PBPhys

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Contents

Introduction

PBPhys is a C library providing structures and functions to simulate system of moving particles in any dimension.

Each particle is represented by a Shapoid, with a speed and acceleration vector, a mass and a drag coefficient. Particles can be fixed. The PBPhys is defined as GSet of particles. The system can emulate or ignore attraction between particles, downward gravity (applied to the second component of vectors, to simulate earth attraction for example), drag force on particle, elastic

collision between particles (considered as perfect spheres). The user can control the system's particle by position, speed or acceleration. The user can step the system by increment of time or until the next collision. The whole system and individual particles can be printed on a stream, saved/loaded in a file.

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

1 Definitions

1.1 Equation of movement

The movement of each particle is calculated as follow. Given $drag$ the drag coefficient of the particle ($drag \in \mathbb{R}^+$, 0.0 means no drag), $\overrightarrow{P}(t)$ the position of the particle at instant t, $\overrightarrow{S}(t)$ the speed of the particle at instant t and $\overrightarrow{A}(t)$ the acceleration of the particle at instant t:

$$\overrightarrow{P}(t+\delta t) = \overrightarrow{P}(t) + \overrightarrow{S}(t)\delta t + 0.5 * (\overrightarrow{A}(t) - drag * \overrightarrow{S}(t))\delta t^2 \quad (1)$$

$$\overrightarrow{S}(t+\delta t) = \overrightarrow{S}(t) + (\overrightarrow{A}(t) - drag * \overrightarrow{S}(t))\delta t \quad (2)$$

If a "downward gravity" is applied, its value is substracted to the second component of the acceleration. If "gravity" is applied each particle P_i 's acceleration is added an attraction force toward others particles equals to:

$$\overrightarrow{F}_i(t) = \sum_j \left(G.\frac{m_i.m_j}{||\overrightarrow{P}_j(t) - \overrightarrow{P}_i(t)||^2}.\frac{\overrightarrow{P_j} - \overrightarrow{P_i}}{||\overrightarrow{P}_j(t) - \overrightarrow{P}_i(t)||} \right) \quad (3)$$

where G is the gravity and m_i is the mass of the particle P_i.

1.2 Detection of collision

The detection of collision between particles is done while approximating particles to spheres.

The distance between two particles moving linearly is calculated as follow. Given $\overrightarrow{P}_0(t)$ and $\overrightarrow{S}_0(t)$ the position and speed of the first particle at time t, and $\overrightarrow{P}_1(t)$ and $\overrightarrow{S}_1(t)$ the position and speed of the second particle

at time t. The distance $D(t)$ betwen the two particles is given by:

$$D(t_0 + dt) = \sqrt{||\overrightarrow{V}(t_0)||^2 + 2(\overrightarrow{V}(t_0).\overrightarrow{W}(t_0))dt + ||\overrightarrow{W}(t_0)||^2 dt^2} \quad (4)$$

where $\overrightarrow{V}(t) = \overrightarrow{P}_1(t) - \overrightarrow{P}_0(t)$ and $\overrightarrow{W}(t) = \overrightarrow{S}_1(t) - \overrightarrow{S}_0(t)$.

One can notice that the square of the distance between particles is a polynomial function of order 2. The time to smallest distance between particles dt_n can then simply be calculated by searching the solution of $D'(t) = 0$, which gives:

$$dt_n = \frac{-b}{2a} \quad (5)$$

where a, b, c represents the coefficients of the polynomial: $D(t) = at^2 + bt + c$.

Finally, given R_0 and R_1 the radius of the spheres approximating the particle, the time dt_h to hit can be calculated as follow:

$$dt_h = \frac{-b - \sqrt{b^2 - 4a(c - (R_0 + R_1)^2)}}{2a} \quad (6)$$

1.3 Elastic collision

The speed after collision of two colliding particles is calculated as follow. Given m_0 and m_1 the masses of the particles, $\overrightarrow{P}_0$ and $\overrightarrow{P}_1$ the position of the particles, $\overrightarrow{S}_0$ and $\overrightarrow{S}_1$ the speed of the particles before collision and $\overrightarrow{S'}_0$ and $\overrightarrow{S'}_1$ the speed of the particles after collision:

$$\overrightarrow{S'}_0 = \overrightarrow{S}_0 - \frac{2m_1}{m_0 + m_1}.\frac{(\overrightarrow{S}_0 - \overrightarrow{S}_1).(\overrightarrow{P}_0 - \overrightarrow{P}_1)}{||\overrightarrow{P}_0 - \overrightarrow{P}_1||^2}(\overrightarrow{P}_0 - \overrightarrow{P}_1) \quad (7)$$

$$\overrightarrow{S'}_1 = \overrightarrow{S}_1 - \frac{2m_0}{m_0 + m_1}.\frac{(\overrightarrow{S}_1 - \overrightarrow{S}_0).(\overrightarrow{P}_1 - \overrightarrow{P}_0)}{||\overrightarrow{P}_1 - \overrightarrow{P}_0||^2}(\overrightarrow{P}_1 - \overrightarrow{P}_0) \quad (8)$$

2 Interface

```
// ============ PBPHYS.H ================

#ifndef PBPHYS_H
#define PBPHYS_H

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

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

// ------------ PBPhysParticle

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

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

typedef struct PBPhysParticle {
  // Shapoid
  Shapoid* _shape;
  // Speed
  VecFloat* _speed;
  // User acceleration
  VecFloat* _accel;
  // System acceleration (used internally for calculation)
  VecFloat* _sysAccel;
  // Mass
  float _mass;
  // Drag per time unit
  float _drag;
  // Flag for fixed particle
  bool _fixed;
  // User data
  void* _data;
} PBPhysParticle;

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

// Create a new PBPhysParticle with dimension 'dim' and a 'shapeType'
// shapoid as shape
// Default values: _mass = 0.0, _drag = 0.0, _fixed = false
PBPhysParticle* PBPhysParticleCreate(int dim, ShapoidType shapeType);

// Free the memory used by the particle 'that'
void PBPhysParticleFree(PBPhysParticle** that);

// Return a clone of the particle 'that'
PBPhysParticle* PBPhysParticleClone(PBPhysParticle* that);

// Print the particle 'that' on the stream 'stream'
void PBPhysParticlePrintln(PBPhysParticle* that, FILE* stream);

// Function which return the JSON encoding of 'that'
JSONNode* PBPhysParticleEncodeAsJSON(PBPhysParticle* that);

// Function which decode from JSON encoding 'json' to 'that'
bool PBPhysParticleDecodeAsJSON(PBPhysParticle** that, JSONNode* json);

// Save the particle 'that' on the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if we could save the particle
// Return false else
// If user data is attached to the particle it must be saved by the user
bool PBPhysParticleSave(PBPhysParticle* that, FILE* stream,
```

```
  bool compact);

// Load the particle 'that' from the stream 'stream'
// Return true if we could load the particle
// Return false else
// If user data is attached to the particle it must be loaded by the user
bool PBPhysParticleLoad(PBPhysParticle** that, FILE* stream);

// Return the dimension of the particle 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysParticleGetDim(PBPhysParticle* that);

// Return the shape type of the particle 'that'
#if BUILDMODE != 0
inline
#endif
ShapoidType PBPhysParticleGetShapeType(PBPhysParticle* that);

// Return the shape of the particle 'that'
#if BUILDMODE != 0
inline
#endif
Shapoid* PBPhysParticleShape(PBPhysParticle* that);

// Return the 'iAxis'-th axis of the shape of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleAxis(PBPhysParticle* that, int iAxis);

// Return the speed of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleSpeed(PBPhysParticle* that);

// Return the accel of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleAccel(PBPhysParticle* that);

// Return the sysAccel of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleSysAccel(PBPhysParticle* that);

// Return the position of the center of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleGetPos(PBPhysParticle* that);

// Set the speed of the particle 'that' to 'speed'
// If the particle is fixed do nothing
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSpeed(PBPhysParticle* that, VecFloat* speed);
```

```
// Set the acceleration of the particle 'that' to 'accel'
// If the particle is fixed do nothing
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetAccel(PBPhysParticle* that, VecFloat* accel);

// Set the position of the center of the particle 'that' to 'pos'
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetPos(PBPhysParticle* that, VecFloat* pos);

// Return true if the particle 'that' is the same is the particle 'tho'
// Return false else
// User data is not compared
#if BUILDMODE != 0
inline
#endif
bool PBPhysParticleIsSame(PBPhysParticle* that, PBPhysParticle* tho);

// Set the shape size of the particle 'that' to 'size'
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSizeVec(PBPhysParticle* that, VecFloat* size);
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSizeScalar(PBPhysParticle* that, float size);

// Return the mass of the particle 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysParticleGetMass(PBPhysParticle* that);

// Set the mass of the particle 'that' to 'mass'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetMass(PBPhysParticle* that, float mass);

// Return the drag of the particle 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysParticleGetDrag(PBPhysParticle* that);

// Set the drag of the particle 'that' to 'drag'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetDrag(PBPhysParticle* that, float drag);

// Move the particle 'that' over a period of time 'dt'
// x(t+dt) = x(t) + v(t)*dt + 0.5*(a(t)-drag*v(t))*dt^2
// v(t+dt) = v(t) + (a(t)-drag*v(t))*dt
void PBPhysParticleMove(PBPhysParticle* that, float dt);

// Return true if the particle 'that' is fixed
```

```
// Return false else
#if BUILDMODE != 0
inline
#endif
bool PBPhysParticleIsFixed(PBPhysParticle* that);

// Set the fixed flag of the particle 'that' to 'fixed'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetFixed(PBPhysParticle* that, bool fixed);

// Set the user data of the particle 'that' to 'data'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetData(PBPhysParticle* that, void* data);

// Get the user data of the particle 'that'
#if BUILDMODE != 0
inline
#endif
void* PBPhysParticleData(PBPhysParticle* that);

// Correct the current speed of the two colliding particles 'that' and
// 'tho' under the hypothesis of elastic collision
// If at least one of the particle as a null mass, do nothing
void PBPhysParticleApplyElasticCollision(PBPhysParticle* that,
  PBPhysParticle* tho);

// Return the coefficients of the polynom describing the square of the
// distance between particles 'that' and 'tho'
// Return a vector such as dist^2(t)=v[0]+v[1]t+v[2]t^2
VecFloat3D PBPhysParticleGetDistPoly(PBPhysParticle* that,
  PBPhysParticle* tho);

// ------------ PBPhys

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

// units : meter, second, kilogram
#define PBPHYS_Gn 9.80665
#define PBPHYS_G 6.6740831e-11
#define PBPHYS_DELTAT 0.01

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

typedef struct PBPhys {
  // Dimension of space
  int _dim;
  // Set of particles
  GSetPBPhysParticle _particles;
  // Delta time used in Step()
  float _deltaT;
  // Downward gravity
  float _downGravity;
  // Gravity between particles
  float _gravity;
  // Current time
  float _curTime;
} PBPhys;
```

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

// Create a new PBPhys for space dimension 'dim'
// Default values: _deltaT = PBPHYS_DELTAT, _downGravity = 0.0,
// _gravity = 0.0, _curTime = 0.0
PBPhys* PBPhysCreate(int dim);

// Free memory used by the PBPhys 'that'
void PBPhysFree(PBPhys** that);

// Return a clone of the PBPhys 'that'
PBPhys* PBPhysClone(PBPhys* that);

// Print the PBPhys 'that' on the stream 'stream'
void PBPhysPrintln(PBPhys* that, FILE* stream);

// Function which return the JSON encoding of 'that'
JSONNode* PBPhysEncodeAsJSON(PBPhys* that);

// Function which decode from JSON encoding 'json' to 'that'
bool PBPhysDecodeAsJSON(PBPhys** that, JSONNode* json);

// Save the PBPhys 'that' on the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if we could save the PBPhys
// Return false else
bool PBPhysSave(PBPhys* that, FILE* stream, bool compact);

