIsInterFacoid, \
    default: PBErrInvalidPolymorphism), \
  Facoid*: _Generic(ShapB, \
    Pyramidoid*: _FacoidIsInterPyramidoid, \
    const Pyramidoid*: _FacoidIsInterPyramidoid, \
    Facoid*: _FacoidIsInterFacoid, \
    const Facoid*: _FacoidIsInterFacoid, \
    default: PBErrInvalidPolymorphism), \
  const Facoid*: _Generic(ShapB, \
    Pyramidoid*: _FacoidIsInterPyramidoid, \
    const Pyramidoid*: _FacoidIsInterPyramidoid, \
    Facoid*: _FacoidIsInterFacoid, \
    const Facoid*: _FacoidIsInterFacoid, \
    default: PBErrInvalidPolymorphism), \
  default: PBErrInvalidPolymorphism) (ShapA, ShapB)
```

```
#define ShapoidGetBoundingRadius(Shap) _Generic(Shap, \
  Shapoid*: _ShapoidGetBoundingRadius, \
  Pyramidoid*: _ShapoidGetBoundingRadius, \
  Facoid*: _ShapoidGetBoundingRadius, \
  Spheroid*: _ShapoidGetBoundingRadius, \
  const Shapoid*: _ShapoidGetBoundingRadius, \
  const Pyramidoid*: _ShapoidGetBoundingRadius, \
  const Facoid*: _ShapoidGetBoundingRadius, \
  const Spheroid*: _ShapoidGetBoundingRadius, \
  default: PBErrInvalidPolymorphism) ((const Shapoid*)(Shap))

// ================ static inliner ====================

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


#endif
```

3 Code

3.1 shapoid.c

```
// ============ SHAPOID.C ================

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

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

// -------------- Shapoid

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

const char* ShapoidTypeString[3] = {
  (const char*)"Facoid", (const char*)"Spheroid",
  (const char*)"Pyramidoid"};

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

// Create a Shapoid of dimension 'dim' and type 'type', default values:
// _pos = null vector
// _axis[d] = unit vector along dimension d
Shapoid* ShapoidCreate(const int dim, const ShapoidType type) {
#if BUILDMODE == 0
  if (dim <= 0) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Invalid dimension (%d>0)", dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a vector used for initialisation
  VecShort2D d = VecShortCreateStatic2D();
  // Declare a identity matrix used for initialisation
  VecSet(&d, 0, dim);
  VecSet(&d, 1, dim);
  MatFloat* mat = MatFloatCreate(&d);
  MatSetIdentity(mat);
  // Allocate memory
  Shapoid* that = NULL;
  if (type == ShapoidTypeSpheroid)
    that = PBErrMalloc(ShapoidErr, sizeof(Spheroid));
  else
    that = PBErrMalloc(ShapoidErr, sizeof(Shapoid));
  // Init pointers
  that->_pos = NULL;
  that->_axis = NULL;
  that->_sysLinEqImport = NULL;
  // Set the dimension and type
  *(ShapoidType*)&(that->_type) = type;
  *(int*)&(that->_dim) = dim;
  // Allocate memory for position
  that->_pos = VecFloatCreate(dim);
  // Allocate memory for array of axis
  that->_axis = PBErrMalloc(ShapoidErr, sizeof(VecFloat*) * dim);
  for (int iAxis = dim; iAxis--;)
    that->_axis[iAxis] = NULL;
  // Allocate memory for each axis
  for (int iAxis = 0; iAxis < dim; ++iAxis) {
    // Allocate memory for position
    that->_axis[iAxis] = VecFloatCreate(dim);
    // Set value of the axis
    VecSet(that->_axis[iAxis], iAxis, 1.0);
  }
  // Create the linear system for coordinate importation
  that->_sysLinEqImport = SysLinEqCreate(mat, (VecFloat*)NULL);
  // Free memory
  MatFree(&mat);
  // Specific properties of Spheroid
  if (type == ShapoidTypeSpheroid) {
    ((Spheroid*)that)->_majAxis = 0;
    ((Spheroid*)that)->_minAxis = 0;
  }
  // Return the new Shapoid
  return that;
}

// Clone a Shapoid
Shapoid* _ShapoidClone(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Create a clone
  Shapoid* clone = ShapoidCreate(that->_dim, that->_type);
  // Set the position and axis of the clone
  ShapoidSetPos(clone, that->_pos);
  for (int iAxis = clone->_dim; iAxis--;)
    VecCopy(clone->_axis[iAxis], that->_axis[iAxis]);
  ShapoidUpdateSysLinEqImport(clone);
  // Clone the SysLinEq
  SysLinEqFree(&(clone->_sysLinEqImport));
  clone->_sysLinEqImport = SysLinEqClone(that->_sysLinEqImport);
  // If it's a spheroid, copy the spheroid properties too
  if (that->_type == ShapoidTypeSpheroid) {
    ((Spheroid*)clone)->_majAxis = ((Spheroid*)that)->_majAxis;
    ((Spheroid*)clone)->_minAxis = ((Spheroid*)that)->_minAxis;
  }
  // Return the clone
  return clone;
}

// Free memory used by a Shapoid
void _ShapoidFree(Shapoid** that) {
  // Check argument
  if (that == NULL || *that == NULL)
    return;
  // Free memory
  for (int iAxis = (*that)->_dim; iAxis--;)
    VecFree((*that)->_axis + iAxis);
  free((*that)->_axis);
  VecFree(&((*that)->_pos));
  SysLinEqFree(&((*that)->_sysLinEqImport));
  free(*that);
  *that = NULL;
}

// Function which return the JSON encoding of 'that'
JSONNode* _ShapoidEncodeAsJSON(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBMathErr->_type = PBErrTypeNullPointer;
    sprintf(PBMathErr->_msg, "'that' is null");
    PBErrCatch(PBMathErr);
  }
#endif
  // Create the JSON structure
  JSONNode* json = JSONCreate();
  // Declare a buffer to convert value into string
  char val[100];
  // Encode the dimension
  sprintf(val, "%d", that->_dim);
  JSONAddProp(json, "_dim", val);
  // Encode the type
  sprintf(val, "%u", that->_type);
  JSONAddProp(json, "_type", val);
  // Encode the position
  JSONAddProp(json, "_pos", VecEncodeAsJSON(ShapoidPos(that)));
  // Encode the axis
  JSONArrayStruct setAxis = JSONArrayStructCreateStatic();
  // For each axis
  for (int iAxis = 0; iAxis < that->_dim; ++iAxis)
    JSONArrayStructAdd(&setAxis,
      VecEncodeAsJSON(ShapoidAxis(that, iAxis)));
  JSONAddProp(json, "_axis", &setAxis);
  // Free memory
  JSONArrayStructFlush(&setAxis);
  // Return the created JSON
  return json;
}

// Function which decode from JSON encoding 'json' to 'that'
bool _ShapoidDecodeAsJSON(Shapoid** that, const JSONNode* const json) {
#if BUILDMODE == 0
```

```
  if (that == NULL) {
    PBMathErr->_type = PBErrTypeNullPointer;
    sprintf(PBMathErr->_msg, "'that' is null");
    PBErrCatch(PBMathErr);
  }
  if (json == NULL) {
    PBMathErr->_type = PBErrTypeNullPointer;
    sprintf(PBMathErr->_msg, "'json' is null");
    PBErrCatch(PBMathErr);
  }
#endif
  // If 'that' is already allocated
  if (*that != NULL)
    // Free memory
    ShapoidFree(that);
  // Get the dim from the JSON
  JSONNode* prop = JSONProperty(json, "_dim");
  if (prop == NULL) {
    return false;
  }
  int dim = atoi(JSONLblVal(prop));
  // Get the type from the JSON
  prop = JSONProperty(json, "_type");
  if (prop == NULL) {
    return false;
  }
  ShapoidType type = atoi(JSONLblVal(prop));
  // If data are invalid
  if (dim <= 0)
    return false;
  // Allocate memory
  *that = ShapoidCreate(dim, type);
  // Get the position from the JSON
  prop = JSONProperty(json, "_pos");
  if (prop == NULL) {
    return false;
  }
  if (!VecDecodeAsJSON(&((*that)->_pos), prop)) {
    return false;
  }
  // Decode the axis
  prop = JSONProperty(json, "_axis");
  if (prop == NULL) {
    return false;
  }
  if (JSONGetNbValue(prop) != dim) {
    return false;
  }
  for (int iAxis = 0; iAxis < dim; ++iAxis) {
    JSONNode* axis = JSONValue(prop, iAxis);
    if (!VecDecodeAsJSON((*that)->_axis + iAxis, axis))
      return false;
    // If the axis is not of the correct dimension
    if (VecGetDim((*that)->_axis[iAxis]) != (*that)->_dim)
      return false;
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(*that);
  // If it's a Spheroid
  if ((*that)->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)*that);
  // Return the success code
  return true;
}

// Load the Shapoid from the stream
// If the Shapoid is already allocated, it is freed before loading
// Return true upon success else false
bool _ShapoidLoad(Shapoid** that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (stream == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'stream' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a json to load the encoded data
  JSONNode* json = JSONCreate();
  // Load the whole encoded data
  if (!JSONLoad(json, stream)) {
    return false;
  }
  // Decode the data from the JSON
  if (!ShapoidDecodeAsJSON(that, json)) {
    return false;
  }
  // Free the memory used by the JSON
  JSONFree(&json);
  // Return success code
  return true;
}

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

// Print the Shapoid on 'stream'
void _ShapoidPrintln(const Shapoid* const that, FILE* const stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (stream == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'stream' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Print the Shapoid
  fprintf(stream, "Type: %s\n", ShapoidTypeString[that->_type]);
  fprintf(stream, "Dim: %d\n", that->_dim);
  fprintf(stream, "Pos: ");
  VecPrint(that->_pos, stream);
  fprintf(stream, "\n");
  for (int iAxis = 0; iAxis < that->_dim; ++iAxis) {
    fprintf(stream, "Axis(%d): ", iAxis);
    VecPrint(that->_axis[iAxis], stream);
    fprintf(stream, "\n");
  }
}

// Get a bounding box of the Shapoid. The bounding box is aligned
// on the standard coordinate system (its axis are colinear with
// the axis of the standard coordinate system).
// The bounding box is returned as a Facoid, which position is
// at the minimum value along each axis.
Facoid* _ShapoidGetBoundingBox(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the Shapoid is a Facoid
  if (that->_type == ShapoidTypeFacoid) {
    return FacoidGetBoundingBox((Facoid*)that);
  // Else, if the Shapoid is a Pyramidoid
  } else  if (that->_type == ShapoidTypePyramidoid) {
    return PyramidoidGetBoundingBox((Pyramidoid*)that);
  // Else, if the Shapoid is a Spheroid
  } else  if (that->_type == ShapoidTypeSpheroid) {
    return SpheroidGetBoundingBox((Spheroid*)that);
  } else {
    return NULL;
  }
}

Facoid* FacoidGetBoundingBox(const Facoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result
  Facoid* res = FacoidCreate(ShapoidGetDim(that));
  // For each axis
  for (int dim = ShapoidGetDim(that); dim--;) {
    // Declare a variable to memorize the bound of the interval on
    // this axis
    float bound[2];
    bound[0] = bound[1] = VecGet(((Shapoid*)that)->_pos, dim);
    // For each parameter
    for (int param = ShapoidGetDim(that); param--;) {
      // Get the value of the axis influencing the current dimension
      float v = VecGet(((Shapoid*)that)->_axis[param], dim);
      // If the value is negative, update the minimum bound
      if (v < 0.0)
        bound[0] += v;
      // Else, if the value is negative, update the minimum bound
      else
        bound[1] += v;
    }
    // Memorize the result
    VecSet(((Shapoid*)res)->_pos, dim, bound[0]);
    VecSet(((Shapoid*)res)->_axis[dim], dim, bound[1] - bound[0]);
  }
  // Return the result
  return res;
}

Facoid* PyramidoidGetBoundingBox(const Pyramidoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result
  Facoid* res = FacoidCreate(ShapoidGetDim(that));
  // For each axis
  for (int dim = ShapoidGetDim(that); dim--;) {
    // Declare a variable to memorize the bound of the interval on
    // this axis
    float bound[2];
    bound[0] = bound[1] = 0.0;
    // For each parameter
    for (int param = ShapoidGetDim(that); param--;) {
      // Get the value of the axis influencing the current dimension
      float v = VecGet(((Shapoid*)that)->_axis[param], dim);
      // Search the min and max values
      if (v < bound[0])
        bound[0] = v;
      if (v > bound[1])
```

```
        bound[1] = v;
    }
    if (bound[0] > 0.0)
      bound[0] = 0.0;
    if (bound[1] < 0.0)
      bound[1] = 0.0;
    // Memorize the result
    VecSet(((Shapoid*)res)->_pos, dim,
      ShapoidPosGet(that, dim) + bound[0]);
    VecSet(((Shapoid*)res)->_axis[dim], dim, bound[1] - bound[0]);
  }
  // Return the result
  return res;
}

Facoid* SpheroidGetBoundingBox(const Spheroid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result
  Facoid* res = FacoidCreate(ShapoidGetDim(that));
  // In case of a Spheroid, things get complicate
  // We'll approximate the bounding box of the Spheroid
  // with the one of the same Spheroid viewed as a Facoid
  // and simply take care that the _pos is at the center of the
  // Spheroid
  // For each axis
  for (int dim = ShapoidGetDim(that); dim--;) {
    // Declare a variable to memorize the bound of the interval on
    // this axis
    float bound[2];
    bound[0] = VecGet(((Shapoid*)that)->_pos, dim);
    // Correct position
    // For each parameter
    for (int param = ShapoidGetDim(that); param--;) {
      // Get the value of the axis influencing the current dimension
      float v = VecGet(((Shapoid*)that)->_axis[param], dim);
      // Correct the pos
      bound[0] -= 0.5 * v;
    }
    bound[1] = bound[0];
    // For each parameter
    for (int param = ShapoidGetDim(that); param--;) {
      // Get the value of the axis influencing the current dimension
      float v = VecGet(((Shapoid*)that)->_axis[param], dim);
      // If the value is negative, update the minimum bound
      if (v < 0.0)
        bound[0] += v;
      // Else, if the value is negative, update the minimum bound
      else
        bound[1] += v;
    }
    // Memorize the result
    VecSet(((Shapoid*)res)->_pos, dim, bound[0]);
    VecSet(((Shapoid*)res)->_axis[dim], dim, bound[1] - bound[0]);
  }
  // Return the result
  return res;
```

```
}

// Get the bounding box of a set of Facoid. The bounding box is aligned
// on the standard coordinate system (its axis are colinear with
// the axis of the standard coordinate system).
// The bounding box is returned as a Facoid, which position is
// at the minimum value along each axis.
Facoid* ShapoidGetBoundingBoxSet(const GSetShapoid* const set) {
#if BUILDMODE == 0
  if (set == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'set' is null");
    PBErrCatch(ShapoidErr);
  }
  if (GSetNbElem(set) > 0) {
    GSetIterForward iter = GSetIterForwardCreateStatic(set);
    int dim = ((Shapoid*)GSetIterGet(&iter))->_dim;
    do {
      if (((Shapoid*)GSetIterGet(&iter))->_dim != dim) {
        ShapoidErr->_type = PBErrTypeInvalidArg;
        sprintf(ShapoidErr->_msg,
          "'set' contains Shapoids of various dimensions");
        PBErrCatch(ShapoidErr);
      }
    } while (GSetIterStep(&iter));
  }
#endif
  // Declare a variable for the result
  Facoid* res = NULL;
  if (GSetNbElem(set) > 0) {
    // Declare an interator on the elements of the set
    GSetIterForward iter = GSetIterForwardCreateStatic(set);
    // Loop on element of the set
    do {
      // Declare a pointer to the Facoid
      Shapoid* shapoid = GSetIterGet(&iter);
      // If it's the first Facoid in the set
      if (res == NULL) {
        // Get the bounding box of this shapoid
        res = ShapoidGetBoundingBox(shapoid);
      // Else, this is not the first Shapoid in the set
      } else {
        // Get the bounding box of this shapoid
        Facoid* bound = ShapoidGetBoundingBox(shapoid);
        // For each dimension
        for (int iDim = ShapoidGetDim(res); iDim--;) {
          // Update the bounding box
          if (VecGet(((Shapoid*)bound)->_pos, iDim) <
            VecGet(((Shapoid*)res)->_pos, iDim)) {
            VecSetAdd(((Shapoid*)res)->_axis[iDim], iDim,
              VecGet(((Shapoid*)res)->_pos, iDim) -
              VecGet(((Shapoid*)bound)->_pos, iDim));
            VecSet(((Shapoid*)res)->_pos, iDim,
            VecGet(((Shapoid*)bound)->_pos, iDim));
          }
          if (VecGet(((Shapoid*)bound)->_pos, iDim) +
            VecGet(((Shapoid*)bound)->_axis[iDim], iDim) >
            VecGet(((Shapoid*)res)->_pos, iDim) +
            VecGet(((Shapoid*)res)->_axis[iDim], iDim))
            VecSetAdd(((Shapoid*)res)->_axis[iDim], iDim,
              VecGet(((Shapoid*)bound)->_axis[iDim], iDim) -
              VecGet(((Shapoid*)res)->_pos, iDim));
        }
        // Free memory used by the bounding box
        ShapoidFree(&bound);
      }
    } while (GSetIterStep(&iter));
  }
  // Return the result
  return res;
}

// Get the percentage of 'tho' included 'that' (in [0.0, 1.0])
// 0.0 -> 'tho' is completely outside of 'that'
// 1.0 -> 'tho' is completely inside of 'that'
// 'that' and 'tho' must me of same dimensions
// delta is the step of the algorithm (in ]0.0, 1.0])
// small -> slow but precise
// big -> fast but rough
float _ShapoidGetCoverageDelta(const Shapoid* const that,
  const Shapoid* const tho, const float delta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'tho' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "Shapoids dimensions are different (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare variables to compute the result
  float ratio = 0.0;
  float sum = 0.0;
  // Declare variables for the relative and absolute position in 'tho'
  VecFloat* pRel = VecFloatCreate(ShapoidGetDim(that));
  VecFloat* pStd = NULL;
  // Declare a variable to memorize the last index in dimension
  long lastI = VecGetDim(pRel) - 1;
  // Declare a variable to memorize the max value of coordinates
  float max = 1.0;
  // If 'tho' is a spheroid, correct the start coordinates and range
  if (tho->_type == ShapoidTypeSpheroid) {
    max = 0.5;
    for (int iDim = ShapoidGetDim(that); iDim--;)
      VecSet(pRel, iDim, -0.5);
  }
  // Loop on relative coordinates
  while (VecGet(pRel, lastI) <= max + PBMATH_EPSILON) {
    // Get the coordinates in standard system
    pStd = ShapoidExportCoord(tho, pRel);
    // If this position is inside 'tho'
    if (ShapoidIsPosInside(tho, pStd) == true) {
      // If this position is inside 'that'
      if (ShapoidIsPosInside(that, pStd) == true)
        // Increment the ratio
        ratio += 1.0;
      sum += 1.0;
    }
    // Free memory
    VecFree(&pStd);
    // Step the relative coordinates
    long iDim = 0;
    while (iDim >= 0) {
      VecSetAdd(pRel, iDim, delta);
      if (iDim != lastI &&
        VecGet(pRel, iDim) > max + PBMATH_EPSILON) {
        VecSet(pRel, iDim, max - 1.0);
        ++iDim;
      } else {
        iDim = -1;
      }
    }
  }
  // Finish the computation of the ratio
  ratio /= sum;
  // Free memory
  VecFree(&pRel);
  // Return the result
  return ratio;
}

// Add a copy of the Facoid 'that' to the GSet 'set' (containing
// other Facoid), taking care to avoid overlaping Facoid
// The copy of 'that' made be resized or divided
// The Facoid in the set and 'that' must be aligned with the
// coordinates system axis and have
// same dimensions
void FacoidAlignedAddClippedToSet(const Facoid* const that,
  GSetShapoid* const set) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (set == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'set' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the set is empty
  if (GSetNbElem(set) == 0) {
    // Add a clone of the facoid
    GSetAppend(set, FacoidClone(that));
  // Else, the set is not empty
  } else {
    // Create a set of sub facoid to be added and initialize it with a
    // clone of 'that'
    GSetShapoid setToAdd = GSetShapoidCreateStatic();
    GSetAppend(&setToAdd, FacoidClone(that));
    // For each sub facoid to add
    GSetIterForward iterToAdd = GSetIterForwardCreateStatic(&setToAdd);
    do {
      // Get the current facoid to add
      Facoid* facoidToAdd = GSetIterGet(&iterToAdd);
      // Declare a flag to skip the loop when possible
      bool flagSkip = false;
      // For each facoid in the set
      GSetIterForward iter = GSetIterForwardCreateStatic(set);
      do {
        // Get the current facoid
        Facoid* facoid = GSetIterGet(&iter);
        // If the facoid to be added is completely included into this
        // facoid
        if (FacoidAlignedIsInsideFacoidAligned(facoidToAdd, facoid)) {
          // This facoid doesn't need to be added, delete it
          ShapoidFree(&facoidToAdd);
          GSetIterSetData(&iterToAdd, NULL);
          // And skip the other facoids in the set
          flagSkip = true;
        // Else, if this facoid is completely include in the facoid to
        // be added
        } else if (FacoidAlignedIsInsideFacoidAligned(facoid,
          facoidToAdd)) {
          // Remove the facoid in the set
          ShapoidFree(&facoid);
          GSetIterSetData(&iter, NULL);
        // Else, if both facoid are in intersection
        } else if (!FacoidAlignedIsOutsideFacoidAligned(facoidToAdd,
          facoid)) {
          // Split the facoid to be added into new facoids
          // which cover the non intersecting area
          GSetShapoid* split =
            FacoidAlignedSplitExcludingFacoidAligned(facoidToAdd,
              facoid);
          GSetAppendSet(&setToAdd, split);
          GSetFree(&split);
          // Delete the splitted facoid
          ShapoidFree(&facoidToAdd);
          GSetIterSetData(&iterToAdd, NULL);
          // And skip the other facoids in the set
          flagSkip = true;
        }
        // Else the facoid to add is completely outside, leave it as
        // it is
      } while (!flagSkip && GSetIterStep(&iter));
    } while (GSetIterStep(&iterToAdd));
    // When we arrive here the set 'setToAdd' contains the facoids
    // to be added to 'set'
    GSetAppendSet(set, &setToAdd);
    // There may have been deleted facoid, ensure the resulting set
    // is clean by removing null pointer
    GSetRemoveAll(set, (Shapoid*)NULL);
    // Free memory used by the set of sub facoid to add
    GSetFlush(&setToAdd);
  }
}