// Load the PBPhys 'that' from the stream 'stream'
// Return true if we could load the PBPhys
// Return false else
bool PBPhysLoad(PBPhys** that, FILE* stream);

// Return the space dimension of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysGetDim(PBPhys* that);

// Return the set of particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
GSetPBPhysParticle* PBPhysParticles(PBPhys* that);

// Return the delta t of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetDeltaT(PBPhys* that);

// Return the current time of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetCurTime(PBPhys* that);

// Return the downward gravity of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
```

```
float PBPhysGetDownGravity(PBPhys* that);

// Return the gravity coefficient between particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetGravity(PBPhys* that);

// Return true if the PBPhys 'that' is the same as PBPhys 'tho'
bool PBPhysIsSame(PBPhys* that, PBPhys* tho);

// Set the delta t of the PBPhys 'that' to 'deltaT'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetDeltaT(PBPhys* that, float deltaT);

// Set the current time of the PBPhys 'that' to 't'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetCurTime(PBPhys* that, float t);

// Set the downward gravity of the PBPhys 'that' to 'gravity'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetDownGravity(PBPhys* that, float gravity);

// Set the gravity coefficient between particles of the PBPhys 'that'
// to 'gravity'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetGravity(PBPhys* that, float gravity);

// Step the PBPhys 'that' by that->_deltaT ignoring collision
void PBPhysNext(PBPhys* that);

// Step the PBPhys 'that' by that->_deltaT managing collision(s)
void PBPhysStep(PBPhys* that);

// Step the PBPhys 'that' by that->_deltaT or until a collision occured
// If no collision occured return NULL
// If a collision occured one can check the collision time with the
// current time that->_curTime, and the returned GSet contains the
// particles wich have collided
GSetPBPhysParticle* PBPhysStepToCollision(PBPhys* that);

// Return the 'iParticle'-th particle of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
PBPhysParticle* PBPhysPart(PBPhys* that, int iParticle);

// Get the number of particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysGetNbParticle(PBPhys* that);

// Add 'nb' particles of shape 'shape' into the PBPhys 'that'
```

```
#if BUILDMODE != 0
inline
#endif
void PBPhysAddParticles(PBPhys* that, int nb, ShapoidType shape);

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

#define PBPhysParticleSetAccel(Particle, Accel) _Generic(Accel, \
  VecFloat*: _PBPhysParticleSetAccel, \
  VecFloat2D*: _PBPhysParticleSetAccel, \
  VecFloat3D*: _PBPhysParticleSetAccel, \
  default: PBErrInvalidPolymorphism)(Particle, (VecFloat*)(Accel))

#define PBPhysParticleSetSpeed(Particle, Speed) _Generic(Speed, \
  VecFloat*: _PBPhysParticleSetSpeed, \
  VecFloat2D*: _PBPhysParticleSetSpeed, \
  VecFloat3D*: _PBPhysParticleSetSpeed, \
  default: PBErrInvalidPolymorphism)(Particle, (VecFloat*)(Speed))

#define PBPhysParticleSetPos(Particle, Pos) _Generic(Pos, \
  VecFloat*: _PBPhysParticleSetPos, \
  VecFloat2D*: _PBPhysParticleSetPos, \
  VecFloat3D*: _PBPhysParticleSetPos, \
  default: PBErrInvalidPolymorphism)(Particle, (VecFloat*)(Pos))

#define PBPhysParticleSetSize(Particle, Size) _Generic(Size, \
  VecFloat*: _PBPhysParticleSetSizeVec, \
  float: _PBPhysParticleSetSizeScalar, \
  default: PBErrInvalidPolymorphism)(Particle, Size)

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

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


#endif
```

3 Code

3.1 pbphys.c

```
// ============ PBPHYS.C ================

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

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

// ------------ PBPhysParticle

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

// Return the displacement of the particle from current position to
// the position after dt
```

```
VecFloat* PBPhysParticleGetNextDisplacement(PBPhysParticle* that,
  float dt);

// Return the coefficients of the polynom describing the square of the
// distance between two lines passing through 'posA' and 'posB' and
// colinear to 'dirA' and 'dirB' respectively
// Return a vector such as dist^2(t)=v[0]+v[1]t+v[2]t^2
VecFloat3D PBPhysGetDistPoly(VecFloat* posA, VecFloat* dirA,
  VecFloat* posB, VecFloat* dirB);

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

// Create a new PBPhysParticle with dimension 'dim' and a 'shapeType'
// shapoid as shape
// Default values: _mass = 0.0, _drag = 0.0, _fixed = false
PBPhysParticle* PBPhysParticleCreate(int dim, ShapoidType shapeType) {
#if BUILDMODE == 0
  if (dim <= 0) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "'dim' is invalid (0<%d)", dim);
    PBErrCatch(PBPhysErr);
  }
#endif
  // Allocate memory
  PBPhysParticle *that = PBErrMalloc(PBPhysErr, sizeof(PBPhysParticle));
  // Set properties
  that->_shape = ShapoidCreate(dim, shapeType);
  that->_speed = VecFloatCreate(dim);
  that->_accel = VecFloatCreate(dim);
  that->_sysAccel = VecFloatCreate(dim);
  that->_mass = 0.0;
  that->_drag = 0.0;
  that->_fixed = false;
  that->_data = NULL;
  // Return the new PBPhysParticle
  return that;
}

// Free the memory used by the particle 'that'
void PBPhysParticleFree(PBPhysParticle** that) {
  // Check arguments
  if (that == NULL || *that == NULL)
    // Nothing to do
    return;
  // Free memory
  ShapoidFree(&((*that)->_shape));
  VecFree(&((*that)->_speed));
  VecFree(&((*that)->_accel));
  VecFree(&((*that)->_sysAccel));
  free(*that);
  *that = NULL;
}

// Return a clone of the particle 'that'
PBPhysParticle* PBPhysParticleClone(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
```

```
  // Declare the clone
  PBPhysParticle* clone = PBPhysParticleCreate(
    PBPhysParticleGetDim(that), PBPhysParticleGetShapeType(that));
  // Copy properties
  PBPhysParticleSetSpeed(clone, PBPhysParticleSpeed(that));
  PBPhysParticleSetAccel(clone, PBPhysParticleAccel(that));
  PBPhysParticleSetMass(clone, PBPhysParticleGetMass(that));
  PBPhysParticleSetFixed(clone, PBPhysParticleIsFixed(that));
  PBPhysParticleSetDrag(clone,
    PBPhysParticleGetDrag(that));
  VecFloat* center = PBPhysParticleGetPos(that);
  PBPhysParticleSetPos(clone, center);
  VecFree(&center);
  // Return the clone
  return clone;
}

// Print the particle 'that' on the stream 'stream'
void PBPhysParticlePrintln(PBPhysParticle* that, FILE* stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  ShapoidPrintln(PBPhysParticleShape(that), stream);
  fprintf(stream, "speed: ");
  VecPrint(PBPhysParticleSpeed(that), stream);
  fprintf(stream, "\n");
  fprintf(stream, "accel: ");
  VecPrint(PBPhysParticleAccel(that), stream);
  fprintf(stream, "\n");
  fprintf(stream, "mass: %.3f\n", PBPhysParticleGetMass(that));
  fprintf(stream, "drag: %.3f\n",
    PBPhysParticleGetDrag(that));
  if (PBPhysParticleIsFixed(that))
    fprintf(stream, "fixed\n");
  else
    fprintf(stream, "unfixed\n");
}

// Function which return the JSON encoding of 'that'
JSONNode* PBPhysParticleEncodeAsJSON(PBPhysParticle* 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 dim
  sprintf(val, "%d", PBPhysParticleGetDim(that));
```

```
  JSONAddProp(json, "_dim", val);
  // Encode the type
  sprintf(val, "%d", PBPhysParticleGetShapeType(that));
  JSONAddProp(json, "_type", val);
  // Encode the shape
  JSONAddProp(json, "_shape",
    ShapoidEncodeAsJSON(PBPhysParticleShape(that)));
  // Encode the speed
  JSONAddProp(json, "_speed",
    VecEncodeAsJSON(PBPhysParticleSpeed(that)));
  // Encode the acceleration
  JSONAddProp(json, "_accel",
    VecEncodeAsJSON(PBPhysParticleAccel(that)));
  // Encode the mass
  sprintf(val, "%f", that->_mass);
  JSONAddProp(json, "_mass", val);
  // Encode the drag
  sprintf(val, "%f", that->_drag);
  JSONAddProp(json, "_drag", val);
  // Encode the fixed
  sprintf(val, "%d", that->_fixed);
  JSONAddProp(json, "_fixed", val);
  // Return the created JSON
  return json;
}

// Function which decode from JSON encoding 'json' to 'that'
bool PBPhysParticleDecodeAsJSON(PBPhysParticle** that, JSONNode* 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
    PBPhysParticleFree(that);
  // Get the dim from the JSON
  JSONNode* prop = JSONProperty(json, "_dim");
  if (prop == NULL) {
    return false;
  }
  int dim = atoi(JSONLabel(JSONValue(prop, 0)));
  // Get the type from the JSON
  prop = JSONProperty(json, "_type");
  if (prop == NULL) {
    return false;
  }
  int type = atoi(JSONLabel(JSONValue(prop, 0)));
  // If the data is invalid
  if (dim <= 0)
    return false;
  // Allocate memory
  *that = PBPhysParticleCreate(dim, type);
  // Decode the shape
```

```
  prop = JSONProperty(json, "_shape");
  if (prop == NULL) {
    return false;
  }
  if (!ShapoidDecodeAsJSON(&((*that)->_shape), prop)) {
    return false;
  }
  // Decode the speed
  prop = JSONProperty(json, "_speed");
  if (prop == NULL) {
    return false;
  }
  if (!VecDecodeAsJSON(&((*that)->_speed), prop)) {
    return false;
  }
  // Decode the accel
  prop = JSONProperty(json, "_accel");
  if (prop == NULL) {
    return false;
  }
  if (!VecDecodeAsJSON(&((*that)->_accel), prop)) {
    return false;
  }
  // Get the mass from the JSON
  prop = JSONProperty(json, "_mass");
  if (prop == NULL) {
    return false;
  }
  (*that)->_mass = atof(JSONLabel(JSONValue(prop, 0)));
  // Get the drag from the JSON
  prop = JSONProperty(json, "_drag");
  if (prop == NULL) {
    return false;
  }
  (*that)->_drag = atof(JSONLabel(JSONValue(prop, 0)));
  // Get the fixed from the JSON
  prop = JSONProperty(json, "_fixed");
  if (prop == NULL) {
    return false;
  }
  (*that)->_fixed = atoi(JSONLabel(JSONValue(prop, 0)));
  // Return the success code
  return true;
}

// Save the particle 'that' on the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if we could save the particle
// Return false else
// If user data is attached to the particle it must be saved by the user
bool PBPhysParticleSave(PBPhysParticle* that, FILE* stream,
  bool compact) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
```

```
    PBErrCatch(PBPhysErr);
  }
#endif
  // Get the JSON encoding
  JSONNode* json = PBPhysParticleEncodeAsJSON(that);
  // Save the JSON
  if (!JSONSave(json, stream, compact)) {
    return false;
  }
  // Free memory
  JSONFree(&json);
  // Return success code
  return true;
}

// Load the particle 'that' from the stream 'stream'
// Return true if we could load the particle
// Return false else
// If user data is attached to the particle it must be loaded by the user
bool PBPhysParticleLoad(PBPhysParticle** that, FILE* stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
    PBErrCatch(PBPhysErr);
  }
#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 (!PBPhysParticleDecodeAsJSON(that, json)) {
    return false;
  }
  // Free the memory used by the JSON
  JSONFree(&json);
  // Return the success code
  return true;
}

// Move the particle 'that' over a period of time 'dt'
// x(t+dt) = x(t) + v(t)*dt + 0.5*(a(t)-drag*v(t))*dt^2
// v(t+dt) = v(t) + (a(t)-drag*v(t))*dt
void PBPhysParticleMove(PBPhysParticle* that, float dt) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  if (!PBPhysParticleIsFixed(that)) {
    // Get the displacement
    VecFloat* disp = PBPhysParticleGetNextDisplacement(that, dt);
```

```
    // Update the position
    VecOp(ShapoidPos(PBPhysParticleShape(that)), 1.0, disp, 1.0);
    // Update the speed
    VecOp(PBPhysParticleSpeed(that), 1.0,
      PBPhysParticleSpeed(that), -dt * PBPhysParticleGetDrag(that));
    VecOp(PBPhysParticleSpeed(that), 1.0,
      PBPhysParticleAccel(that), dt);
    VecOp(PBPhysParticleSpeed(that), 1.0,
      PBPhysParticleSysAccel(that), dt);
    // Free memory
    VecFree(&disp);
  }
}

// Return the displacement of the particle from current position to
// the position after dt
VecFloat* PBPhysParticleGetNextDisplacement(PBPhysParticle* that,
  float dt) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  VecFloat* v = VecGetOp(PBPhysParticleAccel(that), 1.0,
    PBPhysParticleSpeed(that), -1.0 * PBPhysParticleGetDrag(that));
  VecOp(v, 1.0, PBPhysParticleSysAccel(that), 1.0);
  VecOp(v, 0.5 * fsquare(dt), PBPhysParticleSpeed(that), dt);
  return v;
}

// Correct the current speed of the two colliding particles 'that' and
// 'tho' under the hypothesis of elastic collision
// Particles' mass must not be null
void PBPhysParticleApplyElasticCollision(PBPhysParticle* that,
  PBPhysParticle* tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (tho == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'tho' is null");
    PBErrCatch(PBPhysErr);
  }
  if (fabs(PBPhysParticleGetMass(that)) < PBMATH_EPSILON) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "mass of 'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (fabs(PBPhysParticleGetMass(tho)) < PBMATH_EPSILON) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "mass of 'tho' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // Get the center of particles
  VecFloat* posA = PBPhysParticleGetPos(that);
  VecFloat* posB = PBPhysParticleGetPos(tho);
```

```
  // Get the difference in pos
  VecFloat* v = VecGetOp(posA, 1.0, posB, -1.0);
  // Get the difference in speed
  VecFloat* w = VecGetOp(PBPhysParticleSpeed(that), 1.0,
    PBPhysParticleSpeed(tho), -1.0);
  // Get the prod of differences
  float prod = VecDotProd(v, w);
  // Get the norm of difference in pos
  float norm = VecNorm(v);
  // Calculate a temporary value for following calculation
  float c = 2.0 * prod /
    ((PBPhysParticleGetMass(that) + PBPhysParticleGetMass(tho)) *
    fsquare(norm));
  // Update the speed of 'that' if it's not fixed
  if (!PBPhysParticleIsFixed(that))
    VecOp(PBPhysParticleSpeed(that), 1.0, v,
      -1.0 * c * PBPhysParticleGetMass(tho));
  // Update the speed of 'tho' if it's not fixed
  if (!PBPhysParticleIsFixed(tho))
    VecOp(PBPhysParticleSpeed(tho), 1.0, v,
      c * PBPhysParticleGetMass(that));
  // Free memory
  VecFree(&posA);
  VecFree(&posB);
  VecFree(&v);
  VecFree(&w);
}

// Return the coefficients of the polynom describing the square of the
// distance between particles 'that' and 'tho'
// Return a vector such as dist^2(t)=v[0]+v[1]t+v[2]t^2
VecFloat3D PBPhysParticleGetDistPoly(PBPhysParticle* that,
  PBPhysParticle* tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (tho == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'tho' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  VecFloat* posA = PBPhysParticleGetPos(that);
  VecFloat* posB = PBPhysParticleGetPos(tho);
  VecFloat3D ret = PBPhysGetDistPoly(posA, PBPhysParticleSpeed(that),
    posB, PBPhysParticleSpeed(tho));
  VecFree(&posA);
  VecFree(&posB);
  return ret;
}

// ------------ PBPhys

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

// Calculate the system acceleration of the particle 'part' in the
// PBPhys 'that'
void PBPhysUpdateSysAccel(PBPhys* that, PBPhysParticle* part);
```

```
// Return the time to collision between two particles of radius 'rA'
// and 'rB' and the polynom of the square distance between particles
// over time 'distPoly'
float PBPhysGetTimeToHit(float rA, float rB, VecFloat3D* distPoly);

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

// Create a new PBPhys for space dimension 'dim'
// Default values: _deltaT = 0.01, _downGravity = 0.0, _gravity = 0.0,
// _curTime = 0.0
PBPhys* PBPhysCreate(int dim) {
#if BUILDMODE == 0
  if (dim <= 0) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "'dim' is invalid (0<%d)", dim);
    PBErrCatch(PBPhysErr);
  }
#endif
  // Allocate memory
  PBPhys* that = PBErrMalloc(PBPhysErr, sizeof(PBPhys));
  // Set properties
  that->_dim = dim;
  that->_particles = GSetPBPhysParticleCreateStatic();
  that->_deltaT = PBPHYS_DELTAT;
  that->_downGravity = 0.0;
  that->_gravity = false;
  that->_curTime = 0.0;
  // Return the new PBPhys
  return that;
}

// Free memory used by the PBPhys 'that'
void PBPhysFree(PBPhys** that) {
  // Check argument
  if (that == NULL || *that == NULL)
    // Nothing to do
    return;
  // Free memory
  while (PBPhysGetNbParticle(*that) > 0) {
    PBPhysParticle* particle = GSetPop(PBPhysParticles(*that));
    PBPhysParticleFree(&particle);
  }
  free(*that);
  *that = NULL;
}

// Return a clone of the PBPhys 'that'
PBPhys* PBPhysClone(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // Declare the clone
  PBPhys* clone = PBPhysCreate(PBPhysGetDim(that));
  // Copy the properties
  PBPhysSetGravity(clone, PBPhysGetGravity(that));
  PBPhysSetCurTime(clone, PBPhysGetCurTime(that));
  PBPhysSetDeltaT(clone, PBPhysGetDeltaT(that));
  PBPhysSetDownGravity(clone, PBPhysGetDownGravity(that));
```

```
  // Copy the particles
  if (PBPhysGetNbParticle(that) > 0) {
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      PBPhysParticle* clonePart = PBPhysParticleClone(part);
      GSetAppend(PBPhysParticles(clone), clonePart);
    } while (GSetIterStep(&iter));
  }
  // Return the clone
  return clone;
}

// Print the PBPhys 'that' on the stream 'stream'
void PBPhysPrintln(PBPhys* that, FILE* stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  fprintf(stream, "dimension: %d\n", PBPhysGetDim(that));
  fprintf(stream, "t: %f\n", PBPhysGetCurTime(that));
  fprintf(stream, "dt: %f\n", PBPhysGetDeltaT(that));
  fprintf(stream, "down gravity: %f\n", PBPhysGetDownGravity(that));
  fprintf(stream, "gravity: %f\n", PBPhysGetGravity(that));
  fprintf(stream, "nb particles: %d\n", PBPhysGetNbParticle(that));
  if (PBPhysGetNbParticle(that) > 0) {
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    int iPart = 0;
    do {
      fprintf(stream, "particle #%d:\n", iPart);
      PBPhysParticle* part = GSetIterGet(&iter);
      PBPhysParticlePrintln(part, stream);
      ++iPart;
    } while (GSetIterStep(&iter));
  }
}

// Function which return the JSON encoding of 'that'
JSONNode* PBPhysEncodeAsJSON(PBPhys* 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 curTime
  sprintf(val, "%f", that->_curTime);
  JSONAddProp(json, "_curTime", val);
  // Encode the deltat
  sprintf(val, "%f", that->_deltaT);
  JSONAddProp(json, "_deltaT", val);
  // Encode the downGravity
  sprintf(val, "%f", that->_downGravity);
  JSONAddProp(json, "_downGravity", val);
  // Encode the gravity
  sprintf(val, "%f", that->_gravity);
  JSONAddProp(json, "_gravity", val);
  // Encode the nbParticle
  sprintf(val, "%d", PBPhysGetNbParticle(that));
  JSONAddProp(json, "_nbParticle", val);
  // Encode the particles
  // Declare an array of structures converted to string
  JSONArrayStruct setPart = JSONArrayStructCreateStatic();
  if (PBPhysGetNbParticle(that) > 0) {
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      JSONArrayStructAdd(&setPart,
        PBPhysParticleEncodeAsJSON(part));

    } while (GSetIterStep(&iter));
  }
  // Add a key with the array of structures
  JSONAddProp(json, "_particles", &setPart);
  // Free memory
  JSONArrayStructFlush(&setPart);
  // Return the created JSON
  return json;
}

// Function which decode from JSON encoding 'json' to 'that'
bool PBPhysDecodeAsJSON(PBPhys** that, JSONNode* 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
    PBPhysFree(that);
  // Decode the dimension
  JSONNode* prop = JSONProperty(json, "_dim");
  if (prop == NULL) {
    return false;
  }
  int dim = atoi(JSONLabel(JSONValue(prop, 0)));
  // If data is invalid
```

```
  if (dim <= 0)
    return false;
  // Allocate memory
  *that = PBPhysCreate(dim);
  // Decode the curTime
  prop = JSONProperty(json, "_curTime");
  if (prop == NULL) {
    return false;
  }
  (*that)->_curTime = atof(JSONLabel(JSONValue(prop, 0)));
  // Decode the deltaT
  prop = JSONProperty(json, "_deltaT");
  if (prop == NULL) {
    return false;
  }
  (*that)->_deltaT = atof(JSONLabel(JSONValue(prop, 0)));
  // Decode the downGravity
  prop = JSONProperty(json, "_downGravity");
  if (prop == NULL) {
    return false;
  }
  (*that)->_downGravity = atof(JSONLabel(JSONValue(prop, 0)));
  // Decode the gravity
  prop = JSONProperty(json, "_gravity");
  if (prop == NULL) {
    return false;
  }
  (*that)->_gravity = atof(JSONLabel(JSONValue(prop, 0)));
  // Decode the nbParticle
  prop = JSONProperty(json, "_nbParticle");
  if (prop == NULL) {
    return false;
  }
  int nbParticle = atoi(JSONLabel(JSONValue(prop, 0)));
  // Decode the particle
  prop = JSONProperty(json, "_particles");
  if (prop == NULL) {
    return false;
  }
  if (JSONGetNbValue(prop) != nbParticle) {
    return false;
  }
  for (int iPart = 0; iPart < nbParticle; ++iPart) {
    JSONNode* part = JSONValue(prop, iPart);
    PBPhysParticle* p = NULL;
    if (!PBPhysParticleDecodeAsJSON(&p, part))
      return false;
    GSetAppend(PBPhysParticles(*that), p);
  }
  // Return the success code
  return true;
}

// Save the PBPhys 'that' on the stream 'stream'
// If 'compact' equals true it saves in compact form, else it saves in
// readable form
// Return true if we could save the PBPhys
// Return false else
bool PBPhysSave(PBPhys* that, FILE* stream, bool compact) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // Get the JSON encoding
  JSONNode* json = PBPhysEncodeAsJSON(that);
  // Save the JSON
  if (!JSONSave(json, stream, compact)) {
    return false;
  }
  // Free memory
  JSONFree(&json);
  // Return success code
  return true;
}

// Load the PBPhys 'that' from the stream 'stream'
// Return true if we could load the PBPhys
// Return false else
bool PBPhysLoad(PBPhys** that, FILE* stream) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (stream == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'stream' is null");
    PBErrCatch(PBPhysErr);
  }
#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 (!PBPhysDecodeAsJSON(that, json)) {
    return false;
  }
  // Free the memory used by the JSON
  JSONFree(&json);
  // Return the success code
  return true;
}