// Check if the Facoid 'that' is completely included into the Facoid
// 'facoid'
// Both Facoid must be aligned with the coordinates system
// 'that' and 'facoid' must have same dimensions and have
// same dimensions
// Return true if it is included, false else
bool FacoidAlignedIsInsideFacoidAligned(const Facoid* const that,
  const Facoid* const facoid) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (facoid == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'facoid' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(facoid)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'facoid' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(facoid));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Check inclusion for each axis
  for (int iAxis = ShapoidGetDim(that); iAxis--;)
    // If 'that' is outside 'facoid' for this axis
    if (ShapoidPosGet(that, iAxis) <
      ShapoidPosGet(facoid, iAxis) ||
      ShapoidPosGet(that, iAxis) +
      ShapoidAxisGet(that, iAxis, iAxis) >
      ShapoidPosGet(facoid, iAxis) +
      ShapoidAxisGet(facoid, iAxis, iAxis))
      // Return false
      return false;
  // If we reach here it means 'that' is inside 'facoid', return true
  return true;
}

// Check if the Facoid 'that' is completely excluded from the Facoid
// 'facoid'
// Both Facoid must be aligned with the coordinates system and have
// same dimensions
// Return true if it is excluded, false else
bool FacoidAlignedIsOutsideFacoidAligned(const Facoid* const that,
  const Facoid* const facoid) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (facoid == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'facoid' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(facoid)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'facoid' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(facoid));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Check exclusion for each axis
  for (int iAxis = ShapoidGetDim(that); iAxis--;)
    // If 'that' is outside 'facoid' for this axis
    if (ShapoidPosGet(that, iAxis) >
      ShapoidPosGet(facoid, iAxis) +
      ShapoidAxisGet(facoid, iAxis, iAxis) - PBMATH_EPSILON ||
      ShapoidPosGet(that, iAxis) +
      ShapoidAxisGet(that, iAxis, iAxis) <
      ShapoidPosGet(facoid, iAxis) + PBMATH_EPSILON)
      // Return true
      return true;
  // If we reach here it means 'that' intersects 'facoid', return false
  return false;
}

// Get a GSet of Facoid aligned with coordinates system covering the
// Facoid 'that' except for area in the Facoid 'facoid'
// Both Facoid must be aligned with the coordinates system and have
// same dimensions
GSetShapoid* FacoidAlignedSplitExcludingFacoidAligned(
  const Facoid* const that, const Facoid* const facoid) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (facoid == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'facoid' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(facoid)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'facoid' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(facoid));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Ladies and Gentleman, here comes the infamous "Gruyere Algorithm"
  // Declare the result GSet
  GSetShapoid* set = GSetShapoidCreate();
  // Declare a clone of the original facoid
  Facoid* src = FacoidClone(that);
  // For each axis
  for (int iAxis = ShapoidGetDim(that); iAxis--;) {
    // If 'src' has area on the left of 'facoid' along this axis
    if (ShapoidPosGet(src, iAxis) < ShapoidPosGet(facoid, iAxis)) {
      // Create the facoid made of this area
      Facoid* sub = FacoidClone(src);
      ShapoidAxisSet(sub, iAxis, iAxis,
        ShapoidPosGet(facoid, iAxis) - ShapoidPosGet(src, iAxis));
      // Add it to the result set
      GSetAppend(set, sub);
      // Chop the added area from 'src'
      ShapoidAxisSetAdd(src, iAxis, iAxis,
        -1.0 * ShapoidAxisGet(sub, iAxis, iAxis));
      ShapoidPosSet(src, iAxis, ShapoidPosGet(facoid, iAxis));
    }
    // If 'src' has area on the right of 'facoid' along this axis
    if (ShapoidPosGet(src, iAxis) + ShapoidAxisGet(src, iAxis, iAxis) >
      ShapoidPosGet(facoid, iAxis) +
      ShapoidAxisGet(facoid, iAxis, iAxis)) {
      // Create the facoid made of this area
      Facoid* sub = FacoidClone(src);
      ShapoidAxisSet(sub, iAxis, iAxis,
        (ShapoidPosGet(src, iAxis) +
        ShapoidAxisGet(src, iAxis, iAxis)) -
        (ShapoidPosGet(facoid, iAxis) +
        ShapoidAxisGet(facoid, iAxis, iAxis)));
      ShapoidPosSet(sub, iAxis, ShapoidPosGet(facoid, iAxis) +
        ShapoidAxisGet(facoid, iAxis, iAxis));
      // Add it to the result set
      GSetAppend(set, sub);
      // Chop the added area from 'src'
      ShapoidAxisSetAdd(src, iAxis, iAxis,
        -1.0 * ShapoidAxisGet(sub, iAxis, iAxis));
    }
    // If 'src' is empty
    if (ISEQUALF(ShapoidAxisGet(src, iAxis, iAxis), 0.0))
      // End the loop
      iAxis = 0;
  }
  // Free memory
  ShapoidFree(&src);
  // Return the result set
  return set;
}

// Return true if 'that' intersects 'tho'
// Return false else
// 'that' and 'tho' must have same dimension
// https://hal.inria.fr/hal-00646511/PDF/CCD.3.0.pdf
bool _SpheroidIsInterSpheroid(const Spheroid* const that,
  const Spheroid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'tho' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Create the projection of 'tho' in 'that' 's coordinates space
  Spheroid* proj = SpheroidCreate(ShapoidGetDim(tho));
  VecFloat* v = ShapoidImportCoord(that, ShapoidPos(tho));
  ShapoidSetPos(proj, v);
  VecFree(&v);
```

```
for (int iAxis = ShapoidGetDim(tho); iAxis--;) {
  v = ShapoidImportCoord(that, ShapoidAxis(tho, iAxis));
  ShapoidSetAxis(proj, iAxis, v);
  VecFree(&v);
}
// Declare a variable to memorize the distance to the origin of
// 'that' 's coordinate system
float dist = VecNorm(ShapoidPos(proj));
// Check for trivial cases
float majRadius = 0.5 * VecNorm(ShapoidAxis(proj, proj->_majAxis));
if (dist > majRadius + 0.5) {
  ShapoidFree(&proj);
  VecFree(&v);
  return false;
} else if (proj->_majAxis == proj->_minAxis) {
  ShapoidFree(&proj);
  VecFree(&v);
  return true;
}
float minRadius = 0.5 * VecNorm(ShapoidAxis(proj, proj->_minAxis));
if (dist <= minRadius + 0.5) {
  ShapoidFree(&proj);
  VecFree(&v);
  return true;
}
// Non trivial case
// Search a position in the projection of 'tho' less than 1.0 units
// from the origin in 'that' 's coordinates space
// Declare a variable to move in the projection's coordinates space
VecFloat* pos = VecFloatCreate(ShapoidGetDim(tho));
// Declare a variable to memorize the derivative
VecFloat* dPos = VecFloatCreate(ShapoidGetDim(tho));
// Declare a variable to memorize the step for derivate calculation
float delta = 0.01;
// Declare a flag to stop the loop in case of deadlock
bool flag = false;
// Loop until we find a solution or deadlock
while (dist > 0.5 && !flag) {
  // Calculate the derivative along each axis
  v = VecFloatCreate(VecGetDim(pos));
  for (int iAxis = ShapoidGetDim(tho); iAxis--;) {
    // Copy the current position
    VecCopy(v, pos);
    // Move a delta along the current axis
    VecSetAdd(v, iAxis, delta);
    // Get the cooridnate in 'that' 's coordinates system
    VecFloat* w = ShapoidExportCoord(proj, v);
    // Calculate the distance ot origin of 'that' 's coordinates
    // system
    float dp = VecNorm(w);
    // Free memory
    VecFree(&w);
    // Do the same thing with minus delta
    VecSetAdd(v, iAxis, -2.0 * delta);
    w = ShapoidExportCoord(proj, v);
    float dm = VecNorm(w);
    VecFree(&w);
    // Calculate the derivative along the current axis
    VecSet(dPos, iAxis, (dp - dm) / (2.0 * delta));
  }
  // Free memory
  VecFree(&v);
```

```
    // Move toward better solution
    // Declare a variable to memorize the next position
    VecFloat* nPos = VecGetOp(pos, 1.0, dPos, -1.0);
    // Ensure the position stay inside the Spheroid
    if (VecNorm(nPos) > 0.5) {
      VecNormalise(nPos);
      VecScale(nPos, 0.5);
    }
    // If we are stuck to the same position
    if (VecDist(pos, nPos) < PBMATH_EPSILON)
      // Stop the loop
      flag = true;
    // Else we keep moving
    else {
      VecCopy(pos, nPos);
      // Update the current distance
      v = ShapoidExportCoord(proj, pos);
      dist = VecNorm(v);
      VecFree(&v);
    }
    // Free memory
    VecFree(&nPos);
  }
  // Free memory
  ShapoidFree(&proj);
  VecFree(&pos);
  VecFree(&dPos);
  // If we have found a position less than one unit from the origin
  // of 'that' 's coordinates system
  if (dist <= 0.5)
    // The spheroids intersect
    return true;
  else
    // The spheroids do not intersect
    return false;
}

// SAT algorithm on 2D Facoid-Facoid
bool SATFF(const Facoid* const that,
  const Facoid* const tho) {
  // Declare a variable to loop on Frames and commonalize code
  const Shapoid* frameEdge = (const Shapoid*)that;
  // Loop to commonalize code when checking SAT based on that's edges
  // and then tho's edges
  for (
    int iFrame = 2;
    iFrame--;) {
    // Declare a variable to memorize the number of edges, by default 2
    int nbEdges = 2;
    // Loop on the frame's edges
    for (
      int iEdge = nbEdges;
      iEdge--;) {
      // Get the current edge
      const float* edge = frameEdge->_axis[iEdge]->_val;
      // Declare variables to memorize the boundaries of projection
      // of the two frames on the current edge
      float bdgBoxA[2];
      float bdgBoxB[2];
      // Declare two variables to loop on Frames and commonalize code
      const Shapoid* frame = (const Shapoid*)that;
      float* bdgBox = bdgBoxA;
```

```
// Loop on Frames
for (
  int jFrame = 2;
  jFrame--;) {
  // Shortcuts
  const float* frameOrig = frame->_pos->_val;
  const float* frameCompA = frame->_axis[0]->_val;
  const float* frameCompB = frame->_axis[1]->_val;
  // Get the number of vertices of frame
  int nbVertices = 4;
  // Declare a variable to memorize if the current vertex is
  // the first in the loop, used to initialize the boundaries
  bool firstVertex = true;
  // Loop on vertices of the frame
  for (
    int iVertex = nbVertices;
    iVertex--;) {
    // Get the vertex
    float vertex[2];
    vertex[0] = frameOrig[0];
    vertex[1] = frameOrig[1];
    switch (iVertex) {
      case 3:
        vertex[0] += frameCompA[0] + frameCompB[0];
        vertex[1] += frameCompA[1] + frameCompB[1];
        break;
      case 2:
        vertex[0] += frameCompA[0];
        vertex[1] += frameCompA[1];
        break;
      case 1:
        vertex[0] += frameCompB[0];
        vertex[1] += frameCompB[1];
        break;
      default:
        break;
    }
    // Get the projection of the vertex on the normal of the edge
    // Orientation of the normal doesn't matter, so we
    // use arbitrarily the normal (edge[1], -edge[0])
    float proj = vertex[0] * edge[1] - vertex[1] * edge[0];
    // If it's the first vertex
    if (firstVertex == true) {
      // Initialize the boundaries of the projection of the
      // Frame on the edge
      bdgBox[0] = proj;
      bdgBox[1] = proj;
      // Update the flag to memorize we did the first vertex
      firstVertex = false;
    // Else, it's not the first vertex
    } else {
      // Update the boundaries of the projection of the Frame on
      // the edge
      if (bdgBox[0] > proj) {
        bdgBox[0] = proj;
      }
      if (bdgBox[1] < proj) {
        bdgBox[1] = proj;
      }
    }
  }
  // Switch the frame to check the vertices of the second Frame
```

```
        frame = (const Shapoid*)tho;
        bdgBox = bdgBoxB;
      }
      // If the projections of the two frames on the edge are
      // not intersecting
      if (
        bdgBoxB[1] < bdgBoxA[0] ||
        bdgBoxA[1] < bdgBoxB[0]) {
        // There exists an axis which separates the Frames,
        // thus they are not in intersection
        return false;
      }
    }
    // Switch the frames to test against the second Frame's edges
    frameEdge = (const Shapoid*)tho;
  }
  // If we reaches here, it means the two Frames are intersecting
  return true;
}

// SAT algorithm on 2D Facoid-Pyramidoid
bool SATFP(const Facoid* const that,
  const Pyramidoid* const tho) {
  // Declare a variable to loop on Frames and commonalize code
  const Shapoid* frameEdge = (const Shapoid*)that;
  // Loop to commonalize code when checking SAT based on that's edges
  // and then tho's edges
  for (
    int iFrame = 2;
    iFrame--;) {
    // Shortcuts
    const float* frameEdgeCompA = frameEdge->_axis[0]->_val;
    const float* frameEdgeCompB = frameEdge->_axis[1]->_val;
    // Declare a variable to memorize the number of edges, by default 2
    int nbEdges = 2;
    // Declare a variable to memorize the third edge in case of
    // tetrahedron
    float thirdEdge[2];
    // If the frame is a tetrahedron
    if (iFrame == 0) {
      // Initialise the third edge
      thirdEdge[0] = frameEdgeCompB[0] - frameEdgeCompA[0];
      thirdEdge[1] = frameEdgeCompB[1] - frameEdgeCompA[1];
      // Correct the number of edges
      nbEdges = 3;
    }
    // Loop on the frame's edges
    for (
      int iEdge = nbEdges;
      iEdge--;) {
      // Get the current edge
      const float* edge =
        (iEdge == 2 ? thirdEdge : frameEdge->_axis[iEdge]->_val);
      // Declare variables to memorize the boundaries of projection
      // of the two frames on the current edge
      float bdgBoxA[2];
      float bdgBoxB[2];
      // Declare two variables to loop on Frames and commonalize code
      const Shapoid* frame = (const Shapoid*)that;
      float* bdgBox = bdgBoxA;
      // Loop on Frames
      for (
        int jFrame = 2;
        jFrame--;) {
        // Shortcuts
        const float* frameOrig = frame->_pos->_val;
        const float* frameCompA = frame->_axis[0]->_val;
        const float* frameCompB = frame->_axis[1]->_val;
        // Get the number of vertices of frame
        int nbVertices = (jFrame == 0 ? 3 : 4);
        // Declare a variable to memorize if the current vertex is
        // the first in the loop, used to initialize the boundaries
        bool firstVertex = true;
        // Loop on vertices of the frame
        for (
          int iVertex = nbVertices;
          iVertex--;) {
          // Get the vertex
          float vertex[2];
          vertex[0] = frameOrig[0];
          vertex[1] = frameOrig[1];
          switch (iVertex) {
            case 3:
              vertex[0] += frameCompA[0] + frameCompB[0];
              vertex[1] += frameCompA[1] + frameCompB[1];
              break;
            case 2:
              vertex[0] += frameCompA[0];
              vertex[1] += frameCompA[1];
              break;
            case 1:
              vertex[0] += frameCompB[0];
              vertex[1] += frameCompB[1];
              break;
            default:
              break;
          }
          // Get the projection of the vertex on the normal of the edge
          // Orientation of the normal doesn't matter, so we
          // use arbitrarily the normal (edge[1], -edge[0])
          float proj = vertex[0] * edge[1] - vertex[1] * edge[0];
          // If it's the first vertex
          if (firstVertex == true) {
            // Initialize the boundaries of the projection of the
            // Frame on the edge
            bdgBox[0] = proj;
            bdgBox[1] = proj;
            // Update the flag to memorize we did the first vertex
            firstVertex = false;
          // Else, it's not the first vertex
          } else {
            // Update the boundaries of the projection of the Frame on
            // the edge
            if (bdgBox[0] > proj) {
              bdgBox[0] = proj;
            }
            if (bdgBox[1] < proj) {
              bdgBox[1] = proj;
            }
          }
        }
        // Switch the frame to check the vertices of the second Frame
        frame = (const Shapoid*)tho;
        bdgBox = bdgBoxB;
```

```
      }
      // If the projections of the two frames on the edge are
      // not intersecting
      if (
        bdgBoxB[1] < bdgBoxA[0] ||
        bdgBoxA[1] < bdgBoxB[0]) {
        // There exists an axis which separates the Frames,
        // thus they are not in intersection
        return false;
      }
    }
    // Switch the frames to test against the second Frame's edges
    frameEdge = (const Shapoid*)tho;
  }
  // If we reaches here, it means the two Frames are intersecting
  return true;
}

// SAT algorithm on 2D Pyramidoid-Facoid
bool SATPF(const Pyramidoid* const that,
  const Facoid* const tho) {
  // Declare a variable to loop on Frames and commonalize code
  const Shapoid* frameEdge = (const Shapoid*)that;
  // Loop to commonalize code when checking SAT based on that's edges
  // and then tho's edges
  for (
    int iFrame = 2;
    iFrame--;) {
    // Shortcuts
    const float* frameEdgeCompA = frameEdge->_axis[0]->_val;
    const float* frameEdgeCompB = frameEdge->_axis[1]->_val;
    // Declare a variable to memorize the number of edges, by default 2
    int nbEdges = 2;
    // Declare a variable to memorize the third edge in case of
    // tetrahedron
    float thirdEdge[2];
    // If the frame is a tetrahedron
    // Initialise the third edge
    thirdEdge[0] = frameEdgeCompB[0] - frameEdgeCompA[0];
    thirdEdge[1] = frameEdgeCompB[1] - frameEdgeCompA[1];
    // If the frame is a tetrahedron
    if (iFrame == 1) {
      // Initialise the third edge
      thirdEdge[0] = frameEdgeCompB[0] - frameEdgeCompA[0];
      thirdEdge[1] = frameEdgeCompB[1] - frameEdgeCompA[1];
      // Correct the number of edges
      nbEdges = 3;
    }
    // Loop on the frame's edges
    for (
      int iEdge = nbEdges;
      iEdge--;) {
      // Get the current edge
      const float* edge =
        (iEdge == 2 ? thirdEdge : frameEdge->_axis[iEdge]->_val);
      // Declare variables to memorize the boundaries of projection
      // of the two frames on the current edge
      float bdgBoxA[2];
      float bdgBoxB[2];
      // Declare two variables to loop on Frames and commonalize code
      const Shapoid* frame = (const Shapoid*)that;
      float* bdgBox = bdgBoxA;
```

```
// Loop on Frames
for (
  int jFrame = 2;
  jFrame--;) {
  // Shortcuts
  const float* frameOrig = frame->_pos->_val;
  const float* frameCompA = frame->_axis[0]->_val;
  const float* frameCompB = frame->_axis[1]->_val;
  // Get the number of vertices of frame
  int nbVertices = (jFrame == 1 ? 3 : 4);
  // Declare a variable to memorize if the current vertex is
  // the first in the loop, used to initialize the boundaries
  bool firstVertex = true;
  // Loop on vertices of the frame
  for (
    int iVertex = nbVertices;
    iVertex--;) {
    // Get the vertex
    float vertex[2];
    vertex[0] = frameOrig[0];
    vertex[1] = frameOrig[1];
    switch (iVertex) {
      case 3:
        vertex[0] += frameCompA[0] + frameCompB[0];
        vertex[1] += frameCompA[1] + frameCompB[1];
        break;
      case 2:
        vertex[0] += frameCompA[0];
        vertex[1] += frameCompA[1];
        break;
      case 1:
        vertex[0] += frameCompB[0];
        vertex[1] += frameCompB[1];
        break;
      default:
        break;
    }
    // Get the projection of the vertex on the normal of the edge
    // Orientation of the normal doesn't matter, so we
    // use arbitrarily the normal (edge[1], -edge[0])
    float proj = vertex[0] * edge[1] - vertex[1] * edge[0];
    // If it's the first vertex
    if (firstVertex == true) {
      // Initialize the boundaries of the projection of the
      // Frame on the edge
      bdgBox[0] = proj;
      bdgBox[1] = proj;
      // Update the flag to memorize we did the first vertex
      firstVertex = false;
    // Else, it's not the first vertex
    } else {
      // Update the boundaries of the projection of the Frame on
      // the edge
      if (bdgBox[0] > proj) {
        bdgBox[0] = proj;
      }
      if (bdgBox[1] < proj) {
        bdgBox[1] = proj;
      }
    }
  }
  // Switch the frame to check the vertices of the second Frame
```

```
        frame = (const Shapoid*)tho;
        bdgBox = bdgBoxB;
      }
      // If the projections of the two frames on the edge are
      // not intersecting
      if (
        bdgBoxB[1] < bdgBoxA[0] ||
        bdgBoxA[1] < bdgBoxB[0]) {
        // There exists an axis which separates the Frames,
        // thus they are not in intersection
        return false;
      }
    }
    // Switch the frames to test against the second Frame's edges
    frameEdge = (const Shapoid*)tho;
  }
  // If we reaches here, it means the two Frames are intersecting
  return true;
}

// SAT algorithm on 2D Pyramidoid-Pyramidoid
bool SATPP(const Pyramidoid* const that,
  const Pyramidoid* const tho) {
  // Declare a variable to loop on Frames and commonalize code
  const Shapoid* frameEdge = (const Shapoid*)that;
  // Loop to commonalize code when checking SAT based on that's edges
  // and then tho's edges
  for (
    int iFrame = 2;
    iFrame--;) {
    // Shortcuts
    const float* frameEdgeCompA = frameEdge->_axis[0]->_val;
    const float* frameEdgeCompB = frameEdge->_axis[1]->_val;
    // Declare a variable to memorize the number of edges, by default 2
    int nbEdges = 3;
    // Declare a variable to memorize the third edge in case of
    // tetrahedron
    float thirdEdge[2];
    // If the frame is a tetrahedron
    // Initialise the third edge
    thirdEdge[0] = frameEdgeCompB[0] - frameEdgeCompA[0];
    thirdEdge[1] = frameEdgeCompB[1] - frameEdgeCompA[1];
    // Loop on the frame's edges
    for (
      int iEdge = nbEdges;
      iEdge--;) {
      // Get the current edge
      const float* edge =
        (iEdge == 2 ? thirdEdge : frameEdge->_axis[iEdge]->_val);
      // Declare variables to memorize the boundaries of projection
      // of the two frames on the current edge
      float bdgBoxA[2];
      float bdgBoxB[2];
      // Declare two variables to loop on Frames and commonalize code
      const Shapoid* frame = (const Shapoid*)that;
      float* bdgBox = bdgBoxA;
      // Loop on Frames
      for (
        int iFrame = 2;
        iFrame--;) {
        // Shortcuts
        const float* frameOrig = frame->_pos->_val;
        const float* frameCompA = frame->_axis[0]->_val;
        const float* frameCompB = frame->_axis[1]->_val;
        // Get the number of vertices of frame
        int nbVertices = 3;
        // Declare a variable to memorize if the current vertex is
        // the first in the loop, used to initialize the boundaries
        bool firstVertex = true;
        // Loop on vertices of the frame
        for (
          int iVertex = nbVertices;
          iVertex--;) {
          // Get the vertex
          float vertex[2];
          vertex[0] = frameOrig[0];
          vertex[1] = frameOrig[1];
          switch (iVertex) {
            case 2:
              vertex[0] += frameCompA[0];
              vertex[1] += frameCompA[1];
              break;
            case 1:
              vertex[0] += frameCompB[0];
              vertex[1] += frameCompB[1];
              break;
            default:
              break;
          }
          // Get the projection of the vertex on the normal of the edge
          // Orientation of the normal doesn't matter, so we
          // use arbitrarily the normal (edge[1], -edge[0])
          float proj = vertex[0] * edge[1] - vertex[1] * edge[0];
          // If it's the first vertex
          if (firstVertex == true) {
            // Initialize the boundaries of the projection of the
            // Frame on the edge
            bdgBox[0] = proj;
            bdgBox[1] = proj;
            // Update the flag to memorize we did the first vertex
            firstVertex = false;
          // Else, it's not the first vertex
          } else {
            // Update the boundaries of the projection of the Frame on
            // the edge
            if (bdgBox[0] > proj) {
              bdgBox[0] = proj;
            }
            if (bdgBox[1] < proj) {
              bdgBox[1] = proj;
            }
          }
        }
        // Switch the frame to check the vertices of the second Frame
        frame = (const Shapoid*)tho;
        bdgBox = bdgBoxB;
      }
      // If the projections of the two frames on the edge are
      // not intersecting
      if (
        bdgBoxB[1] < bdgBoxA[0] ||
        bdgBoxA[1] < bdgBoxB[0]) {
        // There exists an axis which separates the Frames,
        // thus they are not in intersection
```

```
        return false;
      }
    }
    // Switch the frames to test against the second Frame's edges
    frameEdge = (const Shapoid*)tho;
  }
  // If we reaches here, it means the two Frames are intersecting
  return true;
}

// Eliminate the first variable in the system M.X<=Y
// using the Fourier-Motzkin method and return
// the resulting system in Mp and Yp, and the number of rows of
// the resulting system in nbRemainRows
// (M arrangement is [iRow][iCol])
// Return true if the system becomes inconsistent during elimination,
// else return false
#define neg(x) (x < 0.0 ? x : 0.0)
#define sgn(v) (((0.0 < (v)) ? 1 : 0) - (((v) < 0.0) ? 1 : 0))
bool ElimVar3D(
  const float (*M)[3],
  const float* Y,
  const int nbRows,
  const int nbCols,
  float (*Mp)[3],
  float* Yp,
  int* const nbRemainRows) {
  // Initialize the number of rows in the result system
  int nbResRows = 0;
  // First we process the rows where the eliminated variable is not null
  // For each row except the last one
  for (
    int iRow = 0;
    iRow < nbRows - 1;
    ++iRow) {
    // Shortcuts
    const float fabsMIRowIVar = fabs(M[iRow][0]);
    // If the coefficient for the eliminated variable is not null
    // in this row
    if (fabsMIRowIVar > PBMATH_EPSILON) {
      // Shortcuts
      const float* MiRow = M[iRow];
      const int sgnMIRowIVar = sgn(MiRow[0]);
      const float YIRowDivideByFabsMIRowIVar = Y[iRow] / fabsMIRowIVar;
      // For each following rows
      for (
        int jRow = iRow + 1;
        jRow < nbRows;
        ++jRow) {
        // If coefficients of the eliminated variable in the two rows have
        // different signs and are not null
        if (
          sgnMIRowIVar != sgn(M[jRow][0]) &&
          fabs(M[jRow][0]) > PBMATH_EPSILON) {
          // Shortcuts
          const float* MjRow = M[jRow];
          const float fabsMjRow = fabs(MjRow[0]);
          // Declare a variable to memorize the sum of the negative
          // coefficients in the row
          float sumNegCoeff = 0.0;
          // Add the sum of the two normed (relative to the eliminated
          // variable) rows into the result system. This actually
          // eliminate the variable while keeping the constraints on
          // others variables
          for (
            int iCol = 1;
            iCol < nbCols;
            ++iCol ) {
            Mp[nbResRows][iCol - 1] =
              MiRow[iCol] / fabsMIRowIVar +
              MjRow[iCol] / fabsMjRow;
            // Update the sum of the negative coefficient
            sumNegCoeff += neg(Mp[nbResRows][iCol - 1]);
          }
          // Update the right side of the inequality
          Yp[nbResRows] =
            YIRowDivideByFabsMIRowIVar +
            Y[jRow] / fabsMjRow;
          // If the right side of the inequality is lower than the sum of
          // negative coefficients in the row
          // (Add epsilon for numerical imprecision)
          if (Yp[nbResRows] < sumNegCoeff - PBMATH_EPSILON) {
            // Given that X is in [0,1], the system is inconsistent
            return true;
          }
          // Increment the nb of rows into the result system
          ++nbResRows;
        }
      }
    }
  }
  // Then we copy and compress the rows where the eliminated
  // variable is null
  // Loop on rows of the input system
  for (
    int iRow = 0;
    iRow < nbRows;
    ++iRow) {
    // Shortcut
    const float* MiRow = M[iRow];
    // If the coefficient of the eliminated variable is null on
    // this row
    if (fabs(MiRow[0]) < PBMATH_EPSILON) {
      // Shortcut
      float* MpnbResRows = Mp[nbResRows];
      // Copy this row into the result system excluding the eliminated
      // variable
      for (
        int iCol = 1;
        iCol < nbCols;
        ++iCol) {
        MpnbResRows[iCol - 1] = MiRow[iCol];
      }
      Yp[nbResRows] = Y[iRow];
      // Increment the nb of rows into the result system
      ++nbResRows;
    }
  }
  // Memorize the number of rows in the result system
  *nbRemainRows = nbResRows;
  // If we reach here the system is not inconsistent
  return false;
}
```

```
typedef struct {
  float min[3];
  float max[3];
} AABB3D;

// Get the bounds of the iVar-th variable in the nbRows rows
// system M.X<=Y where the iVar-th variable is on the first column
// and store them in the iVar-th axis of the AABB bdgBox
// (M arrangement is [iRow][iCol])
void GetBoundVar3D(
  const int iVar,
  const float (*M)[3],
  const float* Y,
  const int nbRows,
  const int nbCols,
  AABB3D* const bdgBox) {
  // Shortcuts
  float* bdgBoxMin = bdgBox->min;
  float* bdgBoxMax = bdgBox->max;
  // Initialize the bounds
  bdgBoxMin[iVar] = 0.0;
  bdgBoxMax[iVar] = 1.0;
  // Loop on the rows
  for (
    int iRow = 0;
    iRow < nbRows;
    ++iRow) {
    // Shortcuts
    const float* MIRow = M[iRow];
    float fabsMIRowIVar = fabs(MIRow[0]);
    // If the coefficient of the first variable on this row is not null
    if (fabsMIRowIVar > PBMATH_EPSILON) {
      // Declare two variables to memorize the min and max of the
      // requested variable in this row
      float min = -1.0 * Y[iRow];
      float max = Y[iRow];
      // Loop on columns except the first one which is the one of the
      // requested variable
      for (
        int iCol = 1;
        iCol < nbCols;
        ++iCol) {
        if (MIRow[iCol] > PBMATH_EPSILON) {
          min += MIRow[iCol] * bdgBoxMin[iCol + iVar];
          max -= MIRow[iCol] * bdgBoxMin[iCol + iVar];
        } else if (MIRow[iCol] < PBMATH_EPSILON) {
          min += MIRow[iCol] * bdgBoxMax[iCol + iVar];
          max -= MIRow[iCol] * bdgBoxMax[iCol + iVar];
        }
      }
      min /= -1.0 * MIRow[0];
      max /= MIRow[0];
      if (bdgBoxMin[iVar] > min) {
        bdgBoxMin[iVar] = min;
      }
      if (bdgBoxMax[iVar] < max) {
        bdgBoxMax[iVar] = max;
      }
    }
  }
}
```

```
// Get the bounds of the iVar-th variable in the nbRows rows
// system M.X<=Y which has been reduced to only one variable
// and store them in the iVar-th axis of the
// AABB bdgBox
// (M arrangement is [iRow][iCol])
// May return inconsistent values (max < min), which would
// mean the system has no solution
void GetBoundLastVar3D(
  const int iVar,
  const float (*M)[3],
  const float* Y,
  const int nbRows,
  AABB3D* const bdgBox) {
  // Shortcuts
  float* min = bdgBox->min + iVar;
  float* max = bdgBox->max + iVar;
  // Initialize the bounds to their maximum maximum and minimum minimum
  *min = 0.0;
  *max = 1.0;
  // Loop on rows
  for (
    int jRow = 0;
    jRow < nbRows;
    ++jRow) {
    // Shortcut
    float MjRowiVar = M[jRow][0];
    // If this row has been reduced to the variable in argument
    // and it has a strictly positive coefficient
    if (MjRowiVar > PBMATH_EPSILON) {
      // Get the scaled value of Y for this row
      float y = Y[jRow] / MjRowiVar;
      // If the value is lower than the current maximum bound
      if (*max > y) {
        // Update the maximum bound
        *max = y;
      }
    // Else, if this row has been reduced to the variable in argument
    // and it has a strictly negative coefficient
    } else if (MjRowiVar < -PBMATH_EPSILON) {
      // Get the scaled value of Y for this row
      float y = Y[jRow] / MjRowiVar;
      // If the value is greater than the current minimum bound
      if (*min < y) {
        // Update the minimum bound
        *min = y;
      }
    }
  }
}

// FMB algorithm on 3D Facoid-Facoid
typedef struct {
  float orig[3];
  float comp[3][3];
} Frame3D;
bool FMBFF(const Facoid* const that,
  const Facoid* const tho) {
  // Get the projection of the Frame tho in Frame that coordinates
  // system
  // TODO: should be externalised
  Frame3D thoProj;
  const float* qo  = tho->_s._pos->_val;
```

```
float* qpo = thoProj.orig;
const float* po  = that->_s._pos->_val;
const float* pi = that->_s._sysLinEqImport->_Minv->_val;
float (*qpc)[3] = thoProj.comp;
float v[3];
for (
  int i = 3;
  i--;) {
  v[i] = qo[i] - po[i];
}
for (
  int i = 3;
  i--;) {
  qpo[i] = 0.0;
  for (
    int j = 3;
    j--;) {
    qpo[i] += pi[j + 3 * i] * v[j];
    qpc[j][i] = 0.0;
    for (
      int k = 3;
      k--;) {
      qpc[j][i] += pi[k + 3 * i] * tho->_s._axis[j]->_val[k];
    }
  }
}
// Declare two variables to memorize the system to be solved M.X <= Y
// (M arrangement is [iRow][iCol])
float M[12][3];
float Y[12];
// Create the inequality system
// -sum_iC_j,iX_i<=O_j
M[0][0] = -thoProj.comp[0][0];
M[0][1] = -thoProj.comp[1][0];
M[0][2] = -thoProj.comp[2][0];
Y[0] = thoProj.orig[0];
if (Y[0] < neg(M[0][0]) + neg(M[0][1]) + neg(M[0][2])) {
  return false;
}
M[1][0] = -thoProj.comp[0][1];
M[1][1] = -thoProj.comp[1][1];
M[1][2] = -thoProj.comp[2][1];
Y[1] = thoProj.orig[1];
if (Y[1] < neg(M[1][0]) + neg(M[1][1]) + neg(M[1][2])) {
  return false;
}
M[2][0] = -thoProj.comp[0][2];
M[2][1] = -thoProj.comp[1][2];
M[2][2] = -thoProj.comp[2][2];
Y[2] = thoProj.orig[2];
if (Y[2] < neg(M[2][0]) + neg(M[2][1]) + neg(M[2][2])) {
  return false;
}
// Variable to memorize the nb of rows in the system
int nbRows = 12;
// sum_iC_j,iX_i<=1.0-O_j
M[3][0] = thoProj.comp[0][0];
M[3][1] = thoProj.comp[1][0];
M[3][2] = thoProj.comp[2][0];
Y[3] = 1.0 - thoProj.orig[0];
if (
  Y[3] < neg(M[3][0]) + neg(M[3][1]) + neg(M[3][2])) {
```

```
  return false;
}
M[4][0] = thoProj.comp[0][1];
M[4][1] = thoProj.comp[1][1];
M[4][2] = thoProj.comp[2][1];
Y[4] = 1.0 - thoProj.orig[1];
if (
  Y[4] < neg(M[4][0]) + neg(M[4][1]) + neg(M[4][2])) {
  return false;
}
M[5][0] = thoProj.comp[0][2];
M[5][1] = thoProj.comp[1][2];
M[5][2] = thoProj.comp[2][2];
Y[5] = 1.0 - thoProj.orig[2];
if (
  Y[5] < neg(M[5][0]) + neg(M[5][1]) + neg(M[5][2])) {
  return false;
}
// X_i <= 1.0
M[6][0] = 1.0;
M[6][1] = 0.0;
M[6][2] = 0.0;
Y[6] = 1.0;
M[7][0] = 0.0;
M[7][1] = 1.0;
M[7][2] = 0.0;
Y[7] = 1.0;
M[8][0] = 0.0;
M[8][1] = 0.0;
M[8][2] = 1.0;
Y[8] = 1.0;
// -X_i <= 0.0
M[9][0] = -1.0;
M[9][1] = 0.0;
M[9][2] = 0.0;
Y[9] = 0.0;
M[10][0] = 0.0;
M[10][1] = -1.0;
M[10][2] = 0.0;
Y[10] = 0.0;
M[11][0] = 0.0;
M[11][1] = 0.0;
M[11][2] = -1.0;
Y[11] = 0.0;
// Solve the system
// Declare a AABB to memorize the bounding box of the intersection
// in the coordinates system of tho
AABB3D bdgBoxLocal = {
  .min = {0.0, 0.0, 0.0},
  .max = {0.0, 0.0, 0.0}
};
// Declare variables to eliminate the first variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mp[20][3];
float Yp[20];
int nbRowsP;
// Eliminate the first variable in the original system
bool inconsistency =
  ElimVar3D(
      M,
      Y,
      nbRows,
      3,
      Mp,
      Yp,
      &nbRowsP);
  // If the system is inconsistent
  if (inconsistency == true) {
    // The two Frames are not in intersection
    return false;
  }
  // Declare variables to eliminate the second variable
  // The size of the array given in the doc is a majoring value.
  // Instead I use a smaller value which has proven to be sufficient
  // during tests, validation and qualification, to avoid running
  // into the heap limit and to optimize slightly the performance
  float Mpp[55][3];
  float Ypp[55];
  int nbRowsPP;
  // Eliminate the second variable (which is the first in the new system)
  inconsistency =
    ElimVar3D(
      Mp,
      Yp,
      nbRowsP,
      2,
      Mpp,
      Ypp,
      &nbRowsPP);
  // If the system is inconsistent
  if (inconsistency == true) {
    // The two Frames are not in intersection
    return false;
  }
  // Get the bounds for the remaining third variable
  GetBoundLastVar3D(
    2,
    Mpp,
    Ypp,
    nbRowsPP,
    &bdgBoxLocal);
  // If the bounds are inconsistent
  if (bdgBoxLocal.min[2] >= bdgBoxLocal.max[2]) {
    // The two Frames are not in intersection
    return false;
  }
  // If we've reached here the two Frames are intersecting
  return true;
}

// FMB algorithm on 3D Facoid-Pyramidoid
bool FMBFP(const Facoid* const that,
  const Pyramidoid* const tho) {
  // Get the projection of the Frame tho in Frame that coordinates
  // system
  // TODO: should be externalised
  Frame3D thoProj;
  const float* qo  = tho->_s._pos->_val;
  float* qpo = thoProj.orig;
  const float* po  = that->_s._pos->_val;
  const float* pi = that->_s._sysLinEqImport->_Minv->_val;
```

```
float (*qpc)[3] = thoProj.comp;
float v[3];
for (
  int i = 3;
  i--;) {
  v[i] = qo[i] - po[i];
}
for (
  int i = 3;
  i--;) {
  qpo[i] = 0.0;
  for (
    int j = 3;
    j--;) {
    qpo[i] += pi[j + 3 * i] * v[j];
    qpc[j][i] = 0.0;
    for (
      int k = 3;
      k--;) {
      qpc[j][i] += pi[k + 3 * i] * tho->_s._axis[j]->_val[k];
    }
  }
}
// Declare two variables to memorize the system to be solved M.X <= Y
// (M arrangement is [iRow][iCol])
float M[10][3];
float Y[10];
// Create the inequality system
// -sum_iC_j,iX_i<=O_j
M[0][0] = -thoProj.comp[0][0];
M[0][1] = -thoProj.comp[1][0];
M[0][2] = -thoProj.comp[2][0];
Y[0] = thoProj.orig[0];
if (Y[0] < neg(M[0][0]) + neg(M[0][1]) + neg(M[0][2])) {
  return false;
}
M[1][0] = -thoProj.comp[0][1];
M[1][1] = -thoProj.comp[1][1];
M[1][2] = -thoProj.comp[2][1];
Y[1] = thoProj.orig[1];
if (Y[1] < neg(M[1][0]) + neg(M[1][1]) + neg(M[1][2])) {
  return false;
}
M[2][0] = -thoProj.comp[0][2];
M[2][1] = -thoProj.comp[1][2];
M[2][2] = -thoProj.comp[2][2];
Y[2] = thoProj.orig[2];
if (Y[2] < neg(M[2][0]) + neg(M[2][1]) + neg(M[2][2])) {
  return false;
}
// Variable to memorize the nb of rows in the system
int nbRows = 10;
// sum_iC_j,iX_i<=1.0-O_j
M[3][0] = thoProj.comp[0][0];
M[3][1] = thoProj.comp[1][0];
M[3][2] = thoProj.comp[2][0];
Y[3] = 1.0 - thoProj.orig[0];
if (
  Y[3] < neg(M[3][0]) + neg(M[3][1]) + neg(M[3][2])) {
  return false;
}
M[4][0] = thoProj.comp[0][1];
```

```
M[4][1] = thoProj.comp[1][1];
M[4][2] = thoProj.comp[2][1];
Y[4] = 1.0 - thoProj.orig[1];
if (
  Y[4] < neg(M[4][0]) + neg(M[4][1]) +
  neg(M[4][2])) {
  return false;
}
M[5][0] = thoProj.comp[0][2];
M[5][1] = thoProj.comp[1][2];
M[5][2] = thoProj.comp[2][2];
Y[5] = 1.0 - thoProj.orig[2];
if (
  Y[5] < neg(M[5][0]) + neg(M[5][1]) +
  neg(M[5][2])) {
  return false;
}
// sum_iX_i<=1.0
M[6][0] = 1.0;
M[6][1] = 1.0;
M[6][2] = 1.0;
Y[6] = 1.0;
// -X_i <= 0.0
M[7][0] = -1.0;
M[7][1] = 0.0;
M[7][2] = 0.0;
Y[7] = 0.0;
M[8][0] = 0.0;
M[8][1] = -1.0;
M[8][2] = 0.0;
Y[8] = 0.0;
M[9][0] = 0.0;
M[9][1] = 0.0;
M[9][2] = -1.0;
Y[9] = 0.0;
// Solve the system
// Declare a AABB to memorize the bounding box of the intersection
// in the coordinates system of tho
AABB3D bdgBoxLocal = {
  .min = {0.0, 0.0, 0.0},
  .max = {0.0, 0.0, 0.0}
};
// Declare variables to eliminate the first variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mp[20][3];
float Yp[20];
int nbRowsP;
// Eliminate the first variable in the original system
bool inconsistency =
  ElimVar3D(
    M,
    Y,
    nbRows,
    3,
    Mp,
    Yp,
    &nbRowsP);
// If the system is inconsistent
if (inconsistency == true) {
    // The two Frames are not in intersection
    return false;
  }
  // Declare variables to eliminate the second variable
  // The size of the array given in the doc is a majoring value.
  // Instead I use a smaller value which has proven to be sufficient
  // during tests, validation and qualification, to avoid running
  // into the heap limit and to optimize slightly the performance
  float Mpp[55][3];
  float Ypp[55];
  int nbRowsPP;
  // Eliminate the second variable (which is the first in the new system)
  inconsistency =
    ElimVar3D(
      Mp,
      Yp,
      nbRowsP,
      2,
      Mpp,
      Ypp,
      &nbRowsPP);
  // If the system is inconsistent
  if (inconsistency == true) {
    // The two Frames are not in intersection
    return false;
  }
  // Get the bounds for the remaining third variable
  GetBoundLastVar3D(
    2,
    Mpp,
    Ypp,
    nbRowsPP,
    &bdgBoxLocal);
  // If the bounds are inconsistent
  if (bdgBoxLocal.min[2] >= bdgBoxLocal.max[2]) {
    // The two Frames are not in intersection
    return false;
  }
  // If we've reached here the two Frames are intersecting
  return true;
}