// Step the PBPhys 'that' by that->_deltaT ignoring collision
void PBPhysNext(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
```

```
  // If there is particle
  if (PBPhysGetNbParticle(that) > 0) {
    // Loop on particles
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      // Calculate the system acceleration of the particle
      PBPhysUpdateSysAccel(that, part);
      // Move the particle
      PBPhysParticleMove(part, PBPhysGetDeltaT(that));
    } while (GSetIterStep(&iter));
  }
  // Update current time
  PBPhysSetCurTime(that, PBPhysGetCurTime(that) + PBPhysGetDeltaT(that));
}

// Calculate the system acceleration of the particle 'part' in the
// PBPhys 'that'
void PBPhysUpdateSysAccel(PBPhys* that, PBPhysParticle* particle) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (particle == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'particle' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // If the particle is fixed there is nothing to do
  if (PBPhysParticleIsFixed(particle))
    return;
  // Reset the system acceleration
  VecSetNull(PBPhysParticleSysAccel(particle));
  // If the down gravity is active
  if (fabs(PBPhysGetDownGravity(that)) > PBMATH_EPSILON) {
    // Substract the down gravity to the y axis of the system
    // acceleration
    VecSet(PBPhysParticleSysAccel(particle), 1,
      -1.0 * PBPhysGetDownGravity(that));
  }
  // If the gravity is active
  if (fabs(PBPhysGetGravity(that)) > PBMATH_EPSILON) {
    // Get the center pos of the particle
    VecFloat* centerParticle = PBPhysParticleGetPos(particle);
    // Loop on particles
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      // If the current particle is not the particle in argument
      if (particle != part) {
        // Get the distance between the two particles
        VecFloat* centerPart = PBPhysParticleGetPos(part);
        float dist = VecDist(centerParticle, centerPart);
        if (fabs(dist) > PBMATH_EPSILON) {
          // Get the magnitude of the attraction
          float mag = PBPhysGetGravity(that) *
            PBPhysParticleGetMass(particle) *
```

```
            PBPhysParticleGetMass(part) / fsquare(dist);
          // Apply the attraction toward the other particle
          VecOp(centerPart, 1.0, centerParticle, -1.0);
          VecNormalise(centerPart);
          VecOp(PBPhysParticleSysAccel(particle), 1.0, centerPart, mag);
        }
        // Free memory
        VecFree(&centerPart);
      }
    } while (GSetIterStep(&iter));
    // Free memory
    VecFree(&centerParticle);
  }
}

// Step the PBPhys 'that' by that->_deltaT managing collision(s)
void PBPhysStep(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // Declare a variable to memorize the goal time
  float goalT = PBPhysGetCurTime(that) + PBPhysGetDeltaT(that);
  // Declare a variable to memorize the initial deltat
  float origDeltaT = PBPhysGetDeltaT(that);
  // Loop until we reach the goal time
  while (PBPhysGetCurTime(that) < goalT) {
//printf("curt %f goalt %f\n", PBPhysGetCurTime(that), goalT);
    // Step until next collision
    GSetPBPhysParticle* set = PBPhysStepToCollision(that);
//printf("curt %f goalt %f\n", PBPhysGetCurTime(that), goalT);
    // If there has been collision
    if (set != NULL) {
//printf("hit\n");
      // Manage the collision
      PBPhysParticleApplyElasticCollision(
        GSetGet(set, 0), GSetGet(set, 1));
      // Correct the deltat to reach the initial goal time
      PBPhysSetDeltaT(that, goalT - PBPhysGetCurTime(that));
//printf("deltat %f\n", PBPhysGetDeltaT(that));
      // Free the set
      GSetFree(&set);
    }
  }
  // Reset the initial deltat
  PBPhysSetDeltaT(that, origDeltaT);
}

// Step the PBPhys 'that' for that->_deltaT or until a collision occured
// If no collision occured return NULL
// If a collision occured one can check the collision time with the
// current time that->_curTime, and the returned GSet contains the
// particles wich have collided
GSetPBPhysParticle* PBPhysStepToCollision(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
```

```
  }
#endif
  // Declare a variable to memorize the deltat until next collision
  float deltat = PBPhysGetDeltaT(that);
  // Declare a set to memorize the colliding particle
  GSetPBPhysParticle* setCollision = GSetPBPhysParticleCreate();
  // If there is particle
  if (PBPhysGetNbParticle(that) > 0) {
    // Loop on particles
    GSetIterForward iter =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      // Calculate the system acceleration of the particle
      PBPhysUpdateSysAccel(that, part);
    } while (GSetIterStep(&iter));
    // If there is at least two particles
    if (PBPhysGetNbParticle(that) > 1) {
      // Declare a variabe to memorize the inverse of deltat
      float invDeltaT = 1.0 / PBPhysGetDeltaT(that);
      // Loop on particles once again from the beginning
      GSetIterReset(&iter);
      do {
        PBPhysParticle* part = GSetIterGet(&iter);
        // Get the pos of the center of the particle
        VecFloat* posPart = PBPhysParticleGetPos(part);
        // Get the displacement vector for the current particle
        VecFloat* vPart = PBPhysParticleGetNextDisplacement(part,
          PBPhysGetDeltaT(that));
        // Scale to have the displacement per time unit
        VecScale(vPart, invDeltaT);
        // Get the bounding radius of the particle
        float radPart =
          ShapoidGetBoundingRadius(PBPhysParticleShape(part));
        // Create a new iterator to loop through following particles
        GSetIterForward iterPair = iter;
        GSetIterStep(&iterPair);
        do {
          PBPhysParticle* pair = GSetIterGet(&iterPair);
          // Get the pos of the center of the particle
          VecFloat* posPair = PBPhysParticleGetPos(pair);
          // Get the displacement vector for the current pair
          VecFloat* vPair = PBPhysParticleGetNextDisplacement(pair,
            PBPhysGetDeltaT(that));
          // Scale to have the displacement per time unit
          VecScale(vPair, invDeltaT);
          // Get the bounding radius of the pair
          float radPair =
            ShapoidGetBoundingRadius(PBPhysParticleShape(pair));
          // Check the pair trajectory to determine at what time they
          // are at the closest and what is this closest distance
          VecFloat3D distPoly = PBPhysGetDistPoly(posPart, vPart,
            posPair, vPair);
          float tNearest = deltat;
          if (fabs(VecGet(&distPoly, 2)) > PBMATH_EPSILON)
            tNearest = -0.5 * VecGet(&distPoly, 1) /
              VecGet(&distPoly, 2);
          float distNearest = sqrt(VecGet(&distPoly, 0) +
            tNearest * VecGet(&distPoly, 1) +
            fsquare(tNearest) * VecGet(&distPoly, 2));
          // If there is an impact in future
          if (tNearest > 0.0 && distNearest < radPart + radPair) {
```

```
            // Get the exact time at which particles hit
            float tHit = PBPhysGetTimeToHit(radPart, radPair, &distPoly);
            // If the time at hit is sooner than current delta
            if (tHit < deltat) {
              // Remove the eventual previous colliding particles
              GSetFlush(setCollision);
              // Add the colliding particles
              GSetAppend(setCollision, part);
              GSetAppend(setCollision, pair);
              // Update the time at hit
              deltat = tHit;
            }
          }
          // Free memory
          VecFree(&vPair);
          VecFree(&posPair);
        } while (GSetIterStep(&iterPair));
        // Free memory
        VecFree(&posPart);
        VecFree(&vPart);
      } while (GSetIterStep(&iter) && !GSetIterIsLast(&iter));
    }
    // Move the particles
    GSetIterReset(&iter);
    do {
      PBPhysParticle* part = GSetIterGet(&iter);
      // Move the particle
      PBPhysParticleMove(part, deltat);
    } while (GSetIterStep(&iter));
  }
  // Update current time
  PBPhysSetCurTime(that, PBPhysGetCurTime(that) + deltat);
  // If the set of collision is empty free it
  if (GSetNbElem(setCollision) == 0)
    GSetFree(&setCollision);
  // Return the set of colliding particles
  return setCollision;
}

// Return the time to collision between two particles of radius 'rA'
// and 'rB' and the polynom of the square distance between particles
// over time 'distPoly'
float PBPhysGetTimeToHit(float rA, float rB, VecFloat3D* distPoly) {
  float dist = fsquare(rA + rB);
  float tHit = (-1.0 * VecGet(distPoly, 1) -
    sqrt(fsquare(VecGet(distPoly, 1)) - 4.0 * VecGet(distPoly, 2) *
    (VecGet(distPoly, 0) - dist))) / (2.0 * VecGet(distPoly, 2));
  return tHit;
}

// Return the coefficients of the polynom describing the square of the
// distance between two lines passing through 'posA' and 'posB' and
// colinear to 'dirA' and 'dirB' respectively
// Return a vector such as dist^2(t)=v[0]+v[1]t+v[2]t^2
VecFloat3D PBPhysGetDistPoly(VecFloat* posA, VecFloat* dirA,
  VecFloat* posB, VecFloat* dirB) {
#if BUILDMODE == 0
  if (posA == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'posA' is null");
    PBErrCatch(PBPhysErr);
  }
```

```
  if (posB == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'posB' is null");
    PBErrCatch(PBPhysErr);
  }
  if (dirA == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'dirA' is null");
    PBErrCatch(PBPhysErr);
  }
  if (dirB == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'dirB' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  // Declare the vector result
  VecFloat3D res = VecFloatCreateStatic3D();
  // Loop on dimensions
  for (int iDim = VecGetDim(posA); iDim--;) {
    VecSetAdd(&res, 0,
      fsquare(VecGet(posA, iDim) - VecGet(posB, iDim)));
    VecSetAdd(&res, 1,
      (VecGet(posA, iDim) - VecGet(posB, iDim)) *
      (VecGet(dirA, iDim) - VecGet(dirB, iDim)));
    VecSetAdd(&res, 2,
      fsquare(VecGet(dirA, iDim) - VecGet(dirB, iDim)));
  }
  VecSet(&res, 1, VecGet(&res, 1) * 2.0);
  // Return the result
  return res;
}

// Return true if the PBPhys 'that' is the same as PBPhys 'tho'
bool PBPhysIsSame(PBPhys* that, PBPhys* tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  if (that->_dim != tho->_dim ||
    !ISEQUALF(that->_deltaT, tho->_deltaT) ||
    !ISEQUALF(that->_curTime, tho->_curTime) ||
    !ISEQUALF(that->_downGravity, tho->_downGravity) ||
    that->_gravity != tho->_gravity ||
    PBPhysGetNbParticle(that) != PBPhysGetNbParticle(tho))
    return false;
  if (PBPhysGetNbParticle(that) > 0) {
    GSetIterForward iterA =
      GSetIterForwardCreateStatic(PBPhysParticles(that));
    GSetIterForward iterB =
      GSetIterForwardCreateStatic(PBPhysParticles(tho));
    do {
      PBPhysParticle* partA = GSetIterGet(&iterA);
      PBPhysParticle* partB = GSetIterGet(&iterB);
      if (!PBPhysParticleIsSame(partA, partB))
        return false;
    } while (GSetIterStep(&iterA) && GSetIterStep(&iterB));
  }
  return true;
```

```
}
```

3.2 pbphys-inline.c

```
// ============ PBPHYS-INLINE.C ================

// ------------ PBPhysParticle

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

// Return the dimension of the particle 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysParticleGetDim(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return ShapoidGetDim(that->_shape);
}

// Return the shape type of the particle 'that'
#if BUILDMODE != 0
inline
#endif
ShapoidType PBPhysParticleGetShapeType(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return ShapoidGetType(that->_shape);
}

// Return the shape of the particle 'that'
#if BUILDMODE != 0
inline
#endif
Shapoid* PBPhysParticleShape(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_shape;
}

// Return the 'iAxis'-th axis of the shape of the particle 'that'
#if BUILDMODE != 0
inline
#endif
```