// FMB algorithm on 3D Pyramidoid-Facoid
bool FMBPF(const Pyramidoid* const that,
  const Facoid* const tho) {
  // Get the projection of the Frame tho in Frame that coordinates
  // system
  // TODO: should be externalised
  Frame3D thoProj;
  const float* qo  = tho->_s._pos->_val;
  float* qpo = thoProj.orig;
  const float* po  = that->_s._pos->_val;
  const float* pi = that->_s._sysLinEqImport->_Minv->_val;
  float (*qpc)[3] = thoProj.comp;
  float v[3];
  for (
    int i = 3;
    i--;) {
    v[i] = qo[i] - po[i];
  }
  for (
    int i = 3;
    i--;) {
    qpo[i] = 0.0;
    for (
      int j = 3;
      j--;) {
      qpo[i] += pi[j + 3 * i] * v[j];
      qpc[j][i] = 0.0;
      for (
        int k = 3;
        k--;) {
        qpc[j][i] += pi[k + 3 * i] * tho->_s._axis[j]->_val[k];
      }
    }
  }
  // Declare two variables to memorize the system to be solved M.X <= Y
  // (M arrangement is [iRow][iCol])
  float M[10][3];
  float Y[10];
  // Create the inequality system
  // -sum_iC_j,iX_i<=O_j
  M[0][0] = -thoProj.comp[0][0];
  M[0][1] = -thoProj.comp[1][0];
  M[0][2] = -thoProj.comp[2][0];
  Y[0] = thoProj.orig[0];
  if (Y[0] < neg(M[0][0]) + neg(M[0][1]) + neg(M[0][2])) {
    return false;
  }
  M[1][0] = -thoProj.comp[0][1];
  M[1][1] = -thoProj.comp[1][1];
  M[1][2] = -thoProj.comp[2][1];
  Y[1] = thoProj.orig[1];
  if (Y[1] < neg(M[1][0]) + neg(M[1][1]) + neg(M[1][2])) {
    return false;
  }
  M[2][0] = -thoProj.comp[0][2];
  M[2][1] = -thoProj.comp[1][2];
  M[2][2] = -thoProj.comp[2][2];
  Y[2] = thoProj.orig[2];
  if (Y[2] < neg(M[2][0]) + neg(M[2][1]) + neg(M[2][2])) {
    return false;
  }
  // Variable to memorize the nb of rows in the system
  int nbRows = 10;
  // sum_j(sum_iC_j,iX_i)<=1.0-sum_iO_i
  M[3][0] =
    thoProj.comp[0][0] + thoProj.comp[0][1] + thoProj.comp[0][2];
  M[3][1] =
    thoProj.comp[1][0] + thoProj.comp[1][1] + thoProj.comp[1][2];
  M[3][2] =
    thoProj.comp[2][0] + thoProj.comp[2][1] + thoProj.comp[2][2];
  Y[3] =
    1.0 - thoProj.orig[0] - thoProj.orig[1] - thoProj.orig[2];
  if (
    Y[3] < neg(M[3][0]) + neg(M[3][1]) + neg(M[3][2])) {
    return false;
  }
  // X_i <= 1.0
  M[4][0] = 1.0;
  M[4][1] = 0.0;
  M[4][2] = 0.0;
  Y[4] = 1.0;
  M[5][0] = 0.0;
```

```
M[5][1] = 1.0;
M[5][2] = 0.0;
Y[5] = 1.0;
M[6][0] = 0.0;
M[6][1] = 0.0;
M[6][2] = 1.0;
Y[6] = 1.0;
// -X_i <= 0.0
M[7][0] = -1.0;
M[7][1] = 0.0;
M[7][2] = 0.0;
Y[7] = 0.0;
M[8][0] = 0.0;
M[8][1] = -1.0;
M[8][2] = 0.0;
Y[8] = 0.0;
M[9][0] = 0.0;
M[9][1] = 0.0;
M[9][2] = -1.0;
Y[9] = 0.0;
// Solve the system
// Declare a AABB to memorize the bounding box of the intersection
// in the coordinates system of tho
AABB3D bdgBoxLocal = {
  .min = {0.0, 0.0, 0.0},
  .max = {0.0, 0.0, 0.0}
};
// Declare variables to eliminate the first variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mp[20][3];
float Yp[20];
int nbRowsP;
// Eliminate the first variable in the original system
bool inconsistency =
  ElimVar3D(
    M,
    Y,
    nbRows,
    3,
    Mp,
    Yp,
    &nbRowsP);
// If the system is inconsistent
if (inconsistency == true) {
  // The two Frames are not in intersection
  return false;
}
// Declare variables to eliminate the second variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mpp[55][3];
float Ypp[55];
int nbRowsPP;
// Eliminate the second variable (which is the first in the new system)
inconsistency =
  ElimVar3D(
    Mp,
      Yp,
      nbRowsP,
      2,
      Mpp,
      Ypp,
      &nbRowsPP);
  // If the system is inconsistent
  if (inconsistency == true) {
    // The two Frames are not in intersection
    return false;
  }
  // Get the bounds for the remaining third variable
  GetBoundLastVar3D(
    2,
    Mpp,
    Ypp,
    nbRowsPP,
    &bdgBoxLocal);
  // If the bounds are inconsistent
  if (bdgBoxLocal.min[2] >= bdgBoxLocal.max[2]) {
    // The two Frames are not in intersection
    return false;
  }
  // If we've reached here the two Frames are intersecting
  return true;
}

// FMB algorithm on 3D Pyramidoid-Pyramidoid
bool FMBPP(const Pyramidoid* const that,
  const Pyramidoid* const tho) {
  // Get the projection of the Frame tho in Frame that coordinates
  // system
  // TODO: should be externalised
  Frame3D thoProj;
  const float* qo  = tho->_s._pos->_val;
  float* qpo = thoProj.orig;
  const float* po  = that->_s._pos->_val;
  const float* pi = that->_s._sysLinEqImport->_Minv->_val;
  float (*qpc)[3] = thoProj.comp;
  float v[3];
  for (
    int i = 3;
    i--;) {
    v[i] = qo[i] - po[i];
  }
  for (
    int i = 3;
    i--;) {
    qpo[i] = 0.0;
    for (
      int j = 3;
      j--;) {
      qpo[i] += pi[j + 3 * i] * v[j];
      qpc[j][i] = 0.0;
      for (
        int k = 3;
        k--;) {
        qpc[j][i] += pi[k + 3 * i] * tho->_s._axis[j]->_val[k];
      }
    }
  }
  // Declare two variables to memorize the system to be solved M.X <= Y
  // (M arrangement is [iRow][iCol])
  float M[8][3];
  float Y[8];
  // Create the inequality system
  // -sum_iC_j,iX_i<=O_j
  M[0][0] = -thoProj.comp[0][0];
  M[0][1] = -thoProj.comp[1][0];
  M[0][2] = -thoProj.comp[2][0];
  Y[0] = thoProj.orig[0];
  if (Y[0] < neg(M[0][0]) + neg(M[0][1]) + neg(M[0][2])) {
    return false;
  }
  M[1][0] = -thoProj.comp[0][1];
  M[1][1] = -thoProj.comp[1][1];
  M[1][2] = -thoProj.comp[2][1];
  Y[1] = thoProj.orig[1];
  if (Y[1] < neg(M[1][0]) + neg(M[1][1]) + neg(M[1][2])) {
    return false;
  }
  M[2][0] = -thoProj.comp[0][2];
  M[2][1] = -thoProj.comp[1][2];
  M[2][2] = -thoProj.comp[2][2];
  Y[2] = thoProj.orig[2];
  if (Y[2] < neg(M[2][0]) + neg(M[2][1]) + neg(M[2][2])) {
    return false;
  }
  // Variable to memorize the nb of rows in the system
  int nbRows = 8;
  // sum_j(sum_iC_j,iX_i)<=1.0-sum_iO_i
  M[3][0] =
    thoProj.comp[0][0] + thoProj.comp[0][1] + thoProj.comp[0][2];
  M[3][1] =
    thoProj.comp[1][0] + thoProj.comp[1][1] + thoProj.comp[1][2];
  M[3][2] =
    thoProj.comp[2][0] + thoProj.comp[2][1] + thoProj.comp[2][2];
  Y[3] =
    1.0 - thoProj.orig[0] - thoProj.orig[1] - thoProj.orig[2];
  if (
    Y[3] < neg(M[3][0]) + neg(M[3][1]) + neg(M[3][2])) {
    return false;
  }
  // sum_iX_i<=1.0
  M[4][0] = 1.0;
  M[4][1] = 1.0;
  M[4][2] = 1.0;
  Y[4] = 1.0;
  // -X_i <= 0.0
  M[5][0] = -1.0;
  M[5][1] = 0.0;
  M[5][2] = 0.0;
  Y[5] = 0.0;
  M[6][0] = 0.0;
  M[6][1] = -1.0;
  M[6][2] = 0.0;
  Y[6] = 0.0;
  M[7][0] = 0.0;
  M[7][1] = 0.0;
  M[7][2] = -1.0;
  Y[7] = 0.0;
  // Solve the system
  // Declare a AABB to memorize the bounding box of the intersection
  // in the coordinates system of tho
```

```
AABB3D bdgBoxLocal = {
  .min = {0.0, 0.0, 0.0},
  .max = {0.0, 0.0, 0.0}
};
// Declare variables to eliminate the first variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mp[20][3];
float Yp[20];
int nbRowsP;
// Eliminate the first variable in the original system
bool inconsistency =
  ElimVar3D(
    M,
    Y,
    nbRows,
    3,
    Mp,
    Yp,
    &nbRowsP);
// If the system is inconsistent
if (inconsistency == true) {
  // The two Frames are not in intersection
  return false;
}
// Declare variables to eliminate the second variable
// The size of the array given in the doc is a majoring value.
// Instead I use a smaller value which has proven to be sufficient
// during tests, validation and qualification, to avoid running
// into the heap limit and to optimize slightly the performance
float Mpp[55][3];
float Ypp[55];
int nbRowsPP;
// Eliminate the second variable (which is the first in the new system)
inconsistency =
  ElimVar3D(
    Mp,
    Yp,
    nbRowsP,
    2,
    Mpp,
    Ypp,
    &nbRowsPP);
// If the system is inconsistent
if (inconsistency == true) {
  // The two Frames are not in intersection
  return false;
}
// Get the bounds for the remaining third variable
GetBoundLastVar3D(
  2,
  Mpp,
  Ypp,
  nbRowsPP,
  &bdgBoxLocal);
// If the bounds are inconsistent
if (bdgBoxLocal.min[2] >= bdgBoxLocal.max[2]) {
  // The two Frames are not in intersection
  return false;
}
```

```
  // If we’ve reached here the two Frames are intersecting
  return true;
}

bool _FacoidIsInterFacoid(const Facoid* const that,
  const Facoid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’that’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’tho’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "’that’ and ’tho’ have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != 2 && ShapoidGetDim(that) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "’that’ and ’tho’ have invalid dimensions (2<=%d<=3)",
      ShapoidGetDim(that));
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetDim(that) == 2) {
    return SATFF(that, tho);
  } else if (ShapoidGetDim(that) == 3) {
    return FMBFF(that, tho);
  } else {
    return false;
  }
}

bool _FacoidIsInterPyramidoid(const Facoid* const that,
  const Pyramidoid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’that’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’tho’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "’that’ and ’tho’ have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != 2 && ShapoidGetDim(that) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have invalid dimensions (2<=%d<=3)",
      ShapoidGetDim(that));
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetDim(that) == 2) {
    return SATFP(that, tho);
  } else if (ShapoidGetDim(that) == 3) {
    return FMBFP(that, tho);
  } else {
    return false;
  }
}

bool _PyramidoidIsInterFacoid(const Pyramidoid* const that,
  const Facoid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'tho' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != 2 && ShapoidGetDim(that) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have invalid dimensions (2<=%d<=3)",
      ShapoidGetDim(that));
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetDim(that) == 2) {
    return SATPF(that, tho);
  } else if (ShapoidGetDim(that) == 3) {
    return FMBPF(that, tho);
  } else {
    return false;
  }
}

bool _PyramidoidIsInterPyramidoid(const Pyramidoid* const that,
  const Pyramidoid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'tho' is null");
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != ShapoidGetDim(tho)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have different dimensions (%d==%d)",
      ShapoidGetDim(that), ShapoidGetDim(tho));
    PBErrCatch(ShapoidErr);
  }
  if (ShapoidGetDim(that) != 2 && ShapoidGetDim(that) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' and 'tho' have invalid dimensions (2<=%d<=3)",
      ShapoidGetDim(that));
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetDim(that) == 2) {
    return SATPP(that, tho);
  } else if (ShapoidGetDim(that) == 3) {
    return FMBPP(that, tho);
  } else {
    return false;
  }
}

// Update the major and minor axis of the Spheroid 'that'
void SpheroidUpdateMajMinAxis(Spheroid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  that->_majAxis = 0;
  float maj = VecNorm(ShapoidAxis(that, 0));
  that->_minAxis = 0;
  float min = maj;
  for (int iAxis = ShapoidGetDim(that); iAxis-- && iAxis != 0;) {
    float n = VecNorm(ShapoidAxis(that, iAxis));
    if (n > maj) {
      maj = n;
      that->_majAxis = iAxis;
    } else if (n < min) {
      min = n;
      that->_minAxis = iAxis;
    }
  }
}

// Get the maximum distance from the center of the Shapoid 'that' and
// its surface
// Currenty only defined for spheroid, return 0.0 else
float _ShapoidGetBoundingRadius(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetType(that) == ShapoidTypeSpheroid) {
    return
      VecNorm(ShapoidAxis(that, ((Spheroid*)that)->_majAxis)) * 0.5;
  }
  return 0.0;
}

// ------------- ShapoidIter

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

// Step the ShapoidIter 'that' for a Facoid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepFacoid(ShapoidIter* const that);

// Step the ShapoidIter 'that' for a Pyramidoid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepPyramidoid(ShapoidIter* const that);

// Step the ShapoidIter 'that' for a Spheroid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepSpheroid(ShapoidIter* const that);

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

// Create a new iterator on the Shapoid 'shap' with a step of 'delta'
// (step on the internal coordinates of the Shapoid)
// The iterator is initialized and ready to be stepped
ShapoidIter _ShapoidIterCreateStatic(const Shapoid* const shap,
  const VecFloat* const delta) {
#if BUILDMODE == 0
  if (shap == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'shap' is null");
    PBErrCatch(ShapoidErr);
  }
  if (delta == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'delta' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(delta) != ShapoidGetDim(shap)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'delta' dimensions and 'shap' dimensions don't match (%ld==%d)",
      VecGetDim(delta), ShapoidGetDim(shap));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare the new iterator
  ShapoidIter iter;
  // Set properties
  iter._shap = shap;
  iter._delta = VecClone(delta);
  iter._pos = VecFloatCreate(VecGetDim(delta));
  // Init the position
  ShapoidIterInit(&iter);
  // Return the new iterator
  return iter;
}
```

```
// Free the memory used by the ShapoidIter 'that'
void ShapoidIterFreeStatic(ShapoidIter* const that) {
  // Check argument
  if (that == NULL)
    // Nothing to do
    return;
  // Free memory
  VecFree(&(that->_delta));
  VecFree(&(that->_pos));
}

// Reinitialise the ShapoidIter 'that' to its starting position
void ShapoidIterInit(ShapoidIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Initialise according to the type of Shapoid
  switch(ShapoidGetType(that->_shap)) {
    case ShapoidTypeFacoid:
    case ShapoidTypePyramidoid:
      VecSetNull(that->_pos);
      break;
    case ShapoidTypeSpheroid:
      VecSetNull(that->_pos);
      VecSet(that->_pos, VecGetDim(that->_pos) - 1, -0.5);
      break;
    default:
      break;
  }
}

// Step the ShapoidIter 'that'
// Return false if the iterator is at its end and couldn't be stepped
bool ShapoidIterStep(ShapoidIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a flag for the return value
  bool flag = true;
  // Step according to the type of Shapoid
  switch(ShapoidGetType(that->_shap)) {
    case ShapoidTypeFacoid:
      flag = _ShapoidIterStepFacoid(that);
      break;
    case ShapoidTypePyramidoid:
      flag = _ShapoidIterStepPyramidoid(that);
      break;
    case ShapoidTypeSpheroid:
      flag = _ShapoidIterStepSpheroid(that);
      break;
    default:
      break;
  }
  return flag;
}

// Step the ShapoidIter 'that' for a Facoid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepFacoid(ShapoidIter* const that) {
  // Declare a variable for the returned flag
  bool ret = true;
  // Declare a variable to memorise the dimension currently increasing
  long iDim = VecGetDim(that->_pos) - 1;
  // Declare a flag for the loop condition
  bool flag = true;
  // Increment
  do {
    VecSetAdd(that->_pos, iDim, VecGet(that->_delta, iDim));
    if (VecGet(that->_pos, iDim) > 1.0 + PBMATH_EPSILON) {
      VecSet(that->_pos, iDim, 0.0);
      --iDim;
    } else {
      flag = false;
    }
  } while (iDim >= 0 && flag == true);
  if (iDim == -1)
    ret = false;
  // Return the flag
  return ret;
}

// Step the ShapoidIter 'that' for a Pyramidoid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepPyramidoid(ShapoidIter* const that) {
  // Declare a variable for the returned flag
  bool ret = true;
  // Declare a variable to memorise the dimension currently increasing
  long iDim = VecGetDim(that->_pos) - 1;
  // Declare a flag for the loop condition
  bool flag = true;
  // Increment
  do {
    VecSetAdd(that->_pos, iDim, VecGet(that->_delta, iDim));
    float sum = 0.0;
    for (long iAxis = VecGetDim(that->_pos); iAxis--;)
      sum += VecGet(that->_pos, iAxis);
    if (sum > 1.0 + PBMATH_EPSILON) {
      VecSet(that->_pos, iDim, 0.0);
      --iDim;
    } else {
      flag = false;
    }
  } while (iDim >= 0 && flag == true);
  if (iDim == -1)
    ret = false;
  // Return the flag
  return ret;
}

// Step the ShapoidIter 'that' for a Spheroid
// Return false if the iterator is at its end and couldn't be stepped
bool _ShapoidIterStepSpheroid(ShapoidIter* const that) {
  // Declare a variable to memorise the dimension currently increasing
  long iDim = 0;
  // Declare a flag for the loop condition
```

```
bool flag = true;
// Declare a variable to memorize the norm of the current position
float norm = VecNorm(that->_pos);
// Ladies and Gentleman, here comes the infamous "Worm Algorithm"
// Increment from the first axis
for (iDim = 0; iDim < VecGetDim(that->_pos) && flag == true; ++iDim) {
  float prevNorm = norm;
  // Try to step in this axis
  VecSetAdd(that->_pos, iDim, VecGet(that->_delta, iDim));
  // Get the norm of the new position
  norm = VecNorm(that->_pos);
  // If we have just jumped over the boundary
  if (prevNorm < 0.5 - PBMATH_EPSILON &&
    norm >= 0.5 + PBMATH_EPSILON) {
    // Correct the step to reach exactly the boundary
    // Set the current axis to relax the constraint
    VecSet(that->_pos, iDim, 0.0);
    // Calculate the value for this axis which put back the position
    // at the boundary of the Spheroid (on positive side as we want
    // the end of the boundary)
    norm = VecNorm(that->_pos);
    float val =  0.5 * sqrt(-4.0 * (fastpow(norm, 2) - 0.25));
    VecSet(that->_pos, iDim, val);
    // Correct the norm
    norm = 0.5;
    // We could step on this axis, stop here
    flag = false;
    // To cancel the increment in the loop
    --iDim;
  } else {
    // If the new position is out of bound it means we reach the
    // boundary
    if (norm >= 0.5 + PBMATH_EPSILON) {
      // Set the current axis to 0.0 to relax the constraint on
      // other axis
      VecSet(that->_pos, iDim, 0.0);
    } else {
      // We could step on this axis, stop here
      flag = false;
      // To cancel the increment in the loop
      --iDim;
    }
  }
}
// If we could step, it has modified the constraint on the previous
// axis which must then be updated
if (flag == false) {
  --iDim;
  // If there is actually a previous axis
  if (iDim >= 0) {
    // Calculate the value for this axis which put back the position
    // at the boundary of the Spheroid (on negative side as we will
    // increment from there)
    float val = VecGet(that->_pos, iDim) +
      0.5 * (-2.0 * VecGet(that->_pos, iDim) -
      sqrt(4.0 * (fastpow(VecGet(that->_pos, iDim), 2) -
      fastpow(norm, 2) + 0.25)));
    VecSet(that->_pos, iDim, val);
  }
}
// Return the negative of the flag
return !flag;
```

```
}
```

3.2 shapoid-inline.c

```
// ============ SHAPOID-static inline.C ================

// -------------- Shapoid

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

// Get the dimension of the Shapoid
#if BUILDMODE != 0
static inline
#endif
int _ShapoidGetDim(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return the dimension
  return that->_dim;
}

// Get the dimension of the Shapoid
#if BUILDMODE != 0
static inline
#endif
ShapoidType _ShapoidGetType(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return the type
  return that->_type;
}

// Get the type of the Shapoid as a string
// Return a pointer to a constant string (not to be freed)
#if BUILDMODE != 0
static inline
#endif
const char* _ShapoidGetTypeAsString(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return the type
  return ShapoidTypeString[that->_type];
}

// Return a VecFloat equals to the position of the Shapoid
```

```
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetPos(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return a clone of the position
  return VecClone(that->_pos);
}

// Return a VecFloat equals to the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetAxis(const Shapoid* const that, const int dim) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return a clone of the axis
  return VecClone(that->_axis[dim]);
}

// Return the position of the Shapoid
#if BUILDMODE != 0
static inline
#endif
const VecFloat* _ShapoidPos(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return the position
  return that->_pos;
}

// Return the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
const VecFloat* _ShapoidAxis(const Shapoid* const that, const int dim) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Return the axis
  return that->_axis[dim];
}

// Set the position of the Shapoid to 'pos'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetPos(Shapoid* const that, const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%ld==%d)",
      VecGetDim(pos), that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the position
  VecCopy(that->_pos, pos);
}

// Set the 'iElem'-th value of the position of the Shapoid to 'val'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidPosSet(Shapoid* const that, const int iElem,
  const float val) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'iElem' is invalid (0<=%d<%d)",
      iElem, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the position
  VecSet(that->_pos, iElem, val);
}
```

```
// Set the 'iElem'-th value of the position of the Shapoid to 'val'
// added to its current value
#if BUILDMODE != 0
static inline
#endif
void _ShapoidPosSetAdd(Shapoid* const that, const int iElem,
  const float val) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'iElem' is invalid (0<=%d<%d)",
      iElem, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the position
  VecSetAdd(that->_pos, iElem, val);
}