```
VecFloat* PBPhysParticleAxis(PBPhysParticle* that, int iAxis) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (iAxis < 0 || iAxis >= PBPhysParticleGetDim(that)) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "'iAxis' is invalid (0<=%d<%d)",
      iAxis, PBPhysParticleGetDim(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  return ShapoidAxis(PBPhysParticleShape(that), iAxis);
}

// Return the speed of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleSpeed(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_speed;
}

// Return the acceleration of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleAccel(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_accel;
}

// Return the sysAccel of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleSysAccel(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_sysAccel;
}
```

```
// Return the position of the center of the particle 'that'
#if BUILDMODE != 0
inline
#endif
VecFloat* PBPhysParticleGetPos(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return ShapoidGetCenter(that->_shape);
}

// Set the speed of the particle 'that' to 'speed'
// If the particle is fixed do nothing
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSpeed(PBPhysParticle* that, VecFloat* speed) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (speed == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'speed' is null");
    PBErrCatch(PBPhysErr);
  }
  if (VecGetDim(speed) != PBPhysParticleGetDim(that)) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'speed' 's dimension is invalid (%d=%d)",
      VecGetDim(speed), PBPhysParticleGetDim(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  if (!PBPhysParticleIsFixed(that))
    VecCopy(that->_speed, speed);
}

// Set the acceleration of the particle 'that' to 'accel'
// If the particle is fixed do nothing
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetAccel(PBPhysParticle* that, VecFloat* accel) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (accel == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'accel' is null");
    PBErrCatch(PBPhysErr);
  }
  if (VecGetDim(accel) != PBPhysParticleGetDim(that)) {
    PBPhysErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(PBPhysErr->_msg, "'accel' 's dimension is invalid (%d=%d)",
      VecGetDim(accel), PBPhysParticleGetDim(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  if (!PBPhysParticleIsFixed(that))
    VecCopy(that->_accel, accel);
}

// Set the position of the center of the particle 'that' to 'pos'
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetPos(PBPhysParticle* that, VecFloat* pos) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (pos == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'pos' is null");
    PBErrCatch(PBPhysErr);
  }
  if (VecGetDim(pos) != PBPhysParticleGetDim(that)) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'pos' 's dimension is invalid (%d=%d)",
      VecGetDim(pos), PBPhysParticleGetDim(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  ShapoidSetCenterPos(PBPhysParticleShape(that), pos);
}

// Return true if the particle 'that' is the same is the particle 'tho'
// Return false else
// User data is not compared
#if BUILDMODE != 0
inline
#endif
bool PBPhysParticleIsSame(PBPhysParticle* that, PBPhysParticle* tho) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (tho == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'tho' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  if (!ShapoidIsEqual(PBPhysParticleShape(that),
    PBPhysParticleShape(tho)) ||
    !VecIsEqual(PBPhysParticleSpeed(that), PBPhysParticleSpeed(tho)) ||
    !VecIsEqual(PBPhysParticleAccel(that), PBPhysParticleAccel(tho)) ||
    !ISEQUALF(PBPhysParticleGetMass(that), PBPhysParticleGetMass(tho)) ||
    PBPhysParticleIsFixed(that) != PBPhysParticleIsFixed(tho))
    return false;
  return true;
```

```
}

// Set the shape size of the particle 'that' to 'size'
#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSizeVec(PBPhysParticle* that, VecFloat* size) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (size == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'size' is null");
    PBErrCatch(PBPhysErr);
  }
  if (VecGetDim(size) != PBPhysParticleGetDim(that)) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'size' 's dimension is invalid (%d=%d)",
      VecGetDim(size), PBPhysParticleGetDim(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  for (int iAxis = PBPhysParticleGetDim(that); iAxis--;) {
    VecFloat* axis = ShapoidAxis(PBPhysParticleShape(that), iAxis);
    VecScale(axis, VecGet(size, iAxis) / VecNorm(axis));
  }
}

#if BUILDMODE != 0
inline
#endif
void _PBPhysParticleSetSizeScalar(PBPhysParticle* that, float size) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  for (int iAxis = PBPhysParticleGetDim(that); iAxis--;) {
    VecFloat* axis = ShapoidAxis(PBPhysParticleShape(that), iAxis);
    VecScale(axis, size / VecNorm(axis));
  }
}

// Return the mass of the particle 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysParticleGetMass(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_mass;
}
```

```
// Set the mass of the particle 'that' to 'mass'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetMass(PBPhysParticle* that, float mass) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_mass = mass;
}

// Return the drag of the particle 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysParticleGetDrag(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_drag;
}

// Set the drag of the particle 'that' to 'drag'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetDrag(PBPhysParticle* that, float drag) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_drag = drag;
}

// Return true if the particle 'that' is fixed
// Return false else
#if BUILDMODE != 0
inline
#endif
bool PBPhysParticleIsFixed(PBPhysParticle* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_fixed;
}
```

```
// Set the fixed flag of the particle 'that' to 'fixed'
#if BUILDMODE != 0
inline
#endif
void PBPhysParticleSetFixed(PBPhysParticle* that, bool fixed) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_fixed = fixed;
  if (fixed) {
    VecSetNull(that->_speed);
    VecSetNull(that->_accel);
  }
}

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

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

// ------------ PBPhys

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

// Return the space dimension of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysGetDim(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
```

```
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_dim;
}

// Return the set of particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
GSetPBPhysParticle* PBPhysParticles(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return &(that->_particles);
}

// Return the delta t of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetDeltaT(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_deltaT;
}

// Return the current time of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetCurTime(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_curTime;
}

// Return the downward gravity of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetDownGravity(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
```

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

// Return the gravity coefficient between particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
float PBPhysGetGravity(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return that->_gravity;
}

// Set the delta t of the PBPhys 'that' to 'deltaT'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetDeltaT(PBPhys* that, float deltaT) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_deltaT = deltaT;
}

// Set the current time of the PBPhys 'that' to 't'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetCurTime(PBPhys* that, float t) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_curTime = t;
}

// Set the downward gravity of the PBPhys 'that' to 'gravity'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetDownGravity(PBPhys* that, float gravity) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_downGravity = gravity;
```

```
}

// Set the gravity coefficient between particles of the PBPhys 'that'
// to 'gravity'
#if BUILDMODE != 0
inline
#endif
void PBPhysSetGravity(PBPhys* that, float gravity) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  that->_gravity = gravity;
}

// Return the 'iParticle'-th particle of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
PBPhysParticle* PBPhysPart(PBPhys* that, int iParticle) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (iParticle < 0 || iParticle >= PBPhysGetNbParticle(that)) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "'iParticle' is invalid (0<=%d<%d)",
      iParticle, PBPhysGetNbParticle(that));
    PBErrCatch(PBPhysErr);
  }
#endif
  return GSetGet(&(that->_particles), iParticle);
}

// Get the number of particles of the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
int PBPhysGetNbParticle(PBPhys* that) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
#endif
  return GSetNbElem(&(that->_particles));
}

// Add 'nb' particles of shape 'shape' into the PBPhys 'that'
#if BUILDMODE != 0
inline
#endif
void PBPhysAddParticles(PBPhys* that, int nb, ShapoidType shape) {
#if BUILDMODE == 0
  if (that == NULL) {
    PBPhysErr->_type = PBErrTypeNullPointer;
```

```
    sprintf(PBPhysErr->_msg, "'that' is null");
    PBErrCatch(PBPhysErr);
  }
  if (nb <= 0) {
    PBPhysErr->_type = PBErrTypeInvalidArg;
    sprintf(PBPhysErr->_msg, "'nb' is invalid (0<%d)", nb);
    PBErrCatch(PBPhysErr);
  }
#endif
  for (int iParticle = nb; iParticle--;) {
    PBPhysParticle* particle =
      PBPhysParticleCreate(PBPhysGetDim(that), shape);
    GSetAppend(&(that->_particles), particle);
  }
}
```

4 Makefile

```
#directory
PBERRDIR=../PBErr
SHAPOIDDIR=../Shapoid
PBMATHDIR=../PBMath
GSETDIR=../GSet
GTREEDIR=../GTree
PBJSONDIR=../PBJson

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

include $(PBERRDIR)/Makefile.inc

INCPATH=-I./ -I$(PBERRDIR)/ -I$(PBMATHDIR)/ -I$(GSETDIR)/ -I$(SHAPOIDDIR)/ -I$(PBJSONDIR)/ -I$(GTREEDIR)/
BUILDOPTIONS=$(BUILDPARAM) $(INCPATH)

# compiler
COMPILER=gcc

#rules
all : main

main: main.o pberr.o pbphys.o shapoid.o pbmath.o gset.o pbjson.o gtree.o Makefile
$(COMPILER) main.o pberr.o shapoid.o pbmath.o gset.o pbphys.o pbjson.o gtree.o $(LINKOPTIONS) -o main

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

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

pbjson.o : $(PBJSONDIR)/pbjson.c $(PBJSONDIR)/pbjson-inline.c $(PBJSONDIR)/pbjson.h Makefile
$(COMPILER) $(BUILDOPTIONS) -c $(PBJSONDIR)/pbjson.c

gtree.o : $(GTREEDIR)/gtree.c $(GTREEDIR)/gtree.h $(GTREEDIR)/gtree-inline.c Makefile $(GSETDIR)/gset-inline.c $(GSE
$(COMPILER) $(BUILDOPTIONS) -c $(GTREEDIR)/gtree.c

pberr.o : $(PBERRDIR)/pberr.c $(PBERRDIR)/pberr.h Makefile
```

```
$(COMPILER) $(BUILDOPTIONS) -c $(PBERRDIR)/pberr.c

shapoid.o : $(SHAPOIDDIR)/shapoid.c $(SHAPOIDDIR)/shapoid.h $(SHAPOIDDIR)/shapoid-inline.c $(PBMATHDIR)/pbmath.h $(PB
$(COMPILER) $(BUILDOPTIONS) -c $(SHAPOIDDIR)/shapoid.c

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

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

clean :
rm -rf *.o main

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

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

5 Unit tests

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

#define RANDOMSEED 0

void UnitTestPBPhysParticleCreateFreePrint() {
  PBPhysParticle* particle = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  if (particle == NULL ||
    particle->_shape == NULL ||
    particle->_speed == NULL ||
    particle->_accel == NULL ||
    particle->_fixed == true ||
    ISEQUALF(particle->_mass, 0.0) == false ||
    ISEQUALF(particle->_drag, 0.0) == false ||
    VecGetDim(particle->_speed) != 2 ||
    VecGetDim(particle->_accel) != 2 ||
    ShapoidGetDim(particle->_shape) != 2 ||
    ShapoidGetType(particle->_shape) != ShapoidTypeSpheroid) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleCreate failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysParticlePrintln(particle, stdout);
  PBPhysParticleFree(&particle);
  if (particle != NULL) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleFree failed");
    PBErrCatch(PBPhysErr);
  }
```

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

void UnitTestPBPhysParticleGetSet() {
  int dim = 2;
  ShapoidType type = ShapoidTypeSpheroid;
  PBPhysParticle* particle = PBPhysParticleCreate(dim, type);
  if (PBPhysParticleGetDim(particle) != dim) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleGetDim failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticleGetShapeType(particle) != type) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleGetShapeType failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticleShape(particle) != particle->_shape) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleShape failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticleSpeed(particle) != particle->_speed) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSpeed failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticleAccel(particle) != particle->_accel) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleAccel failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticleIsFixed(particle) != particle->_fixed) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleIsFixed failed");
    PBErrCatch(PBPhysErr);
  }
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 2.0); VecSet(&v, 1, 3.0);
  PBPhysParticleSetSpeed(particle, &v);
  if (VecIsEqual(PBPhysParticleSpeed(particle), &v) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetSpeed failed");
    PBErrCatch(PBPhysErr);
  }
  VecSet(&v, 0, 4.0); VecSet(&v, 1, 5.0);
  PBPhysParticleSetPos(particle, &v);
  VecFloat* pos = PBPhysParticleGetPos(particle);
  if (VecIsEqual(pos, &v) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetPos failed");
    PBErrCatch(PBPhysErr);
  }
  VecFree(&pos);
  VecSet(&v, 0, 6.0); VecSet(&v, 1, 7.0);
  PBPhysParticleSetAccel(particle, &v);
  if (VecIsEqual(PBPhysParticleAccel(particle), &v) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetAccel failed");
    PBErrCatch(PBPhysErr);
  }
  for (int iAxis = dim; iAxis--;)
```

```
  if (PBPhysParticleAxis(particle, iAxis) !=
    ShapoidAxis(PBPhysParticleShape(particle), iAxis)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleAxis failed");
    PBErrCatch(PBPhysErr);
  }
PBPhysParticleSetSize(particle, (VecFloat*)&v);
for (int iAxis = dim; iAxis--;)
  if (!ISEQUALF(VecNorm(PBPhysParticleAxis(particle, iAxis)),
    VecGet(&v, iAxis))) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetSize failed");
    PBErrCatch(PBPhysErr);
  }
float size = 0.5;
PBPhysParticleSetSize(particle, size);
for (int iAxis = dim; iAxis--;)
  if (!ISEQUALF(VecNorm(PBPhysParticleAxis(particle, iAxis)), size)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetSize failed");
    PBErrCatch(PBPhysErr);
  }
float mass = 0.1;
PBPhysParticleSetMass(particle, mass);
if (!ISEQUALF(particle->_mass, mass)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleSetMass failed");
  PBErrCatch(PBPhysErr);
}
if (!ISEQUALF(PBPhysParticleGetMass(particle), mass)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleGetMass failed");
  PBErrCatch(PBPhysErr);
}
float drag = 0.2;
PBPhysParticleSetDrag(particle, drag);
if (!ISEQUALF(particle->_drag, drag)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleSetDrag failed");
  PBErrCatch(PBPhysErr);
}
if (!ISEQUALF(PBPhysParticleGetDrag(particle), drag)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleGetDrag failed");
  PBErrCatch(PBPhysErr);
}
PBPhysParticleSetFixed(particle, true);
if (PBPhysParticleIsFixed(particle) != true) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleSetFixed failed");
  PBErrCatch(PBPhysErr);
}
char data[2];
particle->_data = data;
if (PBPhysParticleData(particle) != data) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysParticleData failed");
  PBErrCatch(PBPhysErr);
}
PBPhysParticleSetData(particle, data + 1);
if (PBPhysParticleData(particle) != data + 1) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(PBPhysErr->_msg, "PBPhysParticleSetData failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysParticleFree(&particle);
  printf("UnitTestPBPhysParticleGetSet OK\n");
}

void UnitTestPBPhysParticleCloneIsSame() {
  PBPhysParticle* particle = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 2.0); VecSet(&v, 1, 3.0);
  PBPhysParticleSetPos(particle, &v);
  VecFloat2D w = VecFloatCreateStatic2D();
  VecSet(&w, 0, 4.0); VecSet(&w, 1, 5.0);
  PBPhysParticleSetSpeed(particle, &w);
  VecSet(&w, 0, 6.0); VecSet(&w, 1, 7.0);
  PBPhysParticleSetAccel(particle, &w);
  PBPhysParticle* clone = PBPhysParticleClone(particle);
  if (PBPhysParticleIsSame(clone, particle) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleClone failed");
    PBErrCatch(PBPhysErr);
  }
  VecSet(&w, 0, 1.0); VecSet(&w, 1, 5.0);
  PBPhysParticleSetSpeed(particle, &w);
  if (PBPhysParticleIsSame(clone, particle) == true) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleIsSame failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysParticleFree(&particle);
  PBPhysParticleFree(&clone);
  printf("UnitTestPBPhysParticleCloneIsSame OK\n");
}

void UnitTestPBPhysParticleLoadSave() {
  PBPhysParticle* particle = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 2.0); VecSet(&v, 1, 3.0);
  PBPhysParticleSetPos(particle, &v);
  VecFloat2D w = VecFloatCreateStatic2D();
  VecSet(&w, 0, 4.0); VecSet(&w, 1, 5.0);
  PBPhysParticleSetSpeed(particle, &w);
  VecSet(&w, 0, 6.0); VecSet(&w, 1, 7.0);
  PBPhysParticleSetAccel(particle, &w);
  PBPhysParticleSetMass(particle, 8.0);
  FILE* fd = fopen("./particle.txt", "w");
  if (PBPhysParticleSave(particle, fd, false) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleSave failed");
    PBErrCatch(PBPhysErr);
  }
  fclose(fd);
  fd = fopen("./particle.txt", "r");
  PBPhysParticle* loaded = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  if (PBPhysParticleLoad(&loaded, fd) == false ||
    PBPhysParticleIsSame(loaded, particle) == false) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticleLoad failed");
```

```
    PBErrCatch(PBPhysErr);
  }
  fclose(fd);
  PBPhysParticleFree(&loaded);
  PBPhysParticleFree(&particle);
  printf("UnitTestPBPhysParticleLoadSave OK\n");
}

void UnitTestPBPhysParticleAccelMove() {
  PBPhysParticle* particle = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 1.0); VecSet(&v, 1, -0.5);
  PBPhysParticleSetAccel(particle, &v);
  float dt = 0.1;
  float checkA[20] = {
    0.005000,-0.002500,0.020000,-0.010000,0.045000,-0.022500,0.080000,
    -0.040000,0.125000,-0.062500,0.180000,-0.090000,0.245000,-0.122500,
    0.320000,-0.160000,0.405000,-0.202500,0.500000,-0.250000};
  VecFloat* pos = ShapoidPos(PBPhysParticleShape(particle));
  for (int i = 0; i < 10; ++i) {
    PBPhysParticleMove(particle, dt);
    if (ISEQUALF(VecGet(PBPhysParticleSpeed(particle), 0),
      (float)(i + 1) * dt) == false ||
      ISEQUALF(VecGet(PBPhysParticleSpeed(particle), 1),
      (float)(i + 1) * dt * -0.5) == false) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysParticleMove failed");
      PBErrCatch(PBPhysErr);
    }
    if (ISEQUALF(VecGet(pos, 0), checkA[2 * i]) == false ||
      ISEQUALF(VecGet(pos, 1), checkA[2 * i + 1]) == false) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysParticleMove failed");
      PBErrCatch(PBPhysErr);
    }
  }
  float drag = 0.1;
  PBPhysParticleSetDrag(particle, drag);
  VecSetNull(pos);
  VecSetNull(PBPhysParticleSpeed(particle));
  float checkC[20] = {
    0.100000,-0.050000,0.199000,-0.099500,0.297010,-0.148505,0.394040,
    -0.197020,0.490099,-0.245050,0.585199,-0.292599,0.679347,-0.339673,
    0.772553,-0.386277,0.864828,-0.432414,0.956179,-0.478090};
  float checkD[20] = {
    0.005000,-0.002500,0.019950,-0.009975,0.044751,-0.022375,0.079303,
    -0.039651,0.123510,-0.061755,0.177275,-0.088637,0.240502,-0.120251,
    0.313097,-0.156549,0.394966,-0.197483,0.486017,-0.243008};
  for (int i = 0; i < 10; ++i) {
    PBPhysParticleMove(particle, dt);
    if (ISEQUALF(VecGet(PBPhysParticleSpeed(particle), 0),
      checkC[2 * i]) == false ||
      ISEQUALF(VecGet(PBPhysParticleSpeed(particle), 1),
      checkC[2 * i + 1]) == false) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysParticleMove failed");
      PBErrCatch(PBPhysErr);
    }
    if (ISEQUALF(VecGet(pos, 0), checkD[2 * i]) == false ||
      ISEQUALF(VecGet(pos, 1), checkD[2 * i + 1]) == false) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
```

```
      sprintf(PBPhysErr->_msg, "PBPhysParticleMove failed");
      PBErrCatch(PBPhysErr);
    }
  }
  PBPhysParticleFree(&particle);
  printf("UnitTestPBPhysParticleAccelMove OK\n");
}

void UnitTestPBPhysParticleTestTrajectory() {
  PBPhysParticle* am = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  PBPhysParticle* amd = PBPhysParticleCreate(2,
    ShapoidTypeSpheroid);
  VecFloat2D accel = VecFloatCreateStatic2D();
  VecSet(&accel, 0, 4.0); VecSet(&accel, 1, 4.0);
  PBPhysParticleSetSpeed(am, &accel);
  PBPhysParticleSetSpeed(amd, &accel);
  VecSet(&accel, 0, 0.0); VecSet(&accel, 1, -1.0 * PBPHYS_Gn);
  PBPhysParticleSetAccel(am, &accel);
  PBPhysParticleSetAccel(amd, &accel);
  float drag = 0.2;
  PBPhysParticleSetDrag(amd, drag);
  float dt = 0.01;
  float t = 0.0;
  FILE* fd = fopen("./traj.txt", "w");
  VecFloat* posam = ShapoidPos(PBPhysParticleShape(am));
  VecFloat* posamd = ShapoidPos(PBPhysParticleShape(amd));
  for (int i = 0; i < 100; ++i) {
    PBPhysParticleMove(am, dt);
    PBPhysParticleMove(amd, dt);
    t += dt;
    fprintf(fd, "%f %f %f %f %f\n", t,
      VecGet(posam, 0), VecGet(posam, 1),
      VecGet(posamd, 0), VecGet(posamd, 1));
  }
  fclose(fd);
  PBPhysParticleFree(&am);
  PBPhysParticleFree(&amd);
  printf("UnitTestPBPhysParticleTestTrajectory OK\n");
}

void UnitTestPBPhysParticle() {
  UnitTestPBPhysParticleCreateFreePrint();
  UnitTestPBPhysParticleGetSet();
  UnitTestPBPhysParticleCloneIsSame();
  UnitTestPBPhysParticleLoadSave();
  UnitTestPBPhysParticleAccelMove();
  UnitTestPBPhysParticleTestTrajectory();
  printf("UnitTestPBPhysParticle OK\n");
}

void UnitTestPBPhysCreateFreePrint() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  if (phys == NULL ||
    phys->_dim != 2 ||
    !ISEQUALF(phys->_deltaT, PBPHYS_DELTAT) ||
    !ISEQUALF(phys->_downGravity, 0.0) ||
    !ISEQUALF(phys->_curTime, 0.0) ||
    phys->_gravity != 0 ||
    GSetNbElem(PBPhysParticles(phys)) != 0) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
```

```
    sprintf(PBPhysErr->_msg, "PBPhysCreate failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysAddParticles(phys, 2, ShapoidTypeSpheroid);
  PBPhysParticleSetMass(PBPhysPart(phys, 1), 1.0);
  PBPhysPrintln(phys, stdout);
  PBPhysFree(&phys);
  if (phys != NULL) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysFree failed");
    PBErrCatch(PBPhysErr);
  }
  printf("UnitTestPBPhysCreateFreePrint OK\n");
}

void UnitTestPBPhysGetSetAdd() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  if (PBPhysGetDim(phys) != dim) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetDim failed");
    PBErrCatch(PBPhysErr);
  }
  phys->_curTime = 0.1;
  if (!ISEQUALF(PBPhysGetCurTime(phys), phys->_curTime)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetCurTime failed");
    PBErrCatch(PBPhysErr);
  }
  if (!ISEQUALF(PBPhysGetDeltaT(phys), PBPHYS_DELTAT)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetDeltaT failed");
    PBErrCatch(PBPhysErr);
  }
  phys->_downGravity = 0.2;
  if (!ISEQUALF(PBPhysGetDownGravity(phys), phys->_downGravity)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetDownGravity failed");
    PBErrCatch(PBPhysErr);
  }
  phys->_gravity = 0.3;
  if (!ISEQUALF(PBPhysGetGravity(phys), phys->_gravity)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetGravity failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysSetCurTime(phys, 0.2);
  if (!ISEQUALF(PBPhysGetCurTime(phys), phys->_curTime)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysSetCurTime failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysSetDeltaT(phys, 0.3);
  if (!ISEQUALF(PBPhysGetDeltaT(phys), phys->_deltaT)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysSetDeltaT failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysSetDownGravity(phys, 0.4);
  if (!ISEQUALF(PBPhysGetDownGravity(phys), phys->_downGravity)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysSetDownGravity failed");
```