// Set the 'iElem'-th value of the position of the Shapoid to 'val'
#if BUILDMODE != 0
static inline
#endif
float _ShapoidPosGet(const Shapoid* const that, const int iElem) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'iElem' is invalid (0<=%d<%d)",
      iElem, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the position
  return VecGet(that->_pos, iElem);
}

// Set the position of the Shapoid such as its center is at 'pos'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetCenterPos(Shapoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%ld==%d)",
      VecGetDim(pos), that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  VecFloat* v = ShapoidGetCenter(that);
  VecOp(v, -1.0, ShapoidPos(that), 1.0);
  VecOp(v, 1.0, pos, 1.0);
  ShapoidSetPos(that, v);
  VecFree(&v);
}

// Set the 'dim'-th axis of the Shapoid to 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetAxis(Shapoid* const that, const int dim,
  const VecFloat* const v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (v == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'v' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(v) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'v' 's dimension is invalid (%d==%ld)",
      dim, VecGetDim(v));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the axis
  VecCopy(that->_axis[dim], v);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Set all the axis of the Shapoid to vectors in 'set' (axis in
// dimensions order
#if BUILDMODE != 0
static inline
#endif
void _ShapoidSetAllAxis(Shapoid* const that, GSetVecFloat* const set) {
```

```
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (set == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'set' is null");
    PBErrCatch(ShapoidErr);
  }
  if (GSetNbElem(set) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "Number of elements in set is invalid (%ld!=%d)",
      GSetNbElem(set), that->_dim);
    PBErrCatch(ShapoidErr);
  }
  for (int iDim = that->_dim; iDim--;) {
    VecFloat* vec = GSetGet(set, iDim);
    if (VecGetDim(vec) != that->_dim) {
      ShapoidErr->_type = PBErrTypeInvalidArg;
      sprintf(ShapoidErr->_msg,
        "%d-th axis' dimension is invalid (%ld!=%d)",
        iDim, VecGetDim(vec), that->_dim);
      PBErrCatch(ShapoidErr);
    }
  }
#endif
  // Set the axis
  GSetIterForward iter = GSetIterForwardCreateStatic(set);
  int iDim = 0;
  do {
    VecFloat* axis = GSetIterGet(&iter);
    VecCopy(that->_axis[iDim], axis);
    ++iDim;
  } while (GSetIterStep(&iter));
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}


// Set the 'iElem'-th element of the 'dim'-th axis of the Shapoid to 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisSet(Shapoid* const that, const int dim,
  const int iElem, const float v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= VecGetDim(ShapoidAxis(that, dim))) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "iElem is invalid (0<=%d<%ld)",
      iElem, VecGetDim(ShapoidAxis(that, dim)));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the axis
  VecSet(that->_axis[dim], iElem, v);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Set the 'iElem'-th element of the 'dim'-th axis of the Shapoid to
// 'v' added to its current value
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisSetAdd(Shapoid* const that, const int dim,
  const int iElem, const float v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= VecGetDim(ShapoidAxis(that, dim))) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "iElem is invalid (0<=%d<%ld)",
      iElem, VecGetDim(ShapoidAxis(that, dim)));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the axis
  VecSetAdd(that->_axis[dim], iElem, v);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Get the 'iElem'-th element of the 'dim'-th axis of the Shapoid
#if BUILDMODE != 0
static inline
#endif
float _ShapoidAxisGet(const Shapoid* const that, const int dim,
  const int iElem) {
#if BUILDMODE == 0
```

```
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (iElem < 0 || iElem >= VecGetDim(ShapoidAxis(that, dim))) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "iElem is invalid (0<=%d<%ld)",
      iElem, VecGetDim(ShapoidAxis(that, dim)));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the axis
  return VecGet(that->_axis[dim], iElem);
}

// Scale the 'dim'-th axis of the Shapoid by 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidAxisScale(Shapoid* const that, const int dim,
  const float v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (dim < 0 || dim >= that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "Axis' index is invalid (0<=%d<%d)",
      dim, that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Set the axis
  VecScale(that->_axis[dim], v);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Translate the Shapoid by 'v'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidTranslate(Shapoid* const that, const VecFloat* const v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (v == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'v' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(v) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'v' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(v));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Translate the position
  VecOp(that->_pos, 1.0, v, 1.0);
}

// Scale the Shapoid by 'v' (each axis is multiplied by v[iAxis])
#if BUILDMODE != 0
static inline
#endif
void _ShapoidScaleVector(Shapoid* const that, const VecFloat* const v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (v == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'v' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(v) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'v' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(v));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Scale each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecScale(that->_axis[iAxis], VecGet(v, iAxis));
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it's a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Scale the Shapoid by 'c'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidScaleScalar(Shapoid* const that, const float c) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
```

```
  // Scale each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecScale(that->_axis[iAxis], c);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
  // If it’s a Spheroid
  if (that->_type == ShapoidTypeSpheroid)
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
}

// Scale the Shapoid by ’v’ (each axis is multiplied by v[iAxis])
// and translate the Shapoid such as its center after scaling
// is at the same position than before scaling
#if BUILDMODE != 0
static inline
#endif
void _ShapoidGrowVector(Shapoid* const that, const VecFloat* const v) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’that’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (v == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "’v’ is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(v) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "’v’ ’s dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(v));
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for ’that’ ’s type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the shapoid is a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
    // Scale
    ShapoidScale(that, v);
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
  // Else, the shapoid is not a spheroid
  } else {
    // Memorize the center
    VecFloat* centerA = ShapoidGetCenter(that);
    // Scale
    ShapoidScale(that, v);
    // Reposition to keep center at the same position
    VecFloat* centerB = ShapoidGetCenter(that);
    VecOp(centerA, 1.0, centerB, -1.0);
    VecOp(that->_pos, 1.0, centerA, 1.0);
    VecFree(&centerA);
    VecFree(&centerB);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Scale the Shapoid by 'c'
// and translate the Shapoid such as its center after scaling
// is at the same position than before scaling
#if BUILDMODE != 0
static inline
#endif
void _ShapoidGrowScalar(Shapoid* const that, const float c) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the shapoid is a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
    // Scale
    ShapoidScale(that, c);
    // Update the major and minor axis
    SpheroidUpdateMajMinAxis((Spheroid*)that);
  // Else, the shapoid is not a spheroid
  } else {
    // Memorize the center
    VecFloat* centerA = ShapoidGetCenter(that);
    // Scale
    ShapoidScale(that, c);
    // Reposition to keep center at the same position
    VecFloat* centerB = ShapoidGetCenter(that);
    VecOp(centerA, 1.0, centerB, -1.0);
    VecOp(that->_pos, 1.0, centerA, 1.0);
    VecFree(&centerA);
    VecFree(&centerB);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to its center
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotCenter(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 2) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==2)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If it's a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRot(that->_axis[iAxis], theta);
  // Else, it's not a spheroid
  } else {
    VecFloat* center = ShapoidGetCenter(that);
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRot(that->_axis[iAxis], theta);
    // Reposition the origin
    VecOp(that->_pos, 1.0, center, -1.0);
    VecRot(that->_pos, theta);

// ???????
// In BUILD_MODE == 1, that->_pos is not updated for an unknown reason
// Adding a dummy fflush here makes it work normally
// ???????
#if BUILDMODE == 1
fflush(stdout);
#endif

    VecOp(that->_pos, 1.0, center, 1.0);
    VecFree(&center);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to its position
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotStart(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 2) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==2)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRot(that->_axis[iAxis], theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 2 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotOrigin(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 2) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==2)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRot(that->_axis[iAxis], theta);
  // Reposition the origin
  VecRot(that->_pos, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisCenter(Shapoid* const that,
  const VecFloat3D* const axis, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (axis == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'axis' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(axis) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'axis' 's dimension is invalid (%ld==3)", VecGetDim(axis));
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If it's a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotAxis(that->_axis[iAxis], axis, theta);
  // Else, it's not a spheroid
  } else {
    VecFloat* center = ShapoidGetCenter(that);
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRotAxis(that->_axis[iAxis], axis, theta);
    // Reposition the origin
    VecFloat* v = VecGetOp(that->_pos, 1.0, center, -1.0);
    VecRotAxis(v, axis, theta);
    VecOp(v, 1.0, center, 1.0);
    VecCopy(that->_pos, v);
    VecFree(&center);
    VecFree(&v);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisStart(Shapoid* const that,
  const VecFloat3D* const axis, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (axis == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'axis' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(axis) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'axis' 's dimension is invalid (%ld==3)", VecGetDim(axis));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotAxis(that->_axis[iAxis], axis, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around 'axis'
// 'axis' must be normalized
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotAxisOrigin(Shapoid* const that,
  const VecFloat3D* const axis, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (axis == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'axis' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(axis) != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'axis' 's dimension is invalid (%ld==3)", VecGetDim(axis));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotAxis(that->_axis[iAxis], axis, theta);
  // Reposition the origin
  VecRotAxis(that->_pos, axis, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXCenter(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If it's a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotX(that->_axis[iAxis], theta);
  // Else, it's not a spheroid
  } else {
    VecFloat* center = ShapoidGetCenter(that);
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRotX(that->_axis[iAxis], theta);
    // Reposition the origin
    VecFloat* v = VecGetOp(that->_pos, 1.0, center, -1.0);
    VecRotX(v, theta);
    VecOp(v, 1.0, center, 1.0);
    VecCopy(that->_pos, v);
    VecFree(&center);
    VecFree(&v);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXStart(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
```

```
    VecRotX(that->_axis[iAxis], theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around X
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotXOrigin(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotX(that->_axis[iAxis], theta);
  // Reposition the origin
  VecRotX(that->_pos, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYCenter(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If it's a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotY(that->_axis[iAxis], theta);
  // Else, it's not a spheroid
  } else {
    VecFloat* center = ShapoidGetCenter(that);
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRotY(that->_axis[iAxis], theta);
    // Reposition the origin
    VecFloat* v = VecGetOp(that->_pos, 1.0, center, -1.0);
    VecRotY(v, theta);
    VecOp(v, 1.0, center, 1.0);
    VecCopy(that->_pos, v);
    VecFree(&center);
    VecFree(&v);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYStart(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotY(that->_axis[iAxis], theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around Y
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotYOrigin(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotY(that->_axis[iAxis], theta);
  // Reposition the origin
  VecRotY(that->_pos, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its center around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZCenter(Shapoid* const that, const float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If it's a spheroid
  if (that->_type == ShapoidTypeSpheroid) {
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;) {
    VecRotZ(that->_axis[iAxis], theta);
  }
  // Else, it's not a spheroid
  } else {
    VecFloat* center = ShapoidGetCenter(that);
    // Rotate each axis
    for (int iAxis = that->_dim; iAxis--;)
      VecRotZ(that->_axis[iAxis], theta);
    // Reposition the origin
    VecFloat* v = VecGetOp(that->_pos, 1.0, center, -1.0);
    VecRotZ(v, theta);
    VecOp(v, 1.0, center, 1.0);
    VecCopy(that->_pos, v);
    VecFree(&center);
    VecFree(&v);
  }
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to its position around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZStart(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotZ(that->_axis[iAxis], theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}

// Rotate the Shapoid of dimension 3 by 'theta' (in radians, CCW)
// relatively to the origin of the global coordinates system
// around Z
#if BUILDMODE != 0
static inline
#endif
void _ShapoidRotZOrigin(Shapoid* const that,
  float theta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_dim != 3) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg,
      "'that' 's dimension is invalid (%d==3)", that->_dim);
    PBErrCatch(ShapoidErr);
  }
#endif
  // Rotate each axis
  for (int iAxis = that->_dim; iAxis--;)
    VecRotZ(that->_axis[iAxis], theta);
  // Reposition the origin
  VecRotZ(that->_pos, theta);
  // Update the SysLinEq
  ShapoidUpdateSysLinEqImport(that);
}
```

```
// Convert the coordinates of 'pos' from standard coordinate system
// toward the Shapoid coordinates system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidImportCoord(const Shapoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Update the system solver for the requested position
  VecFloat* v = VecGetOp(pos, 1.0, that->_pos, -1.0);
  SysLinEqSetV(that->_sysLinEqImport, v);
  // Solve the system
  VecFloat* res = SysLinEqSolve(that->_sysLinEqImport);
  // Free memory
  VecFree(&v);
  // return the result
  return res;
}

// Convert the coordinates of 'pos' from the Shapoid coordinates system
// toward standard coordinate system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidExportCoord(const Shapoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Allocate memory for the result
  VecFloat* res = VecClone(that->_pos);
  for (int dim = that->_dim; dim--;)
    VecOp(res, 1.0, that->_axis[dim], VecGet(pos, dim));
  // Return the result
  return res;
}

// Get the center of the shapoid in standard coordinate system
#if BUILDMODE != 0
static inline
#endif
VecFloat* _ShapoidGetCenter(const Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  if (ShapoidGetType(that) == ShapoidTypeFacoid)
    return FacoidGetCenter((Facoid*)that);
  else if (ShapoidGetType(that) == ShapoidTypePyramidoid)
    return PyramidoidGetCenter((Pyramidoid*)that);
  else if (ShapoidGetType(that) == ShapoidTypeSpheroid)
    return SpheroidGetCenter((Spheroid*)that);
  else
    return NULL;
}

#if BUILDMODE != 0
static inline
#endif
VecFloat* FacoidGetCenter(const Facoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result in Shapoid
  // coordinate system
  VecFloat* coord = VecFloatCreate(ShapoidGetDim(that));
  // For each dimension
  for (int dim = ShapoidGetDim(that); dim--;)
    VecSet(coord, dim, 0.5);
  // Convert the coordinates in standard coordinate system
  VecFloat* res = ShapoidExportCoord(that, coord);
  // Free memory
  VecFree(&coord);
  // Return the result
  return res;
}

#if BUILDMODE != 0
```

```
static inline
#endif
VecFloat* PyramidoidGetCenter(const Pyramidoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result in Shapoid
  // coordinate system
  VecFloat* coord = VecFloatCreate(ShapoidGetDim(that));
  // For each dimension
  for (int dim = ShapoidGetDim(that); dim--;)
    VecSet(coord, dim, 1.0 / (1.0 + ShapoidGetDim(that)));
  // Convert the coordinates in standard coordinate system
  VecFloat* res = ShapoidExportCoord(that, coord);
  // Free memory
  VecFree(&coord);
  // Return the result
  return res;
}

#if BUILDMODE != 0
static inline
#endif
VecFloat* SpheroidGetCenter(const Spheroid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Declare a variable to memorize the result in Shapoid
  // coordinate system
  VecFloat* coord = VecFloatCreate(ShapoidGetDim(that));
  // Convert the coordinates in standard coordinate system
  VecFloat* res = ShapoidExportCoord(that, coord);
  // Free memory
  VecFree(&coord);
  // Return the result
  return res;
}

// Check if shapoid 'that' and 'tho' are equals
#if BUILDMODE != 0
static inline
#endif
bool _ShapoidIsEqual(const Shapoid* const that,
  const Shapoid* const tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (tho == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'tho' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  // Check the dimension, type and position
  if (that->_dim != tho->_dim ||
    that->_type != tho->_type ||
    VecIsEqual(that->_pos, tho->_pos) == false)
    return false;
  // Check the axis
  for (int i = that->_dim; i--;)
    if (VecIsEqual(that->_axis[i], tho->_axis[i]) == false)
      return false;
  // If the Shapoid is a Spheroid, check Spheroid properties
  if (that->_type == ShapoidTypeSpheroid) {
    if (((Spheroid*)that)->_majAxis != ((Spheroid*)tho)->_majAxis ||
      ((Spheroid*)that)->_minAxis != ((Spheroid*)tho)->_minAxis)
      return false;
  }
  // Return the success code
  return true;
}

// Update the system of linear equation used to import coordinates
#if BUILDMODE != 0
static inline
#endif
void ShapoidUpdateSysLinEqImport(Shapoid* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  VecShort2D dim = VecShortCreateStatic2D();
  // Set a pointer to the matrix in the SysLinEq
  MatFloat* mat = MatClone(that->_sysLinEqImport->_M);
  // Set the values of the matrix
  for (VecSet(&dim, 0, 0); VecGet(&dim, 0) < that->_dim;
    VecSetAdd(&dim, 0, 1)) {
    for (VecSet(&dim, 1, 0); VecGet(&dim, 1) < that->_dim;
      VecSetAdd(&dim, 1, 1)) {
      MatSet(mat, &dim, VecGet(that->_axis[VecGet(&dim, 0)],
        VecGet(&dim, 1)));
    }
  }
  // Update the SysLinEq
  SysLinEqSetM(that->_sysLinEqImport, mat);
  // Free memory
  MatFree(&mat);
}

// Return true if 'pos' (in stand coordinate system) is inside the
// Shapoid
// Else return false
#if BUILDMODE != 0
static inline
#endif
bool _ShapoidIsPosInside(const Shapoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the Shapoid is a Facoid
  if (that->_type == ShapoidTypeFacoid) {
    return FacoidIsPosInside((Facoid*)that, pos);
  // Else, if the Shapoid is a Pyramidoid
  } else if (that->_type == ShapoidTypePyramidoid) {
    return PyramidoidIsPosInside((Pyramidoid*)that, pos);
  // Else, if the Shapoid is a Spheroid
  } else if (that->_type == ShapoidTypeSpheroid) {
    return SpheroidIsPosInside((Spheroid*)that, pos);
  } else
    return false;
}

#if BUILDMODE != 0
static inline
#endif
bool FacoidIsPosInside(const Facoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  bool ret = false;
  // pos is in the Shapoid if all the coord in Shapoid coord
  // system are in [0.0, 1.0]
  ret = true;
  for (int dim = ShapoidGetDim(that); dim-- && ret == true;) {
    float v = VecGet(coord, dim);
    if (v < 0.0 || v > 1.0)
      ret = false;
  }
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}

#if BUILDMODE != 0
static inline
#endif
bool PyramidoidIsPosInside(const Pyramidoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  bool ret = false;
  // pos is in the Shapoid if all the coord in Shapoid coord
  // system are in [0.0, 1.0] and their sum is in [0.0, 1.0]
  ret = true;
  float sum = 0.0;
  for (int dim = ShapoidGetDim(that); dim-- && ret == true;) {
    float v = VecGet(coord, dim);
    sum += v;
    if (v < 0.0 || v > 1.0)
      ret = false;
  }
  if (ret == true && sum > 1.0)
    ret = false;
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}

#if BUILDMODE != 0
static inline
#endif
```

```
bool SpheroidIsPosInside(const Spheroid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  bool ret = false;
  // pos is in the Shapoid if its norm is in [0.0, 0.5]
  float norm = VecNorm(coord);
  if (norm <= 0.5)
    ret = true;
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}

// Get the depth value in the Shapoid of 'pos'
// The depth is defined as follow: the point with depth equals 1.0 is
// the farthest point from the surface of the Shapoid (inside it),
// points with depth equals to 0.0 are point on the surface of the
// Shapoid. Depth is continuous and derivable over the volume of the
// Shapoid
#if BUILDMODE != 0
static inline
#endif
float _ShapoidGetPosDepth(const Shapoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != that->_dim) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      that->_dim, VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
  if (that->_type != ShapoidTypeFacoid &&
    that->_type != ShapoidTypeSpheroid &&
    that->_type != ShapoidTypePyramidoid) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "No implementation for 'that' 's type");
    PBErrCatch(ShapoidErr);
  }
#endif
  // If the Shapoid is a Facoid
  if (that->_type == ShapoidTypeFacoid) {
    return FacoidGetPosDepth((Facoid*)that, pos);
  // Else, if the Shapoid is a Pyramidoid
  } else if (that->_type == ShapoidTypePyramidoid) {
    return PyramidoidGetPosDepth((Pyramidoid*)that, pos);
  // Else, if the Shapoid is a Spheroid
  } else if (that->_type == ShapoidTypeSpheroid) {
    return SpheroidGetPosDepth((Spheroid*)that, pos);
  } else {
    return 0.0;
  }
}

#if BUILDMODE != 0
static inline
#endif
float FacoidGetPosDepth(const Facoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  float ret = 1.0;
  for (int dim = ShapoidGetDim(that); dim-- && ret > PBMATH_EPSILON;) {
    float v = VecGet(coord, dim);
    if (v < 0.0 || VecGet(coord, dim) > 1.0)
      ret = 0.0;
    else
      ret *= 1.0 - pow(0.5 - v, 2.0) * 4.0;
  }
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}
```

```
#if BUILDMODE != 0
static inline
#endif
float PyramidoidGetPosDepth(const Pyramidoid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  float ret = 1.0;
  float sum = 0.0;
  bool flag = true;
  for (int dim = ShapoidGetDim(that); dim-- && ret > PBMATH_EPSILON;) {
    float v = VecGet(coord, dim);
    sum += v;
    if (v < 0.0 || v > 1.0)
      flag = false;
  }
  if (flag == true && sum > 1.0)
    flag = false;
  if (flag == false)
    ret = 0.0;
  else {
    ret = 1.0;
    for (int dim = ShapoidGetDim(that); dim--;) {
      float z = 0.0;
      for (int d = ShapoidGetDim(that); d--;)
        if (d != dim)
          z += VecGet(coord, d);
      ret *=
        (1.0 - 4.0 * pow(0.5 - VecGet(coord, dim) / (1.0 - z), 2.0));
    }
  }
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}

#if BUILDMODE != 0
static inline
#endif
float SpheroidGetPosDepth(const Spheroid* const that,
  const VecFloat* const pos) {
#if BUILDMODE == 0
```

```
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
  if (pos == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'pos' is null");
    PBErrCatch(ShapoidErr);
  }
  if (VecGetDim(pos) != ShapoidGetDim(that)) {
    ShapoidErr->_type = PBErrTypeInvalidArg;
    sprintf(ShapoidErr->_msg, "'pos' 's dimension is invalid (%d==%ld)",
      ShapoidGetDim(that), VecGetDim(pos));
    PBErrCatch(ShapoidErr);
  }
#endif
  // Get the coordinates of pos in the Shapoid coordinate system
  VecFloat* coord = ShapoidImportCoord(that, pos);
  // Declare a variable to memorize the result
  float ret = 0.0;
  float norm = VecNorm(coord);
  if (norm <= 0.5)
    ret = 1.0 - norm * 2.0;
  // Free memory
  VecFree(&coord);
  // Return the result
  return ret;
}

#if BUILDMODE != 0
static inline
#endif
bool FacoidLoad(Facoid** that, FILE* const stream) {
  bool ret = _ShapoidLoad((Shapoid**)that, stream);
  if (!ret || ShapoidGetType(*that) != ShapoidTypeFacoid) {
    ShapoidFree(that);
    return false;
  }
  return true;
}

#if BUILDMODE != 0
static inline
#endif
bool PyramidoidLoad(Pyramidoid** that, FILE* const stream) {
  bool ret = _ShapoidLoad((Shapoid**)that, stream);
  if (!ret || ShapoidGetType(*that) != ShapoidTypePyramidoid) {
    ShapoidFree(that);
    return false;
  }
  return true;
}

#if BUILDMODE != 0
static inline
#endif
bool SpheroidLoad(Spheroid** that, FILE* const stream) {
  bool ret = _ShapoidLoad((Shapoid**)that, stream);
  if (!ret || ShapoidGetType(*that) != ShapoidTypeSpheroid) {
    ShapoidFree(that);
    return false;
  }
  return true;
}

// ------------- ShapoidIter

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

// Return the current position in Shapoid coordinates of the
// ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
VecFloat* ShapoidIterGetInternalPos(const ShapoidIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  return VecClone(that->_pos);
}

// Return the current position in standard coordinates of the
// ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
VecFloat* ShapoidIterGetExternalPos(const ShapoidIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  return ShapoidExportCoord(that->_shap, that->_pos);
}

// Set the attached Shapoid of the ShapoidIter 'that' to 'shap'
// The iterator is reset to its initial position
#if BUILDMODE != 0
static inline
#endif
void _ShapoidIterSetShapoid(ShapoidIter* const that,
  const Shapoid* const shap) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  that->_shap = shap;
}

// Get the Shapoid of the ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
const Shapoid* ShapoidIterShapoid(const ShapoidIter* const that) {
```

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

// Set the delta of the ShapoidIter 'that' to a copy of 'delta'
#if BUILDMODE != 0
static inline
#endif
void _ShapoidIterSetDelta(ShapoidIter* const that,
  const VecFloat* const delta) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  VecFree(&(that->_delta));
  that->_delta = VecClone(delta);
}

// Get the delta of the ShapoidIter 'that'
#if BUILDMODE != 0
static inline
#endif
const VecFloat* ShapoidIterDelta(const ShapoidIter* const that) {
#if BUILDMODE == 0
  if (that == NULL) {
    ShapoidErr->_type = PBErrTypeNullPointer;
    sprintf(ShapoidErr->_msg, "'that' is null");
    PBErrCatch(ShapoidErr);
  }
#endif
  return that->_delta;
}
```