```
    PBErrCatch(PBPhysErr);
  }
  PBPhysSetGravity(phys, 0.5);
  if (!ISEQUALF(PBPhysGetGravity(phys), phys->_gravity)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysSetGravity failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysParticles(phys) != &(phys->_particles)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysParticles failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysGetNbParticle(phys) != 0) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetNbParticle failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysAddParticles(phys, 2, ShapoidTypeSpheroid);
  if (GSetNbElem(PBPhysParticles(phys)) != 2) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysAddParticles failed");
    PBErrCatch(PBPhysErr);
  }
  if (PBPhysGetNbParticle(phys) != 2) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysGetNbParticle failed");
    PBErrCatch(PBPhysErr);
  }
  if (GSetGet(PBPhysParticles(phys), 0) != PBPhysPart(phys, 0) ||
    GSetGet(PBPhysParticles(phys), 1) != PBPhysPart(phys, 1)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysPart failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysFree(&phys);
  printf("UnitTestPBPhysGetSetAdd OK\n");
}

void UnitTestPBPhysCloneIsSame() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysAddParticles(phys, 2, ShapoidTypeSpheroid);
  PBPhysParticleSetMass(PBPhysPart(phys, 1), 1.0);
  PBPhys* clone = PBPhysClone(phys);
  if (!PBPhysIsSame(clone, phys)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysClone failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysParticleSetMass(PBPhysPart(clone, 1), 2.0);
  if (PBPhysIsSame(clone, phys)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysIsSame failed");
    PBErrCatch(PBPhysErr);
  }
  PBPhysFree(&phys);
  PBPhysFree(&clone);
  printf("UnitTestPBPhysCloneIsSame OK\n");
}

void UnitTestPBPhysLoadSave() {
```

```
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysAddParticles(phys, 2, ShapoidTypeSpheroid);
  PBPhysParticleSetMass(PBPhysPart(phys, 1), 1.0);
  FILE* fd = fopen("./phys.txt", "w");
  if (!PBPhysSave(phys, fd, false)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysSave failed");
    PBErrCatch(PBPhysErr);
  }
  fclose(fd);
  PBPhys* loaded = PBPhysCreate(dim);
  fd = fopen("./phys.txt", "r");
  if (!PBPhysLoad(&loaded, fd) ||
    !PBPhysIsSame(phys, loaded)) {
    PBPhysErr->_type = PBErrTypeUnitTestFailed;
    sprintf(PBPhysErr->_msg, "PBPhysLoad failed");
    PBErrCatch(PBPhysErr);
  }
  fclose(fd);
  PBPhysFree(&phys);
  PBPhysFree(&loaded);
  printf("UnitTestPBPhysLoadSave OK\n");
}

void UnitTestPBPhysStepFree() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysAddParticles(phys, 1, ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 1.0); VecSet(&v, 1, 0.5);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 0), &v);
  float check[20] = {
    0.010000,0.005000,0.020000,0.010000,0.030000,0.015000,0.040000,
    0.020000,0.050000,0.025000,0.060000,0.030000,0.070000,0.035000,
    0.080000,0.040000,0.090000,0.045000,.100000,0.050000};
  for (int i = 0; i < 10; ++i) {
    PBPhysNext(phys);
    VecSet(&v, 0, check[2 * i]); VecSet(&v, 1, check[2 * i + 1]);
    if (!VecIsEqual(
      ShapoidPos(PBPhysParticleShape(PBPhysPart(phys, 0))),
      &v)) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysStep failed");
      PBErrCatch(PBPhysErr);
    }
  }
  PBPhysFree(&phys);
  printf("UnitTestPBPhysStepFree OK\n");
}

void UnitTestPBPhysStepDownGravity() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysSetDownGravity(phys, PBPHYS_Gn);
  PBPhysAddParticles(phys, 1, ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 1.0); VecSet(&v, 1, 0.5);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 0), &v);
  float check[20] = {
    0.010000,0.004510,0.020000,0.008039,0.030000,0.010587,0.040000,
    0.012155,0.050000,0.012742,0.060000,0.012348,0.070000,0.010974,
```

```
    0.080000,0.008619,0.090000,0.005283,0.100000,0.000967};
  for (int i = 0; i < 10; ++i) {
    PBPhysNext(phys);
    VecSet(&v, 0, check[2 * i]); VecSet(&v, 1, check[2 * i + 1]);
    if (!VecIsEqual(
      ShapoidPos(PBPhysParticleShape(PBPhysPart(phys, 0))),
      &v)) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysStep failed");
      PBErrCatch(PBPhysErr);
    }
  }
  PBPhysFree(&phys);
  printf("UnitTestPBPhysStepDownGravity OK\n");
}

void UnitTestPBPhysStepGravity() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysSetGravity(phys, 1.0);
  PBPhysAddParticles(phys, 2, ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 1.0); VecSet(&v, 1, 0.5);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 0), &v);
  PBPhysParticleSetMass(PBPhysPart(phys, 0), 1.0);
  VecSet(&v, 0, 1.0); VecSet(&v, 1, 1.0);
  PBPhysParticleSetPos(PBPhysPart(phys, 1), &v);
  PBPhysParticleSetMass(PBPhysPart(phys, 1), 1.0);
  PBPhysParticleSetFixed(PBPhysPart(phys, 1), true);
  float check[20] = {
    0.010018,0.005018,0.020071,0.010071,0.030160,0.015161,0.040286,
    0.020287,0.050449,0.025452,0.060649,0.030654,0.070887,0.035896,
    0.081164,0.041177,0.091479,0.046499,.101834,0.051862};
  for (int i = 0; i < 10; ++i) {
    PBPhysNext(phys);
    VecSet(&v, 0, check[2 * i]); VecSet(&v, 1, check[2 * i + 1]);
    if (!VecIsEqual(
      ShapoidPos(PBPhysParticleShape(PBPhysPart(phys, 0))),
      &v)) {
      PBPhysErr->_type = PBErrTypeUnitTestFailed;
      sprintf(PBPhysErr->_msg, "PBPhysStep failed");
      PBErrCatch(PBPhysErr);
    }
//VecFloatPrint(ShapoidPos(PBPhysParticleShape(PBPhysPart(phys, 0))), stdout, 6);printf("\n");
  }
  PBPhysFree(&phys);
  printf("UnitTestPBPhysStepDownGravity OK\n");
  printf("UnitTestPBPhysStepGravity OK\n");
}

void UnitTestPBPhysStepToCollisionApplyElasticCollision() {
  int dim = 2;
  PBPhys* phys = PBPhysCreate(dim);
  PBPhysAddParticles(phys, 3, ShapoidTypeSpheroid);
  VecFloat2D v = VecFloatCreateStatic2D();
  VecSet(&v, 0, 1.0); VecSet(&v, 1, 1.0);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 0), &v);
  PBPhysParticleSetMass(PBPhysPart(phys, 0), 1.0);
  VecSet(&v, 0, 0.0); VecSet(&v, 1, 2.0);
  PBPhysParticleSetPos(PBPhysPart(phys, 1), &v);
  VecSet(&v, 0, 0.5); VecSet(&v, 1, -0.5);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 1), &v);
```

```
PBPhysParticleSetMass(PBPhysPart(phys, 1), 1.0);
VecSet(&v, 0, 2.0); VecSet(&v, 1, 2.0);
PBPhysParticleSetPos(PBPhysPart(phys, 2), &v);
VecSet(&v, 0, -1.0); VecSet(&v, 1, -1.0);
PBPhysParticleSetSpeed(PBPhysPart(phys, 2), &v);
PBPhysParticleSetMass(PBPhysPart(phys, 2), 2.0);
PBPhysSetDeltaT(phys, 2.0);
GSetPBPhysParticle* set = PBPhysStepToCollision(phys);
if (!ISEQUALF(PBPhysGetCurTime(phys), 0.646447) ||
  !ISEQUALF(PBPhysPart(phys,0)->_shape->_pos->_val[0], 0.646447) ||
  !ISEQUALF(PBPhysPart(phys,0)->_shape->_pos->_val[1], 0.646447) ||
  !ISEQUALF(PBPhysPart(phys,1)->_shape->_pos->_val[0], 0.323223) ||
  !ISEQUALF(PBPhysPart(phys,1)->_shape->_pos->_val[1], 1.676777) ||
  !ISEQUALF(PBPhysPart(phys,2)->_shape->_pos->_val[0], 1.353553) ||
  !ISEQUALF(PBPhysPart(phys,2)->_shape->_pos->_val[1], 1.353553) ||
  GSetNbElem(set) != 2 ||
  GSetGet(set, 0) != PBPhysPart(phys,0) ||
  GSetGet(set, 1) != PBPhysPart(phys,2)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysStepToCollision failed");
  PBErrCatch(PBPhysErr);
}
PBPhysParticleApplyElasticCollision(GSetGet(set, 0), GSetGet(set, 1));
if (!ISEQUALF(PBPhysPart(phys,0)->_speed->_val[0], -1.666667) ||
  !ISEQUALF(PBPhysPart(phys,0)->_speed->_val[1], -1.666667) ||
  !ISEQUALF(PBPhysPart(phys,2)->_speed->_val[0], 0.333334) ||
  !ISEQUALF(PBPhysPart(phys,2)->_speed->_val[1], 0.333334)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg,
    "PBPhysParticleApplyElasticCollision failed");
  PBErrCatch(PBPhysErr);
}
GSetFree(&set);
set = PBPhysStepToCollision(phys);
if (!ISEQUALF(PBPhysGetCurTime(phys), 0.878937) ||
  !ISEQUALF(PBPhysPart(phys,0)->_shape->_pos->_val[0], 0.258963) ||
  !ISEQUALF(PBPhysPart(phys,0)->_shape->_pos->_val[1], 0.258963) ||
  !ISEQUALF(PBPhysPart(phys,1)->_shape->_pos->_val[0], 0.439468) ||
  !ISEQUALF(PBPhysPart(phys,1)->_shape->_pos->_val[1], 1.560532) ||
  !ISEQUALF(PBPhysPart(phys,2)->_shape->_pos->_val[0], 1.431050) ||
  !ISEQUALF(PBPhysPart(phys,2)->_shape->_pos->_val[1], 1.431050) ||
  GSetNbElem(set) != 2 ||
  GSetGet(set, 0) != PBPhysPart(phys,1) ||
  GSetGet(set, 1) != PBPhysPart(phys,2)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg, "PBPhysStepToCollision failed");
  PBErrCatch(PBPhysErr);
}
PBPhysParticleApplyElasticCollision(GSetGet(set, 0), GSetGet(set, 1));
if (!ISEQUALF(PBPhysPart(phys,1)->_speed->_val[0], 0.138846) ||
  !ISEQUALF(PBPhysPart(phys,1)->_speed->_val[1], -0.452840) ||
  !ISEQUALF(PBPhysPart(phys,2)->_speed->_val[0], 0.513910) ||
  !ISEQUALF(PBPhysPart(phys,2)->_speed->_val[1], 0.309754)) {
  PBPhysErr->_type = PBErrTypeUnitTestFailed;
  sprintf(PBPhysErr->_msg,
    "PBPhysParticleApplyElasticCollision failed");
  PBErrCatch(PBPhysErr);
}
GSetFree(&set);
VecSet(&v, 0, 0.0); VecSet(&v, 1, 0.0);
PBPhysParticleSetPos(PBPhysPart(phys, 0), &v);
VecSet(&v, 0, 1.0); VecSet(&v, 1, 1.0);
```