4 Makefile

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

all: 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)
```

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

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

5 Unit tests

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

#define RANDOMSEED 0

void UnitTestCreateCloneIsEqualFree() {
  int dim = 3;
  Shapoid* facoid = ShapoidCreate(dim, ShapoidTypeFacoid);
  if (facoid == NULL || facoid->_dim != dim ||
    facoid->_type != ShapoidTypeFacoid || facoid->_pos == NULL ||
    VecGetDim(facoid->_pos) != dim || facoid->_sysLinEqImport == NULL ||
    facoid->_axis == NULL) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidCreate failed");
    PBErrCatch(ShapoidErr);
  }
  for (int iDim = dim; iDim--;) {
    if (ISEQUALF(VecGet(facoid->_pos, iDim), 0.0) == false ||
      facoid->_axis[iDim] == NULL ||
      VecGetDim(facoid->_axis[iDim]) != dim) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidCreate failed");
      PBErrCatch(ShapoidErr);
    }
    for (int jDim = dim; jDim--;) {
      if ((iDim == jDim &&
        ISEQUALF(VecGet(facoid->_axis[iDim], jDim), 1.0) == false) ||
        (iDim != jDim &&
        ISEQUALF(VecGet(facoid->_axis[iDim], jDim), 0.0) == false)) {
        ShapoidErr->_type = PBErrTypeUnitTestFailed;
        sprintf(ShapoidErr->_msg, "ShapoidCreate failed");
        PBErrCatch(ShapoidErr);
      }
    }
    if (ISEQUALF(VecGet(facoid->_sysLinEqImport->_V, iDim),
      0.0) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidCreate failed");
      PBErrCatch(ShapoidErr);
    }
  }
  VecShort2D u = VecShortCreateStatic2D();
  VecSet(&u, 0, dim); VecSet(&u, 1, dim);
  VecShort2D v = VecShortCreateStatic2D();
  do {
    if ((VecGet(&v, 0) == VecGet(&v, 1) &&
      ISEQUALF(MatGet(facoid->_sysLinEqImport->_M, &v), 1.0) == false) ||
      (VecGet(&v, 0) != VecGet(&v, 1) &&
      ISEQUALF(MatGet(facoid->_sysLinEqImport->_M, &v), 0.0) == false) ||
      (VecGet(&v, 0) == VecGet(&v, 1) &&
      ISEQUALF(MatGet(facoid->_sysLinEqImport->_Minv, &v),
        1.0) == false) ||
      (VecGet(&v, 0) != VecGet(&v, 1) &&
      ISEQUALF(MatGet(facoid->_sysLinEqImport->_Minv, &v),
        0.0) == false)) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidCreate failed");
      PBErrCatch(ShapoidErr);
    }
  } while (VecStep(&v, &u));
  Shapoid* clone = ShapoidClone(facoid);
  if (facoid->_dim != clone->_dim ||
    facoid->_type != clone->_type ||
    VecIsEqual(facoid->_pos, clone->_pos) == false ||
    MatIsEqual(facoid->_sysLinEqImport->_M,
      clone->_sysLinEqImport->_M) == false ||
    MatIsEqual(facoid->_sysLinEqImport->_Minv,
      clone->_sysLinEqImport->_Minv) == false ||
    VecIsEqual(facoid->_sysLinEqImport->_V,
      clone->_sysLinEqImport->_V) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidClone failed");
    PBErrCatch(ShapoidErr);
  }
  for (int i = dim; i--;) {
    if (VecIsEqual(facoid->_axis[i], clone->_axis[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidClone failed");
      PBErrCatch(ShapoidErr);
    }
  }
  if (ShapoidIsEqual(facoid, clone) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsEqual failed");
    PBErrCatch(ShapoidErr);
  }
  *(ShapoidType*)&(clone->_type) = ShapoidTypePyramidoid;
  if (ShapoidIsEqual(facoid, clone) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsEqual failed");
    PBErrCatch(ShapoidErr);
  }
  *(ShapoidType*)&(clone->_type) = facoid->_type;
  *(int*)&(clone->_dim) = dim + 1;
  if (ShapoidIsEqual(facoid, clone) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(ShapoidErr->_msg, "ShapoidIsEqual failed");
    PBErrCatch(ShapoidErr);
  }
  *(int*)&(clone->_dim) = facoid->_dim;
  VecSet(clone->_pos, 0, 1.0);
  if (ShapoidIsEqual(facoid, clone) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsEqual failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(clone->_pos, 0, 0.0);
  VecSet(clone->_axis[0], 0, 2.0);
  if (ShapoidIsEqual(facoid, clone) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsEqual failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(clone->_axis[0], 0, 1.0);
  ShapoidFree(&facoid);
  if (facoid != NULL) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidFree failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&clone);
  printf("UnitTestCreateCloneIsEqualFree OK\n");
}

void UnitTestLoadSavePrint() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  FILE* file = fopen("./facoid.txt", "w");
  if (ShapoidSave(facoid, file, false) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidSave failed");
    PBErrCatch(ShapoidErr);
  }
  fclose(file);
  file = fopen("./facoid.txt", "r");
  Facoid* load = FacoidCreate(dim);
  if (ShapoidLoad(&load, file) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidLoad failed");
    PBErrCatch(ShapoidErr);
  }
  fclose(file);
  if (ShapoidIsEqual(facoid, load) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidLoad/Save failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidPrintln(facoid, stdout);
  ShapoidFree(&facoid);
  ShapoidFree(&load);
  printf("UnitTestLoadSavePrint OK\n");
}

void UnitTestGetSetTypeDimPosAxis() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
```

```
if (ShapoidGetType(facoid) != ShapoidTypeFacoid ||
  ShapoidGetType(pyramidoid) != ShapoidTypePyramidoid ||
  ShapoidGetType(spheroid) != ShapoidTypeSpheroid) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidGetType failed");
  PBErrCatch(ShapoidErr);
}
if (ShapoidGetDim(facoid) != dim) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidGetDim failed");
  PBErrCatch(ShapoidErr);
}
VecFloat* v = VecFloatCreate(dim);
VecFloat* u = ShapoidGetPos(facoid);
if (VecIsEqual(v, u) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidGetPos failed");
  PBErrCatch(ShapoidErr);
}
VecFree(&u);
for (int i = dim; i--;) {
  u = ShapoidGetAxis(facoid, i);
  for (int j = dim; j--;)
    if ((i == j && ISEQUALF(VecGet(u, j), 1.0) == false) ||
      (i != j && ISEQUALF(VecGet(u, j), 0.0) == false)) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetAxis failed");
      PBErrCatch(ShapoidErr);
    }
  VecFree(&u);
}
for (int i = dim; i--;)
  VecSet(v, i, (float)i);
ShapoidSetPos(facoid, v);
if (VecIsEqual(v, ShapoidPos(facoid)) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidSetPos failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  VecSetNull(v);
  VecSet(v, i, 2.0);
  ShapoidSetAxis(facoid, i, v);
  if (VecIsEqual(v, ShapoidAxis(facoid, i)) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidSetAxis failed");
    PBErrCatch(ShapoidErr);
  }
}
for (int i = dim; i--;)
  VecSet(v, i, i);
ShapoidSetCenterPos(facoid, v);
VecFloat* center = ShapoidGetCenter(facoid);
if (VecIsEqual(v, center) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidSetCenterPos failed");
  PBErrCatch(ShapoidErr);
}
VecFree(&center);
VecSet(v, 0, 1.0); VecSet(v, 1, 2.0); VecSet(v, 2, 0.5);
ShapoidScale(spheroid, v);
if (!ISEQUALF(ShapoidGetBoundingRadius(spheroid), 1.0)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetBoundingRadius failed");
    PBErrCatch(ShapoidErr);
  }
  VecFree(&v);
  ShapoidPosSet(facoid, 1, -1.0);
  if (!ISEQUALF(((Shapoid*)facoid)->_pos->_val[1], -1.0)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidPosSet failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidPosSetAdd(facoid, 1, -1.0);
  if (!ISEQUALF(((Shapoid*)facoid)->_pos->_val[1], -2.0)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidPosSet failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidAxisSet(facoid, 2, 1, -1.0);
  if (!ISEQUALF(((Shapoid*)facoid)->_axis[2]->_val[1], -1.0)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidAxisSet failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidAxisSetAdd(facoid, 2, 1, -1.0);
  if (!ISEQUALF(((Shapoid*)facoid)->_axis[2]->_val[1], -2.0)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidAxisSetAdd failed");
    PBErrCatch(ShapoidErr);
  }
  VecFloat* w = ShapoidGetAxis(facoid, 2);
  VecScale(w, 2.0);
  ShapoidAxisScale(facoid, 2, 2.0);
  if (!VecIsEqual(ShapoidAxis(facoid, 2), w)) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidAxisScale failed");
    PBErrCatch(ShapoidErr);
  }
  VecFree(&w);
  for (int i = dim; i--;) {
    if (!ISEQUALF(ShapoidPosGet(facoid, i),
      VecGet(ShapoidGetPos(facoid), i))) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidPosGet failed");
      PBErrCatch(ShapoidErr);
    }
    for (int j = dim; j--;) {
      if (!ISEQUALF(ShapoidAxisGet(facoid, i, j),
        VecGet(ShapoidGetAxis(facoid, i), j))) {
        ShapoidErr->_type = PBErrTypeUnitTestFailed;
        sprintf(ShapoidErr->_msg, "ShapoidAxisGet failed");
        PBErrCatch(ShapoidErr);
      }
    }
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestGetSetTypeDimPosAxis OK\n");
}

void UnitTestTranslateScaleGrow() {
  int dim = 2;
```

```
Facoid* facoid = FacoidCreate(dim);
VecFloat* v = VecFloatCreate(dim);
for (int i = dim; i--;)
  VecSet(v, i, 1.0);
ShapoidTranslate(facoid, v);
if (VecIsEqual(v, ((Shapoid*)facoid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidTranslate failed");
  PBErrCatch(ShapoidErr);
}
float scale = 2.0;
ShapoidScale(facoid, scale);
VecSetNull(v);
VecSetNull(((Shapoid*)facoid)->_pos);
if (VecIsEqual(v, ((Shapoid*)facoid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidScaleScalar failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, scale);
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)facoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidScaleScalar failed");
    PBErrCatch(ShapoidErr);
  }
}
for (int i = dim; i--;)
  VecSet(v, i, 1.0 + (float)i);
ShapoidScale(facoid, v);
VecSetNull(v);
if (VecIsEqual(v, ((Shapoid*)facoid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidScaleVector failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, scale * (1.0 + (float)i));
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)facoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidScaleVector failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidFree(&facoid);
facoid = FacoidCreate(dim);
scale = 2.0;
ShapoidGrow(facoid, scale);
for (int i = dim; i--;)
  VecSet(v, i, -0.5);
if (VecIsEqual(v, ((Shapoid*)facoid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, scale);
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)facoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
    PBErrCatch(ShapoidErr);
  }
}
Pyramidoid* pyramidoid = PyramidoidCreate(dim);
VecFloat* centerA = ShapoidGetCenter(pyramidoid);
ShapoidGrow(pyramidoid, scale);
VecFloat* centerB = ShapoidGetCenter(pyramidoid);
if (VecIsEqual(centerA, centerB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, scale);
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)pyramidoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
    PBErrCatch(ShapoidErr);
  }
}
VecFree(&centerA);
VecFree(&centerB);
Spheroid* spheroid = SpheroidCreate(dim);
ShapoidGrow(spheroid, scale);
VecSetNull(v);
if (VecIsEqual(v, ((Shapoid*)spheroid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, scale);
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)spheroid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowScalar failed");
    PBErrCatch(ShapoidErr);
  }
}
VecFloat* scalev = VecFloatCreate(dim);
for (int i = dim; i--;)
  VecSet(scalev, i, 1.0 + (float)i);
ShapoidFree(&facoid);
ShapoidFree(&pyramidoid);
ShapoidFree(&spheroid);
```

```
facoid = FacoidCreate(dim);
ShapoidGrow(facoid, scalev);
float pa[2] = {0.000,-0.500};
for (int i = dim; i--;)
  VecSet(v, i, pa[i]);
if (VecIsEqual(v, ((Shapoid*)facoid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, VecGet(scalev, i));
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)facoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
    PBErrCatch(ShapoidErr);
  }
}
pyramidoid = PyramidoidCreate(dim);
centerA = ShapoidGetCenter(pyramidoid);
ShapoidGrow(pyramidoid, scalev);
centerB = ShapoidGetCenter(pyramidoid);
if (VecIsEqual(centerA, centerB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, VecGet(scalev, i));
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)pyramidoid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
    PBErrCatch(ShapoidErr);
  }
}
VecFree(&centerA);
VecFree(&centerB);
spheroid = SpheroidCreate(dim);
ShapoidGrow(spheroid, scalev);
VecSetNull(v);
if (VecIsEqual(v, ((Shapoid*)spheroid)->_pos) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
  PBErrCatch(ShapoidErr);
}
for (int i = dim; i--;) {
  for (int j = dim; j--;)
    if (i == j)
      VecSet(v, j, VecGet(scalev, i));
    else
      VecSet(v, j, 0.0);
  if (VecIsEqual(v, ((Shapoid*)spheroid)->_axis[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "_ShapoidGrowVector failed");
```

```
      PBErrCatch(ShapoidErr);
    }
  }
  VecFree(&scalev);
  VecFree(&v);
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestTranslateScaleGrow OK\n");
}

void UnitTestRotate() {
  int dim = 2;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  float theta = PBMATH_HALFPI;
  ShapoidRotCenter(facoid, theta);
  float pb[2] = {1.0, 0.0};
  float pc[2] = {0.0, 1.0};
  float pd[2] = {-1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pc[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pd[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotCenter(pyramidoid, theta);
  float pe[2] = {0.6666667, 0.0};
  float pf[2] = {0.0, 1.0};
  float pg[2] = {-1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      pf[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pg[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotCenter(spheroid, theta);
  float ph[2] = {0.0, 0.0};
  float pi[2] = {0.0, 1.0};
  float pj[2] = {-1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pi[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pj[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotOrigin(facoid, theta);
  float pk[2] = {0.0, 1.0};
  float pl[2] = {-1.0, 0.0};
  float pm[2] = {0.0, -1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pk[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pl[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pm[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotOrigin(pyramidoid, theta);
  float pn[2] = {0.0, 0.6666667};
  float po[2] = {-1.0, 0.0};
  float pp[2] = {0.0, -1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pn[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      po[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pp[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotOrigin(spheroid, theta);
  float pq[2] = {0.0, 0.0};
  float pr[2] = {-1.0, 0.0};
  float ps[2] = {0.0, -1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pq[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pr[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      ps[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotStart(facoid, theta);
  float pt[2] = {0.0, 1.0};
  float pu[2] = {0.0, -1.0};
  float pv[2] = {1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pt[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pu[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pv[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotStart(pyramidoid, theta);
  float pw[2] = {0.0, 0.6666667};
  float px[2] = {0.0, -1.0};
  float py[2] = {1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pw[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      px[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      py[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotStart(spheroid, theta);
  float pz[2] = {0.0, 0.0};
  float paa[2] = {0.0, -1.0};
  float pab[2] = {1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pz[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      paa[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pab[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestRotate OK\n");
}

void UnitTestRotateAxis() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  float theta = PBMATH_HALFPI;
  VecFloat3D axis = VecFloatCreateStatic3D();
  VecSet(&axis, 0, 1.0); VecSet(&axis, 1, 1.0); VecSet(&axis, 2, 1.0);
  VecNormalise(&axis);
  ShapoidRotAxisCenter(facoid, &axis, theta);
  float pb[3] = {0.0, 0.0, 0.0};
  float pc[3] = {0.333333, 0.910684, -0.244017};
  float pd[3] = {-0.244017, 0.333333, 0.910684};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pc[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pd[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisCenter(pyramidoid, &axis, theta);
  float pe[3] = {0.000000, 0.000000, 0.000000};
  float pf[3] = {0.333333, 0.910684, -0.244017};
  float pg[3] = {-0.244017, 0.333333, 0.910684};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      pf[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pg[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisCenter(spheroid, &axis, theta);
  float ph[3] = {0.0, 0.0, 0.0};
  float pi[3] = {0.333333, 0.910684, -0.244017};
  float pj[3] = {-0.244017, 0.333333, 0.910684};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pi[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pj[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisOrigin(facoid, &axis, theta);
  float pk[3] = {0.0, 0.0, 0.0};
  float pl[3] = {-0.333333, 0.666667, 0.666667};
  float pm[3] = {0.666667, -0.333333, 0.666667};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pk[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pl[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pm[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisOrigin(pyramidoid, &axis, theta);
  float pn[3] = {0.0, 0.0, 0.0};
  float po[3] = {-0.333333, 0.666667, 0.666667};
  float pp[3] = {0.666667, -0.333333, 0.666667};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pn[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      po[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pp[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisOrigin(spheroid, &axis, theta);
  float pq[3] = {0.0, 0.0, 0.0};
  float pr[3] = {-0.333333, 0.666667, 0.666667};
  float ps[3] = {0.666667, -0.333333, 0.666667};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pq[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pr[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      ps[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisStart(facoid, &axis, theta);
  float pt[3] = {0.0, 0.0, 0.0};
  float pu[3] = {0.333333, -0.244017, 0.910683};
  float pv[3] = {0.910683, 0.333333, -0.244017};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pt[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pu[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pv[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisStart(pyramidoid, &axis, theta);
  float pw[3] = {0.0, 0.0, 0.0};
  float px[3] = {0.333333, -0.244017, 0.910683};
  float py[3] = {0.910683, 0.333333, -0.244017};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pw[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      px[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      py[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotAxisStart(spheroid, &axis, theta);
  float pz[3] = {0.0, 0.0, 0.0};
  float paa[3] = {0.333333, -0.244017, 0.910683};
  float pab[3] = {0.910683, 0.333333, -0.244017};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pz[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      paa[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pab[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
```

```
      sprintf(ShapoidErr->_msg, "ShapoidRotAxisStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestRotateAxis OK\n");
}

void UnitTestRotateX() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  float theta = PBMATH_HALFPI;
  ShapoidRotXCenter(facoid, theta);
  float pb[3] = {0.0, 1.0, 0.0};
  float pc[3] = {1.0, 0.0, 0.0};
  float pd[3] = {0.0, 0.0, 1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pc[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pd[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotXCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotXCenter(pyramidoid, theta);
  float pe[3] = {0.0, 0.5, 0.0};
  float pf[3] = {1.0, 0.0, 0.0};
  float pg[3] = {0.0, 0.0, 1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      pf[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pg[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotXCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotXCenter(spheroid, theta);
  float ph[3] = {0.0, 0.0, 0.0};
  float pi[3] = {1.0, 0.0, 0.0};
  float pj[3] = {0.0, 0.0, 1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pi[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pj[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotXCenter failed");
      PBErrCatch(ShapoidErr);
    }
```

```
}
ShapoidRotXOrigin(facoid, theta);
float pk[3] = {0.0, 0.0, 1.0};
float pl[3] = {1.0, 0.0, 0.0};
float pm[3] = {0.0, -1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pk[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
    pl[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
    pm[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotXOrigin failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotXOrigin(pyramidoid, theta);
float pn[3] = {0.0, 0.0, 0.5};
float po[3] = {1.0, 0.0, 0.0};
float pp[3] = {0.0, -1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
    pn[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
    po[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
    pp[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotXOrigin failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotXOrigin(spheroid, theta);
float pq[3] = {0.0, 0.0, 0.0};
float pr[3] = {1.0, 0.0, 0.0};
float ps[3] = {0.0, -1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
    pq[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
    pr[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
    ps[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotXOrigin failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotXStart(facoid, theta);
float pt[3] = {0.0, 0.0, 1.0};
float pu[3] = {1.0, 0.0, 0.0};
float pv[3] = {0.0, 0.0, -1.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pt[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
    pu[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
    pv[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotXStart failed");
    PBErrCatch(ShapoidErr);
  }
  }
  ShapoidRotXStart(pyramidoid, theta);
  float pw[3] = {0.0, 0.0, 0.5};
  float px[3] = {1.0, 0.0, 0.0};
  float py[3] = {0.0, 0.0, -1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pw[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      px[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      py[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotXStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotXStart(spheroid, theta);
  float pz[3] = {0.0, 0.0, 0.0};
  float paa[3] = {1.0, 0.0, 0.0};
  float pab[3] = {0.0, 0.0, -1.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pz[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      paa[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pab[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotXStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestRotateX OK\n");
}

void UnitTestRotateY() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  float theta = PBMATH_HALFPI;
  ShapoidRotYCenter(facoid, theta);
  float pb[3] = {0.0, 0.0, 1.0};
  float pc[3] = {0.0, 0.0, -1.0};
  float pd[3] = {0.0, 1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pc[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pd[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotYCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotYCenter(pyramidoid, theta);
  float pe[3] = {0.0, 0.0, 0.5};
  float pf[3] = {0.0, 0.0, -1.0};
  float pg[3] = {0.0, 1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      pf[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pg[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotYCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotYCenter(spheroid, theta);
  float ph[3] = {0.0, 0.0, 0.0};
  float pi[3] = {0.0, 0.0, -1.0};
  float pj[3] = {0.0, 1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pi[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pj[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotYCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotYOrigin(facoid, theta);
  float pk[3] = {1.0, 0.0, 0.0};
  float pl[3] = {-1.0, 0.0, 0.0};
  float pm[3] = {0.0, 1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pk[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pl[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pm[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotYOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotYOrigin(pyramidoid, theta);
  float pn[3] = {0.5, 0.0, 0.0};
  float po[3] = {-1.0, 0.0, 0.0};
  float pp[3] = {0.0, 1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pn[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      po[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pp[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotYOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotYOrigin(spheroid, theta);
```

```
float pq[3] = {0.0, 0.0, 0.0};
float pr[3] = {-1.0, 0.0, 0.0};
float ps[3] = {0.0, 1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
    pq[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
    pr[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
    ps[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotYOrigin failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotYStart(facoid, theta);
float pt[3] = {1.0, 0.0, 0.0};
float pu[3] = {0.0, 0.0, 1.0};
float pv[3] = {0.0, 1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pt[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
    pu[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
    pv[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotYStart failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotYStart(pyramidoid, theta);
float pw[3] = {0.5, 0.0, 0.0};
float px[3] = {0.0, 0.0, 1.0};
float py[3] = {0.0, 1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
    pw[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
    px[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
    py[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotYStart failed");
    PBErrCatch(ShapoidErr);
  }
}
ShapoidRotYStart(spheroid, theta);
float pz[3] = {0.0, 0.0, 0.0};
float paa[3] = {0.0, 0.0, 1.0};
float pab[3] = {0.0, 1.0, 0.0};
for (int i = dim; i--;) {
  if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
    pz[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
    paa[i]) == false ||
    ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
    pab[i]) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidRotYStart failed");
    PBErrCatch(ShapoidErr);
  }
}
```

```
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestRotateY OK\n");
}

void UnitTestRotateZ() {
  int dim = 3;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  float theta = PBMATH_HALFPI;
  ShapoidRotZCenter(facoid, theta);
  float pb[3] = {1.0, 0.0, 0.0};
  float pc[3] = {0.0, 1.0, 0.0};
  float pd[3] = {-1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pc[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pd[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZCenter(pyramidoid, theta);
  float pe[3] = {0.5, 0.0, 0.0};
  float pf[3] = {0.0, 1.0, 0.0};
  float pg[3] = {-1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      pf[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pg[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZCenter(spheroid, theta);
  float ph[3] = {0.0, 0.0, 0.0};
  float pi[3] = {0.0, 1.0, 0.0};
  float pj[3] = {-1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pi[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pj[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZCenter failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZOrigin(facoid, theta);
  float pk[3] = {0.0, 1.0, 0.0};
  float pl[3] = {-1.0, 0.0, 0.0};
  float pm[3] = {0.0, -1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pk[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pl[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pm[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZOrigin(pyramidoid, theta);
  float pn[3] = {0.0, 0.5, 0.0};
  float po[3] = {-1.0, 0.0, 0.0};
  float pp[3] = {0.0, -1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pn[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      po[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      pp[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZOrigin(spheroid, theta);
  float pq[3] = {0.0, 0.0, 0.0};
  float pr[3] = {-1.0, 0.0, 0.0};
  float ps[3] = {0.0, -1.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pq[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      pr[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      ps[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZOrigin failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZStart(facoid, theta);
  float pt[3] = {0.0, 1.0, 0.0};
  float pu[3] = {0.0, -1.0, 0.0};
  float pv[3] = {1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)facoid)->_pos, i), pt[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[0], i),
      pu[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)facoid)->_axis[1], i),
      pv[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZStart(pyramidoid, theta);
  float pw[3] = {0.0, 0.5, 0.0};
  float px[3] = {0.0, -1.0, 0.0};
```

```
  float py[3] = {1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_pos, i),
      pw[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[0], i),
      px[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)pyramidoid)->_axis[1], i),
      py[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidRotZStart(spheroid, theta);
  float pz[3] = {0.0, 0.0, 0.0};
  float paa[3] = {0.0, -1.0, 0.0};
  float pab[3] = {1.0, 0.0, 0.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)spheroid)->_pos, i),
      pz[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[0], i),
      paa[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)spheroid)->_axis[1], i),
      pab[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidRotZStart failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestRotateZ OK\n");
}

void UnitTestImportExportCoordIsPosInside() {
  int dim = 2;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  VecFloat* v = VecFloatCreate(dim);
  for (int i = dim; i--;)
    VecSet(v, i, 1.0 + (float)i);
  ShapoidTranslate(facoid, v);
  ShapoidTranslate(pyramidoid, v);
  ShapoidTranslate(spheroid, v);
  float scale = -2.0;
  ShapoidScale(facoid, scale);
  ShapoidScale(pyramidoid, scale);
  ShapoidScale(spheroid, scale);
  int nbTest = 100;
  srandom(RANDOMSEED);
  for (int iTest = nbTest; iTest--;) {
    VecFloat* posReal = VecFloatCreate(dim);
    for (int i = dim; i--;)
      VecSet(posReal, i, (rnd() - 0.5) * 10.0);
    VecFloat* posShapoidA = ShapoidImportCoord(facoid, posReal);
    bool isInside = ShapoidIsPosInside(facoid, posReal);
    if (VecGet(posShapoidA, 0) >= 0.0 &&
      VecGet(posShapoidA, 0) <= 1.0 &&
      VecGet(posShapoidA, 1) >= 0.0 &&
      VecGet(posShapoidA, 1) <= 1.0) {
```

```
  if (isInside == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
    PBErrCatch(ShapoidErr);
  }
} else {
  if (isInside == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
    PBErrCatch(ShapoidErr);
  }
}
VecOp(posShapoidA, scale, v, 1.0);
if (VecIsEqual(posReal, posShapoidA) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidImportCoord failed");
  PBErrCatch(ShapoidErr);
}
VecFree(&posShapoidA);
VecFloat* posShapoidB = ShapoidImportCoord(pyramidoid, posReal);
isInside = ShapoidIsPosInside(pyramidoid, posReal);
if (VecGet(posShapoidB, 0) >= 0.0 &&
  VecGet(posShapoidB, 0) <= 1.0 &&
  VecGet(posShapoidB, 1) >= 0.0 &&
  VecGet(posShapoidB, 1) <= 1.0 &&
  VecGet(posShapoidB, 0) + VecGet(posShapoidB, 1) <= 1.0) {
  if (isInside == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
    PBErrCatch(ShapoidErr);
  }
} else {
  if (isInside == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
    PBErrCatch(ShapoidErr);
  }
}
VecOp(posShapoidB, scale, v, 1.0);
if (VecIsEqual(posReal, posShapoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidImportCoord failed");
  PBErrCatch(ShapoidErr);
}
VecFree(&posShapoidB);
VecFloat* posShapoidC = ShapoidImportCoord(spheroid, posReal);
isInside = ShapoidIsPosInside(spheroid, posReal);
if (VecGet(posShapoidC, 0) >= -0.5 &&
  VecGet(posShapoidC, 0) <= 0.5 &&
  VecGet(posShapoidC, 1) >= -0.5 &&
  VecGet(posShapoidC, 1) <= 0.5 &&
  pow(VecGet(posShapoidC, 0), 2.0) +
  pow(VecGet(posShapoidC, 1), 2.0) <= 0.25) {
  if (isInside == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
    PBErrCatch(ShapoidErr);
  }
} else {
  if (isInside == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsPosInside failed");
```

```
        PBErrCatch(ShapoidErr);
      }
    }
    VecOp(posShapoidC, scale, v, 1.0);
    if (VecIsEqual(posReal, posShapoidC) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidImportCoord failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&posShapoidC);
    VecFree(&posReal);
  }
  for (int iTest = nbTest; iTest--;) {
    VecFloat* posShapoid = VecFloatCreate(dim);
    for (int i = dim; i--;)
      VecSet(posShapoid, i, (rnd() - 0.5) * 10.0);
    VecFloat* posRealA = ShapoidExportCoord(facoid, posShapoid);
    VecOp(posRealA, 1.0, v, -1.0);
    VecScale(posRealA, 1.0 / scale);
    if (VecIsEqual(posRealA, posShapoid) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidExportCoord failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&posRealA);
    VecFloat* posRealB = ShapoidExportCoord(pyramidoid, posShapoid);
    VecOp(posRealB, 1.0, v, -1.0);
    VecScale(posRealB, 1.0 / scale);
    if (VecIsEqual(posRealB, posShapoid) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidExportCoord failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&posRealB);
    VecFloat* posRealC = ShapoidExportCoord(facoid, posShapoid);
    VecOp(posRealC, 1.0, v, -1.0);
    VecScale(posRealC, 1.0 / scale);
    if (VecIsEqual(posRealC, posShapoid) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidExportCoord failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&posRealC);
    VecFree(&posShapoid);
  }
  VecFree(&v);
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestImportExportCoordIsPosInside OK\n");
}

void UnitTestGetBoundingBox() {
  int dim = 2;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  VecFloat* v = VecFloatCreate(dim);
  for (int i = dim; i--;)
    VecSet(v, i, 1.0 + (float)i);
  ShapoidTranslate(facoid, v);
  ShapoidTranslate(pyramidoid, v);
  ShapoidTranslate(spheroid, v);
  float scale = -2.0;
  ShapoidScale(facoid, scale);
  ShapoidScale(pyramidoid, scale);
  ShapoidScale(spheroid, scale);
  float theta = PBMATH_QUARTERPI;
  ShapoidRotCenter(facoid, theta);
  ShapoidRotCenter(pyramidoid, theta);
  ShapoidRotCenter(spheroid, theta);
  Facoid* boundA = ShapoidGetBoundingBox(facoid);
  float pa[2] = {-1.414214, -0.414213};
  float pb[2] = {2.828427, 0.0};
  float pc[2] = {0.0, 2.828427};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundA)->_pos, i),
      pa[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundA)->_axis[0], i),
      pb[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundA)->_axis[1], i),
      pc[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  Facoid* boundB = ShapoidGetBoundingBox(pyramidoid);
  float pd[2] = {-1.08088, 0.86193};
  float pe[2] = {2.82843, 0.0};
  float pf[2] = {0.0, 1.41421};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundB)->_pos, i), pd[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundB)->_axis[0], i),
      pe[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundB)->_axis[1], i),
      pf[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  Facoid* boundC = ShapoidGetBoundingBox(spheroid);
  float pg[2] = {-0.414214, 0.585786};
  float ph[2] = {2.828427, 0.0};
  float pi[2] = {0.0, 2.828427};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundC)->_pos, i), pg[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundC)->_axis[0], i),
      ph[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundC)->_axis[1], i),
      pi[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  GSetShapoid set = GSetShapoidCreateStatic();
  GSetPush(&set, facoid);
  GSetPush(&set, pyramidoid);
  GSetPush(&set, spheroid);
  Facoid* boundD = ShapoidGetBoundingBox(&set);
  float pj[2] = {-1.41421,-0.41421};
  float pk[2] = {3.828427, 0.0};
  float pl[2] = {0.0, 3.828427};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundD)->_pos, i), pj[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundD)->_axis[0], i),
      pk[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundD)->_axis[1], i),
      pl[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  GSetFlush(&set);
  VecSet(v, 0, 2.0); VecSet(v, 1, 4.0);
  ShapoidSetPos(facoid, v);
  ShapoidSetPos(pyramidoid, v);
  VecSet(v, 0, 7.0); VecSet(v, 1, 0.0);
  ShapoidSetAxis(facoid, 0, v);
  ShapoidSetAxis(pyramidoid, 0, v);
  VecSet(v, 0, 0.0); VecSet(v, 1, 4.0);
  ShapoidSetAxis(facoid, 1, v);
  ShapoidSetAxis(pyramidoid, 1, v);
  Facoid* boundE = ShapoidGetBoundingBox(facoid);
  float pm[2] = {2.0, 4.0};
  float pn[2] = {7.0, 0.0};
  float po[2] = {0.0, 4.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundE)->_pos, i), pm[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundE)->_axis[0], i),
      pn[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundE)->_axis[1], i),
      po[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  Facoid* boundF = ShapoidGetBoundingBox(pyramidoid);
  float pp[2] = {2.0, 4.0};
  float pq[2] = {7.0, 0.0};
  float pr[2] = {0.0, 4.0};
  for (int i = dim; i--;) {
    if (ISEQUALF(VecGet(((Shapoid*)boundF)->_pos, i), pp[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundF)->_axis[0], i),
      pq[i]) == false ||
      ISEQUALF(VecGet(((Shapoid*)boundF)->_axis[1], i),
      pr[i]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidGetBoundingBox failed");
      PBErrCatch(ShapoidErr);
    }
  }
  ShapoidFree(&boundA);
  ShapoidFree(&boundB);
  ShapoidFree(&boundC);
  ShapoidFree(&boundD);
  ShapoidFree(&boundE);
  ShapoidFree(&boundF);
  VecFree(&v);
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
```

```
  printf("UnitTestGetBoundingBox OK\n");
}

void UnitTestGetPosDepthCenterCoverage() {
  int dim = 2;
  Facoid* facoid = FacoidCreate(dim);
  Pyramidoid* pyramidoid = PyramidoidCreate(dim);
  Spheroid* spheroid = SpheroidCreate(dim);
  VecFloat* center = ShapoidGetCenter(facoid);
  if (ISEQUALF(VecGet(center, 0), 0.5) == false ||
    ISEQUALF(VecGet(center, 1), 0.5) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCenter failed");
    PBErrCatch(ShapoidErr);
  }
  VecFree(&center);
  center = ShapoidGetCenter(pyramidoid);
  if (ISEQUALF(VecGet(center, 0), 0.333333) == false ||
    ISEQUALF(VecGet(center, 1), 0.333333) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCenter failed");
    PBErrCatch(ShapoidErr);
  }
  VecFree(&center);
  center = ShapoidGetCenter(spheroid);
  if (ISEQUALF(VecGet(center, 0), 0.0) == false ||
    ISEQUALF(VecGet(center, 1), 0.0) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCenter failed");
    PBErrCatch(ShapoidErr);
  }
  VecFree(&center);
  float coverage = ShapoidGetCoverageDelta(facoid, pyramidoid, 0.001);
  if (ISEQUALF(coverage, 1.0) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  coverage = ShapoidGetCoverageDelta(pyramidoid, facoid, 0.001);
  if (ISEQUALF(coverage, 0.500499) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  coverage = ShapoidGetCoverageDelta(pyramidoid, spheroid, 0.001);
  if (ISEQUALF(coverage, 0.24937) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  coverage = ShapoidGetCoverageDelta(spheroid, pyramidoid, 0.001);
  if (ISEQUALF(coverage, 0.39251) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  coverage = ShapoidGetCoverageDelta(facoid, spheroid, 0.001);
  if (ISEQUALF(coverage, 0.24937) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  coverage = ShapoidGetCoverageDelta(spheroid, facoid, 0.001);
  if (ISEQUALF(coverage, 0.196451) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetCoverage failed");
    PBErrCatch(ShapoidErr);
  }
  VecFloat2D pos = VecFloatCreateStatic2D();
  VecSet(&pos, 0, 0.333333); VecSet(&pos, 1, 0.333333);
  float depth = ShapoidGetPosDepth(facoid, (VecFloat*)&pos);
  if (ISEQUALF(depth, 0.790123) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetPosDepth failed");
    PBErrCatch(ShapoidErr);
  }
  depth = ShapoidGetPosDepth(pyramidoid, (VecFloat*)&pos);
  if (ISEQUALF(depth, 1.0) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetPosDepth failed");
    PBErrCatch(ShapoidErr);
  }
  depth = ShapoidGetPosDepth(spheroid, (VecFloat*)&pos);
  if (ISEQUALF(depth, 0.057192) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidGetPosDepth failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&facoid);
  ShapoidFree(&pyramidoid);
  ShapoidFree(&spheroid);
  printf("UnitTestGetPosDepthCenterCoverage OK\n");
}

void UnitTestFacoidAlignedIsInsideFacoidAligned() {
  Facoid* facA = FacoidCreate(2);
  Facoid* facB = FacoidCreate(2);
  VecFloat2D p = VecFloatCreateStatic2D();
  VecFloat2D u = VecFloatCreateStatic2D();
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.0);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetPos(facA, &p);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  VecSet(&p, 0, 2.0); VecSet(&p, 1, 2.0);
  VecSet(&u, 0, 0.5); VecSet(&v, 1, 0.5);
  ShapoidSetPos(facB, &p);
  ShapoidSetAxis(facB, 0, &u);
  ShapoidSetAxis(facB, 1, &v);
  if (FacoidAlignedIsInsideFacoidAligned(facA, facB) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsInsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&p, 0, 0.1); VecSet(&p, 1, 0.1);
  ShapoidSetPos(facB, &p);
  if (FacoidAlignedIsInsideFacoidAligned(facB, facA) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsInsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetAxis(facB, 0, &u);
  ShapoidSetAxis(facB, 1, &v);
  if (FacoidAlignedIsInsideFacoidAligned(facB, facA) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsInsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&facA);
  ShapoidFree(&facB);
  printf("UnitTestFacoidAlignedIsInsideFacoidAligned OK\n");
}

void UnitTestFacoidAlignedIsOutsideFacoidAligned() {
  Facoid* facA = FacoidCreate(2);
  Facoid* facB = FacoidCreate(2);
  VecFloat2D p = VecFloatCreateStatic2D();
  VecFloat2D u = VecFloatCreateStatic2D();
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.0);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetPos(facA, &p);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  VecSet(&p, 0, 2.0); VecSet(&p, 1, 2.0);
  VecSet(&u, 0, 0.5); VecSet(&v, 1, 0.5);
  ShapoidSetPos(facB, &p);
  ShapoidSetAxis(facB, 0, &u);
  ShapoidSetAxis(facB, 1, &v);
  if (FacoidAlignedIsOutsideFacoidAligned(facA, facB) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsOutsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&p, 0, 0.1); VecSet(&p, 1, 0.1);
  ShapoidSetPos(facB, &p);
  if (FacoidAlignedIsOutsideFacoidAligned(facB, facA) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsOutsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetAxis(facB, 0, &u);
  ShapoidSetAxis(facB, 1, &v);
  if (FacoidAlignedIsOutsideFacoidAligned(facB, facA) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedIsOutsideFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&facA);
  ShapoidFree(&facB);
  printf("UnitTestFacoidAlignedIsOutsideFacoidAligned OK\n");
}

void UnitTestFacoidAlignedSplitExcludingFacoidAligned() {
  Facoid* facA = FacoidCreate(2);
  Facoid* facB = FacoidCreate(2);
  VecFloat2D p = VecFloatCreateStatic2D();
  VecFloat2D u = VecFloatCreateStatic2D();
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.0);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetPos(facA, &p);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  VecSet(&p, 0, 0.5); VecSet(&p, 1, 0.5);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetPos(facB, &p);
  ShapoidSetAxis(facB, 0, &u);
  ShapoidSetAxis(facB, 1, &v);
  GSetShapoid* split =
    FacoidAlignedSplitExcludingFacoidAligned(facA, facB);
  Facoid* facC = (Facoid*)GSetPop(split);
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.0);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 0.5);
  if (VecIsEqual(ShapoidPos(facC), &p) == false ||
    VecIsEqual(ShapoidAxis(facC, 0), &u) == false ||
    VecIsEqual(ShapoidAxis(facC, 1), &v) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedSplitExcludingFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  Facoid* facD = (Facoid*)GSetPop(split);
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.5);
  VecSet(&u, 0, 0.5); VecSet(&v, 1, 0.5);
  if (VecIsEqual(ShapoidPos(facD), &p) == false ||
    VecIsEqual(ShapoidAxis(facD, 0), &u) == false ||
    VecIsEqual(ShapoidAxis(facD, 1), &v) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedSplitExcludingFacoidAligned failed");
    PBErrCatch(ShapoidErr);
  }
  GSetFree(&split);
  ShapoidFree(&facA);
  ShapoidFree(&facB);
  ShapoidFree(&facC);
  ShapoidFree(&facD);
  printf("UnitTestFacoidAlignedSplitExcludingFacoidAligned OK\n");
}

void UnitTestFacoidAlignedAddClippedToSet() {
  Facoid* facA = FacoidCreate(2);
  VecFloat2D p = VecFloatCreateStatic2D();
  VecFloat2D u = VecFloatCreateStatic2D();
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&p, 0, 0.0); VecSet(&p, 1, 0.0);
  VecSet(&u, 0, 10.0); VecSet(&v, 1, 10.0);
  ShapoidSetPos(facA, &p);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  GSetShapoid set = GSetShapoidCreateStatic();
  FacoidAlignedAddClippedToSet(facA, &set);
  VecSet(&p, 0, 15.0); VecSet(&p, 1, 15.0);
  ShapoidSetPos(facA, &p);
  FacoidAlignedAddClippedToSet(facA, &set);
  VecSet(&p, 0, 8.0); VecSet(&p, 1, 8.0);
  ShapoidSetPos(facA, &p);
  FacoidAlignedAddClippedToSet(facA, &set);
  VecSet(&p, 0, 12.0); VecSet(&p, 1, 9.0);
  ShapoidSetPos(facA, &p);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 10.0);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  FacoidAlignedAddClippedToSet(facA, &set);
  VecSet(&p, 0, 5.0); VecSet(&p, 1, 5.0);
  ShapoidSetPos(facA, &p);
  VecSet(&u, 0, 1.0); VecSet(&v, 1, 1.0);
  ShapoidSetAxis(facA, 0, &u);
  ShapoidSetAxis(facA, 1, &v);
  FacoidAlignedAddClippedToSet(facA, &set);
  if (GSetNbElem(&set) != 6) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg,
      "FacoidAlignedAddClippedToSet failed");
    PBErrCatch(ShapoidErr);
  }
  int iCheck = 0;
  float checkp[12] = {
      0.0, 0.0, 15.0, 15.0, 10.0, 8.0, 8.0,
      10.0, 8.0, 15.0, 12.0, 18.0};
  float checku[6] = {10.0, 10.0, 8.0, 10.0, 7.0, 1.0};
  float checkv[6] = {10.0, 10.0, 2.0, 5.0, 3.0, 1.0};
  do {
    Facoid* fac = (Facoid*)GSetPop(&set);
    VecSet(&p, 0, checkp[2 * iCheck]);
    VecSet(&p, 1, checkp[2 * iCheck + 1]);
    VecSet(&u, 0, checku[iCheck]); VecSet(&v, 1, checkv[iCheck]);
    if (VecIsEqual(ShapoidPos(fac), &p) == false ||
      VecIsEqual(ShapoidAxis(fac, 0), &u) == false ||
      VecIsEqual(ShapoidAxis(fac, 1), &v) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg,
        "FacoidAlignedAddClippedToSet failed");
      PBErrCatch(ShapoidErr);
    }
    ShapoidFree(&fac);
    ++iCheck;
  } while(GSetNbElem(&set) > 0);
  ShapoidFree(&facA);
  printf("UnitTestFacoidAlignedAddClippedToSet OK\n");
}

void UnitTestIsInter() {
  Spheroid* spheroidA = SpheroidCreate(3);
  Spheroid* spheroidB = SpheroidCreate(3);
  VecFloat3D v = VecFloatCreateStatic3D();
  if (ShapoidIsInter(spheroidA, spheroidB) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsInter failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&v, 0, 1.1);
  ShapoidSetPos(spheroidB, &v);
  if (ShapoidIsInter(spheroidB, spheroidA) == true) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsInter failed");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&v, 1, 1.0);
  ShapoidSetPos(spheroidB, &v);
```

```
if (ShapoidIsInter(spheroidA, spheroidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed");
  PBErrCatch(ShapoidErr);
}
VecSet(&v, 0, 0.0); VecSet(&v, 1, 1.1);
ShapoidSetPos(spheroidB, &v);
VecSet(&v, 0, 1.0); VecSet(&v, 1, 2.0); VecSet(&v, 2, 1.0);
ShapoidScale(spheroidB, (VecFloat*)&v);
if (ShapoidIsInter(spheroidA, spheroidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed");
  PBErrCatch(ShapoidErr);
}
ShapoidRotZCenter(spheroidB, -PBMATH_QUARTERPI);
VecSet(&v, 0, 1.0); VecSet(&v, 1, 1.0); VecSet(&v, 2, 0.0);
ShapoidSetPos(spheroidB, &v);
if (ShapoidIsInter(spheroidA, spheroidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed");
  PBErrCatch(ShapoidErr);
}
ShapoidFree(&spheroidA);
ShapoidFree(&spheroidB);

Pyramidoid* pyramidoidA = PyramidoidCreate(2);
Pyramidoid* pyramidoidB = PyramidoidCreate(2);
Facoid* facoidA = FacoidCreate(2);
Facoid* facoidB = FacoidCreate(2);
VecFloat2D w = VecFloatCreateStatic2D();
if (ShapoidIsInter(pyramidoidA, pyramidoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPP 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidA, facoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPF 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidA, pyramidoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFP 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidA, facoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFF 1)");
  PBErrCatch(ShapoidErr);
}
VecSet(&w, 0, 0.51);
ShapoidSetPos(pyramidoidB, &w);
if (ShapoidIsInter(pyramidoidA, pyramidoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPP 2)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidB, facoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPF 2)");
  PBErrCatch(ShapoidErr);
}
```

```
if (ShapoidIsInter(facoidB, pyramidoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFP 2)");
  PBErrCatch(ShapoidErr);
}
VecSet(&w, 1, 0.51);
ShapoidSetPos(pyramidoidB, &w);
if (ShapoidIsInter(pyramidoidA, pyramidoidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPP 3)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidB, facoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPF 3)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidB, pyramidoidB) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFP 3)");
  PBErrCatch(ShapoidErr);
}
VecSet(&w, 0, 1.5);
ShapoidSetPos(pyramidoidB, &w);
if (ShapoidIsInter(pyramidoidA, pyramidoidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPP 4)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidB, facoidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATPF 4)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidB, pyramidoidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFP 4)");
  PBErrCatch(ShapoidErr);
}
ShapoidSetPos(facoidB, &w);
if (ShapoidIsInter(facoidA, facoidB) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (SATFF 5)");
  PBErrCatch(ShapoidErr);
}
ShapoidFree(&pyramidoidA);
ShapoidFree(&pyramidoidB);
ShapoidFree(&facoidA);
ShapoidFree(&facoidB);

Pyramidoid* pyramidoidC = PyramidoidCreate(3);
Pyramidoid* pyramidoidD = PyramidoidCreate(3);
Facoid* facoidC = FacoidCreate(3);
Facoid* facoidD = FacoidCreate(3);
VecFloat3D u = VecFloatCreateStatic3D();
if (ShapoidIsInter(pyramidoidC, pyramidoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPP 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidC, pyramidoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBFP 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidC, facoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPF 1)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidC, facoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBFF 1)");
  PBErrCatch(ShapoidErr);
}
VecSet(&u, 0, 0.51);
ShapoidSetPos(pyramidoidC, &u);
if (ShapoidIsInter(pyramidoidC, pyramidoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPP 2)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidC, pyramidoidC) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBFP 2)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidC, facoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPF 2)");
  PBErrCatch(ShapoidErr);
}
VecSet(&u, 1, 0.51);
VecSet(&u, 2, 0.51);
ShapoidSetPos(pyramidoidC, &u);
if (ShapoidIsInter(pyramidoidC, pyramidoidD) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPP 3)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidC, pyramidoidC) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBFP 3)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidC, facoidD) == false) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPF 3)");
  PBErrCatch(ShapoidErr);
}
VecSet(&u, 0, 1.51);
ShapoidSetPos(pyramidoidC, &u);
if (ShapoidIsInter(pyramidoidC, pyramidoidD) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPP 4)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(facoidC, pyramidoidC) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
  sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBFP 4)");
  PBErrCatch(ShapoidErr);
}
if (ShapoidIsInter(pyramidoidC, facoidD) == true) {
  ShapoidErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPF 4)");
    PBErrCatch(ShapoidErr);
  }
  VecSet(&u, 0, -0.5);
  VecSet(&u, 1, -0.5);
  VecSet(&u, 2, -0.5);
  ShapoidSetPos(pyramidoidC, &u);
  VecSet(&u, 0, 1.0);
  VecSet(&u, 1, 1.0);
  VecSet(&u, 2, -1.0);
  ShapoidSetAxis(pyramidoidC, 0, &u);
  VecSet(&u, 0, 0.0);
  VecSet(&u, 1, 1.0);
  VecSet(&u, 2, -1.0);
  ShapoidSetAxis(pyramidoidC, 1, &u);
  VecSet(&u, 0, 1.0);
  VecSet(&u, 1, 1.0);
  VecSet(&u, 2, 1.0);
  ShapoidSetAxis(pyramidoidC, 2, &u);
  if (ShapoidIsInter(pyramidoidC, facoidD) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIsInter failed (FMBPF 5)");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&pyramidoidC);
  ShapoidFree(&pyramidoidD);
  ShapoidFree(&facoidC);
  ShapoidFree(&facoidD);

  printf("UnitTestIsInter OK\n");
}

void UnitTestShapoidIterCreateFree() {
  Facoid* facoid = FacoidCreate(2);
  VecFloat2D delta = VecFloatCreateStatic2D();
  ShapoidIter iter = ShapoidIterCreateStatic(facoid, &delta);
  if (iter._shap != (Shapoid*)facoid ||
    iter._pos == NULL ||
    iter._delta == NULL ||
    VecGetDim(iter._pos) != 2 ||
    VecGetDim(iter._delta) != 2) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterFreeStatic failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&facoid);
  ShapoidIterFreeStatic(&iter);
  if (iter._pos != NULL ||
    iter._delta != NULL) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterFreeStatic failed");
    PBErrCatch(ShapoidErr);
  }
  printf("UnitTestShapoidIterCreateFree OK\n");
}

void UnitTestShapoidIterGetSet() {
  Facoid* facoidA = FacoidCreate(2);
  Facoid* facoidB = FacoidCreate(2);
  VecFloat2D deltaA = VecFloatCreateStatic2D();
  VecFloat2D deltaB = VecFloatCreateStatic2D();
  for (int i = 2; i--;) {
    VecSet(&deltaA, i, 0.1);
    VecSet(&deltaB, i, 0.2);
  }
  ShapoidIter iter = ShapoidIterCreateStatic(facoidA, &deltaA);
  if (ShapoidIterShapoid(&iter) != (Shapoid*)facoidA) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterShapoid failed");
    PBErrCatch(ShapoidErr);
  }
  if (VecIsEqual(ShapoidIterDelta(&iter), &deltaA) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterDelta failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidIterSetShapoid(&iter, facoidB);
  ShapoidIterSetDelta(&iter, &deltaB);
  if (ShapoidIterShapoid(&iter) != (Shapoid*)facoidB) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterSetShapoid failed");
    PBErrCatch(ShapoidErr);
  }
  if (VecIsEqual(ShapoidIterDelta(&iter), &deltaB) == false) {
    ShapoidErr->_type = PBErrTypeUnitTestFailed;
    sprintf(ShapoidErr->_msg, "ShapoidIterSetDelta failed");
    PBErrCatch(ShapoidErr);
  }
  ShapoidFree(&facoidA);
  ShapoidFree(&facoidB);
  ShapoidIterFreeStatic(&iter);
  printf("UnitTestShapoidIterGetSet OK\n");
}

void UnitTestShapoidIterStepFacoid() {
  Facoid* facoid = FacoidCreate(2);
  VecFloat2D delta = VecFloatCreateStatic2D();
  for (int i = 2; i--;)
    VecSet(&delta, i, 0.25);
  ShapoidIter iter = ShapoidIterCreateStatic(facoid, &delta);
  int iCheck = 0;
  float check[50] = {0.000,0.000,0.000,0.250,0.000,0.500,0.000,0.750,
    0.000,1.000,0.250,0.000,0.250,0.250,0.250,0.500,0.250,0.750,0.250,
    1.000,0.500,0.000,0.500,0.250,0.500,0.500,0.500,0.750,0.500,1.000,
    0.750,0.000,0.750,0.250,0.750,0.500,0.750,0.750,0.750,1.000,1.000,
    0.000,1.000,0.250,1.000,0.500,1.000,0.750,1.000,1.000
    };
  do {
    VecFloat* v = ShapoidIterGetInternalPos(&iter);
    if (ISEQUALF(VecGet(v, 0), check[2 * iCheck]) == false ||
      ISEQUALF(VecGet(v, 1), check[2 * iCheck + 1]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidIterStep failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&v);
    ++iCheck;
  } while (ShapoidIterStep(&iter));
  ShapoidFree(&facoid);
  ShapoidIterFreeStatic(&iter);
  printf("UnitTestShapoidIterStepFacoid OK\n");
}

void UnitTestShapoidIterStepPyramidoid() {
  Pyramidoid* pyramidoid = PyramidoidCreate(3);
  VecFloat3D delta = VecFloatCreateStatic3D();
  for (int i = 3; i--;)
    VecSet(&delta, i, 0.25);
  ShapoidIter iter = ShapoidIterCreateStatic(pyramidoid, &delta);
  int iCheck = 0;
  float check[105] = {0.000,0.000,0.000,0.000,0.000,0.250,0.000,0.000,
    0.500,0.000,0.000,0.750,0.000,0.000,1.000,0.000,0.250,0.000,0.000,
    0.250,0.250,0.000,0.250,0.500,0.000,0.250,0.750,0.000,0.500,0.000,
    0.000,0.500,0.250,0.000,0.500,0.500,0.000,0.750,0.000,0.000,0.750,
    0.250,0.000,1.000,0.000,0.250,0.000,0.000,0.250,0.000,0.250,0.250,
    0.000,0.500,0.250,0.000,0.750,0.250,0.250,0.000,0.250,0.250,0.250,
    0.250,0.250,0.500,0.250,0.500,0.000,0.250,0.500,0.250,0.250,0.750,
    0.000,0.500,0.000,0.000,0.500,0.000,0.250,0.500,0.000,0.500,0.500,
    0.250,0.000,0.500,0.250,0.250,0.500,0.500,0.000,0.750,0.000,0.000,
    0.750,0.000,0.250,0.750,0.250,0.000,1.000,0.000,0.000
    };
  do {
    VecFloat* v = ShapoidIterGetInternalPos(&iter);
    if (ISEQUALF(VecGet(v, 0), check[3 * iCheck]) == false ||
      ISEQUALF(VecGet(v, 1), check[3 * iCheck + 1]) == false ||
      ISEQUALF(VecGet(v, 2), check[3 * iCheck + 2]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidIterStep failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&v);
    ++iCheck;
  } while (ShapoidIterStep(&iter));
  ShapoidFree(&pyramidoid);
  ShapoidIterFreeStatic(&iter);
  printf("UnitTestShapoidIterStepPyramidoid OK\n");
}

void UnitTestShapoidIterStepSpheroid() {
  int dim = 3;
  Spheroid* spheroid = SpheroidCreate(dim);
  VecFloat* delta = VecFloatCreate(dim);
  for (int i = dim; i--;)
    VecSet(delta, i, 0.25);
  ShapoidIter iter = ShapoidIterCreateStatic(spheroid, delta);
  int iCheck = 0;
  float check[147] = {
    0.00000,0.00000,-0.50000,0.00000,-0.43301,-0.25000,-0.39244,
    -0.18301,-0.25000,-0.14244,-0.18301,-0.25000,0.10756,-0.18301,
    -0.25000,0.35756,-0.18301,-0.25000,0.39244,-0.18301,-0.25000,
    -0.42780,0.06699,-0.25000,-0.17780,0.06699,-0.25000,0.07220,
    0.06699,-0.25000,0.32220,0.06699,-0.25000,0.42780,0.06699,
    -0.25000,-0.29499,0.31699,-0.25000,-0.04499,0.31699,-0.25000,
    0.20501,0.31699,-0.25000,0.29499,0.31699,-0.25000,0.00000,
    -0.50000,0.00000,-0.43301,-0.25000,0.00000,-0.18301,-0.25000,
    0.00000,0.06699,-0.25000,0.00000,0.31699,-0.25000,0.00000,0.43301,
    -0.25000,0.00000,-0.50000,0.00000,0.00000,-0.25000,0.00000,0.00000,
    0.00000,0.00000,0.00000,0.25000,0.00000,0.00000,0.50000,0.00000,
    0.00000,-0.43301,0.25000,0.00000,-0.18301,0.25000,0.00000,0.06699,
    0.25000,0.00000,0.31699,0.25000,0.00000,0.43301,0.25000,0.00000,
    0.00000,0.50000,0.00000,0.00000,-0.43301,0.25000,-0.39244,-0.18301,
    0.25000,-0.14244,-0.18301,0.25000,0.10756,-0.18301,0.25000,0.35756,
    -0.18301,0.25000,0.39244,-0.18301,0.25000,-0.42780,0.06699,0.25000,
    -0.17780,0.06699,0.25000,0.07220,0.06699,0.25000,0.32220,0.06699,
    0.25000,0.42780,0.06699,0.25000,-0.29499,0.31699,0.25000,-0.04499,
    0.31699,0.25000,0.20501,0.31699,0.25000,0.29499,0.31699,0.25000,
    0.00000,0.00000,0.50000
    };
  do {
    VecFloat* v = ShapoidIterGetInternalPos(&iter);
    if (ISEQUALF(VecGet(v, 0), check[3 * iCheck]) == false ||
      ISEQUALF(VecGet(v, 1), check[3 * iCheck + 1]) == false ||
      ISEQUALF(VecGet(v, 2), check[3 * iCheck + 2]) == false) {
      ShapoidErr->_type = PBErrTypeUnitTestFailed;
      sprintf(ShapoidErr->_msg, "ShapoidIterStep failed");
      PBErrCatch(ShapoidErr);
    }
    VecFree(&v);
    ++iCheck;
  } while (ShapoidIterStep(&iter));
  ShapoidFree(&spheroid);
  ShapoidIterFreeStatic(&iter);
  VecFree(&delta);
  printf("UnitTestShapoidIterStepSpheroid OK\n");
}

void UnitTestShapoidIter() {
  UnitTestShapoidIterCreateFree();
  UnitTestShapoidIterGetSet();
  UnitTestShapoidIterStepFacoid();
  UnitTestShapoidIterStepPyramidoid();
  UnitTestShapoidIterStepSpheroid();

  printf("UnitTestShapoidIter OK\n");
}

void UnitTestAll() {
  UnitTestCreateCloneIsEqualFree();
  UnitTestLoadSavePrint();
  UnitTestGetSetTypeDimPosAxis();
  UnitTestTranslateScaleGrow();
  UnitTestRotate();
  UnitTestRotateAxis();
  UnitTestRotateX();
  UnitTestRotateY();
  UnitTestRotateZ();
  UnitTestImportExportCoordIsPosInside();
  UnitTestGetBoundingBox();
  UnitTestGetPosDepthCenterCoverage();
  UnitTestFacoidAlignedIsInsideFacoidAligned();
  UnitTestFacoidAlignedIsOutsideFacoidAligned();
  UnitTestFacoidAlignedSplitExcludingFacoidAligned();
  UnitTestFacoidAlignedAddClippedToSet();
  UnitTestIsInter();
  UnitTestShapoidIter();
  printf("UnitTestAll OK\n");
}

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

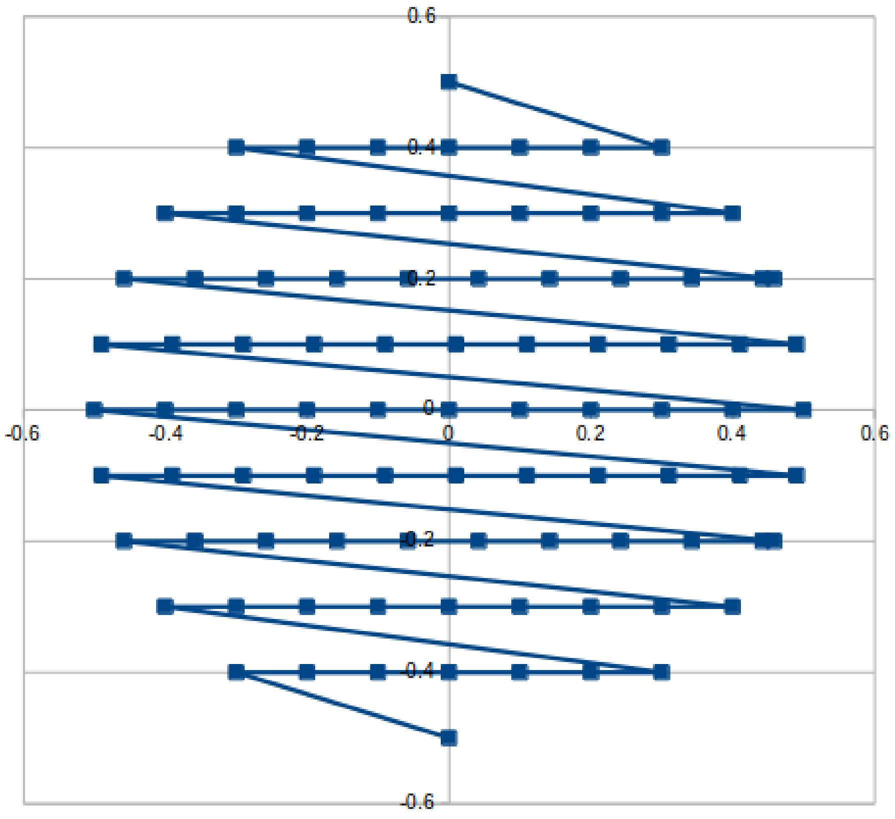
6 Unit tests output

```
UnitTestCreateCloneIsEqualFree OK
Type: Facoid
Dim: 3
Pos: <0.000,0.000,0.000>
Axis(0): <1.000,0.000,0.000>
Axis(1): <0.000,1.000,0.000>
Axis(2): <0.000,0.000,1.000>
UnitTestLoadSavePrint OK
UnitTestGetSetTypeDimPosAxis OK
UnitTestTranslateScaleGrow OK
UnitTestRotate OK
UnitTestRotateAxis OK
UnitTestRotateX OK
UnitTestRotateY OK
UnitTestRotateZ OK
UnitTestImportExportCoordIsPosInside OK
UnitTestGetBoundingBox OK
UnitTestGetPosDepthCenterCoverage OK
UnitTestFacoidAlignedIsInsideFacoidAligned OK
UnitTestFacoidAlignedIsOutsideFacoidAligned OK
UnitTestFacoidAlignedSplitExcludingFacoidAligned OK
UnitTestFacoidAlignedAddClippedToSet OK
UnitTestIsInter OK
UnitTestShapoidIterCreateFree OK
UnitTestShapoidIterGetSet OK
UnitTestShapoidIterStepFacoid OK
UnitTestShapoidIterStepPyramidoid OK
UnitTestShapoidIterStepSpheroid OK
UnitTestShapoidIter OK
UnitTestAll OK
```

facoid.txt

```
{
  "_dim":"3",
  "_type":"0",
  "_pos":{
    "_dim":"3",
    "_val":["0.000000","0.000000","0.000000"]
  },
  "_axis":[
    {
      "_dim":"3",
      "_val":["1.000000","0.000000","0.000000"]
    },
    {
      "_dim":"3",
      "_val":["0.000000","1.000000","0.000000"]
    },
    {
      "_dim":"3",
      "_val":["0.000000","0.000000","1.000000"]
    }
  ]
}
```

Example of path on a 2D Spheroid using the ShapoidIterator:


0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.6
-0.4
-0.2
0
0.2
0.4
0.6