```
  PBPhysParticleSetSpeed(PBPhysPart(phys, 0), &v);
  VecSet(&v, 0, 0.0); VecSet(&v, 1, 2.0);
  PBPhysParticleSetPos(PBPhysPart(phys, 1), &v);
  VecSet(&v, 0, 0.5); VecSet(&v, 1, -0.5);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 1), &v);
  VecSet(&v, 0, 2.0); VecSet(&v, 1, 2.0);
  PBPhysParticleSetPos(PBPhysPart(phys, 2), &v);
  VecSet(&v, 0, -1.0); VecSet(&v, 1, -1.0);
  PBPhysParticleSetSpeed(PBPhysPart(phys, 2), &v);
  ShapoidScale(PBPhysParticleShape(PBPhysPart(phys, 2)), (float)2.0);
  PBPhysSetDeltaT(phys, 0.05);
  PBPhysSetCurTime(phys, 0.0);
  FILE* fd = fopen("./collision.txt", "w");
  for (int i = 0; i < 20; ++i) {
    PBPhysStep(phys);
    fprintf(fd, "%f %f %f %f %f %f %f\n", PBPhysGetCurTime(phys),
      PBPhysPart(phys,0)->_shape->_pos->_val[0],
      PBPhysPart(phys,0)->_shape->_pos->_val[1],
      PBPhysPart(phys,1)->_shape->_pos->_val[0],
      PBPhysPart(phys,1)->_shape->_pos->_val[1],
      PBPhysPart(phys,2)->_shape->_pos->_val[0],
      PBPhysPart(phys,2)->_shape->_pos->_val[1]);
  }
  fclose(fd);
  PBPhysFree(&phys);
  printf("UnitTestPBPhysStepToCollisionApplyElasticCollision OK\n");
}

void UnitTestPBPhysNext() {
  UnitTestPBPhysStepFree();
  UnitTestPBPhysStepDownGravity();
  UnitTestPBPhysStepGravity();
  UnitTestPBPhysStepToCollisionApplyElasticCollision();
  printf("UnitTestPBPhysStep OK\n");
}

void UnitTestPBPhys() {
  UnitTestPBPhysCreateFreePrint();
  UnitTestPBPhysGetSetAdd();
  UnitTestPBPhysCloneIsSame();
  UnitTestPBPhysLoadSave();
  UnitTestPBPhysNext();

  printf("UnitTestPBPhys OK\n");
}

void UnitTestAll() {
  UnitTestPBPhysParticle();
  UnitTestPBPhys();
  printf("UnitTestAll OK\n");
}

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

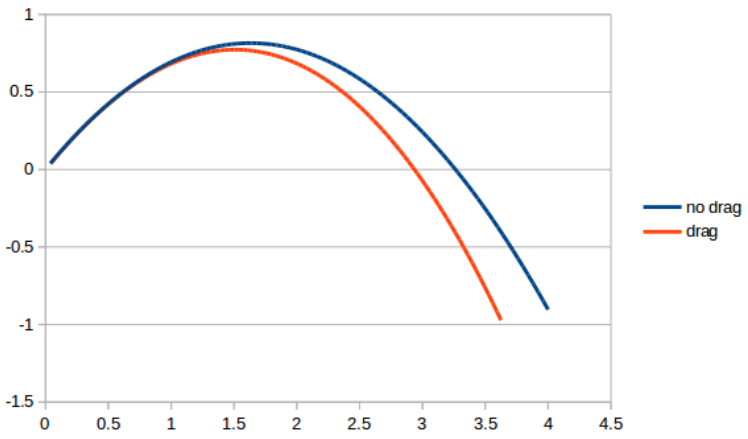
6 Unit tests output

```
Type: Spheroid
Dim: 2
Pos: <0.000,0.000>
Axis(0): <1.000,0.000>
Axis(1): <0.000,1.000>
speed: <0.000,0.000>
accel: <0.000,0.000>
mass: 0.000
drag: 0.000
unfixed
UnitTestPBPhysParticleCreateFreePrint OK
UnitTestPBPhysParticleGetSet OK
UnitTestPBPhysParticleCloneIsSame OK
UnitTestPBPhysParticleLoadSave OK
UnitTestPBPhysParticleAccelMove OK
UnitTestPBPhysParticleTestTrajectory OK
UnitTestPBPhysParticle OK
dimension: 2
t: 0.000000
dt: 0.010000
down gravity: 0.000000
gravity: 0.000000
nb particles: 2
particle #0:
Type: Spheroid
Dim: 2
Pos: <0.000,0.000>
Axis(0): <1.000,0.000>
Axis(1): <0.000,1.000>
speed: <0.000,0.000>
accel: <0.000,0.000>
mass: 0.000
drag: 0.000
unfixed
particle #1:
Type: Spheroid
Dim: 2
Pos: <0.000,0.000>
Axis(0): <1.000,0.000>
Axis(1): <0.000,1.000>
speed: <0.000,0.000>
accel: <0.000,0.000>
mass: 1.000
drag: 0.000
unfixed
UnitTestPBPhysCreateFreePrint OK
UnitTestPBPhysGetSetAdd OK
UnitTestPBPhysCloneIsSame OK
UnitTestPBPhysLoadSave OK
UnitTestPBPhysStepFree OK
UnitTestPBPhysStepDownGravity OK
UnitTestPBPhysStepDownGravity OK
UnitTestPBPhysStepGravity OK
UnitTestPBPhysStepToCollisionApplyElasticCollision OK
UnitTestPBPhysStep OK
UnitTestPBPhys OK
UnitTestAll OK
```

traj.txt:

```
0.010000 0.040000 0.039510 0.039960 0.039470
0.020000 0.080000 0.078039 0.079840 0.077880
0.030000 0.120000 0.115587 0.119640 0.115232
0.040000 0.160000 0.152155 0.159361 0.151530
0.050000 0.200000 0.187742 0.199002 0.186773
0.060000 0.240000 0.222348 0.238564 0.220966
0.070000 0.280000 0.255974 0.278047 0.254110
0.080000 0.320000 0.288619 0.317451 0.286207
0.090000 0.360000 0.320283 0.356776 0.317259
0.100000 0.400000 0.350967 0.396023 0.347268
0.110000 0.440000 0.380670 0.435191 0.376236
0.120000 0.480000 0.409392 0.474280 0.404166
0.130000 0.520000 0.437134 0.513292 0.431060
0.140000 0.560000 0.463895 0.552225 0.456918
0.150000 0.600000 0.489675 0.591081 0.481745
0.160000 0.640000 0.514475 0.629858 0.505541
0.170000 0.680000 0.538294 0.668559 0.528309
0.180000 0.720000 0.561132 0.707182 0.550051
0.190000 0.760000 0.582990 0.745727 0.570768
0.200000 0.800000 0.603867 0.784196 0.590464
0.210000 0.840000 0.623763 0.822587 0.609139
0.220000 0.880000 0.642679 0.860902 0.626797
0.230000 0.920000 0.660614 0.899140 0.643438
0.240000 0.960000 0.677568 0.937302 0.659066
0.250000 1.000000 0.693542 0.975388 0.673681
0.260000 1.040000 0.708535 1.013397 0.687287
0.270000 1.080000 0.722547 1.051330 0.699885
0.280000 1.120000 0.735579 1.089187 0.711477
0.290000 1.160000 0.747630 1.126969 0.722065
0.300000 1.200000 0.758701 1.164675 0.731651
0.310000 1.240000 0.768790 1.202306 0.740237
0.320000 1.280000 0.777899 1.239861 0.747826
0.330000 1.320000 0.786028 1.277341 0.754419
0.340000 1.360000 0.793175 1.314746 0.760018
0.350000 1.400000 0.799342 1.352077 0.764625
0.360000 1.440000 0.804529 1.389333 0.768242
0.370000 1.480000 0.808735 1.426514 0.770871
0.380000 1.520000 0.811960 1.463621 0.772514
0.390000 1.560000 0.814204 1.500654 0.773174
0.400000 1.600000 0.815468 1.537613 0.772851
0.410000 1.640000 0.815751 1.574497 0.771548
0.420000 1.679999 0.815053 1.611308 0.769268
0.430000 1.719999 0.813375 1.648046 0.766011
0.440000 1.759999 0.810716 1.684710 0.761780
0.450000 1.799999 0.807076 1.721300 0.756577
0.460000 1.839999 0.802456 1.757818 0.750403
0.470000 1.879999 0.796855 1.794262 0.743262
0.480000 1.919999 0.790274 1.830634 0.735153
0.490000 1.959999 0.782711 1.866932 0.726081
0.500000 1.999999 0.774168 1.903159 0.716046
0.510000 2.039999 0.764645 1.939312 0.705050
0.520000 2.079999 0.754140 1.975394 0.693096
0.530000 2.119999 0.742656 2.011403 0.680185
0.540000 2.159999 0.730190 2.047340 0.666319
0.550000 2.199999 0.716744 2.083205 0.651500
0.560000 2.239999 0.702317 2.118999 0.635730
0.570000 2.279999 0.686909 2.154721 0.619011
0.580000 2.319999 0.670521 2.190372 0.601345
0.590000 2.359999 0.653152 2.225951 0.582733
0.600000 2.399999 0.634803 2.261459 0.563178
0.610000 2.439999 0.615472 2.296896 0.542681
0.620000 2.479999 0.595161 2.332262 0.521245
```

```
0.630000 2.519999 0.573870 2.367558 0.498871
0.640000 2.559999 0.551598 2.402783 0.475561
0.650000 2.599999 0.528345 2.437937 0.451317
0.660000 2.639999 0.504111 2.473021 0.426141
0.670000 2.679999 0.478897 2.508035 0.400034
0.680000 2.719999 0.452702 2.542979 0.372999
0.690000 2.759999 0.425526 2.577853 0.345038
0.700000 2.799999 0.397370 2.612658 0.316152
0.710000 2.839998 0.368233 2.647392 0.286342
0.720000 2.879998 0.338116 2.682057 0.255612
0.730000 2.919998 0.307018 2.716653 0.223963
0.740000 2.959998 0.274939 2.751180 0.191396
0.750000 2.999998 0.241879 2.785638 0.157914
0.760000 3.039998 0.207839 2.820027 0.123517
0.770000 3.079998 0.172818 2.854347 0.088210
0.780000 3.119998 0.136816 2.888598 0.051992
0.790000 3.159998 0.099834 2.922781 0.014865
0.800000 3.199998 0.061871 2.956895 -0.023167
0.810000 3.239998 0.022928 2.990941 -0.062104
0.820000 3.279998 -0.016996 3.024919 -0.101944
0.830000 3.319998 -0.057901 3.058830 -0.142685
0.840000 3.359998 -0.099787 3.092672 -0.184326
0.849999 3.399998 -0.142653 3.126446 -0.226863
0.859999 3.439998 -0.186500 3.160154 -0.270296
0.869999 3.479998 -0.231327 3.193793 -0.314623
0.879999 3.519998 -0.277136 3.227366 -0.359842
0.889999 3.559998 -0.323925 3.260871 -0.405951
0.899999 3.599998 -0.371694 3.294309 -0.452949
0.909999 3.639998 -0.420444 3.327681 -0.500833
0.919999 3.679998 -0.470175 3.360985 -0.549602
0.929999 3.719998 -0.520887 3.394223 -0.599255
0.939999 3.759998 -0.572579 3.427395 -0.649788
0.949999 3.799998 -0.625252 3.460500 -0.701201
0.959999 3.839998 -0.678905 3.493539 -0.753493
0.969999 3.879997 -0.733539 3.526512 -0.806660
0.979999 3.919997 -0.789154 3.559419 -0.860701
0.989999 3.959997 -0.845750 3.592260 -0.915615
0.999999 3.999997 -0.903326 3.625036 -0.971400
```



collision.txt:

```
0.050000 0.050000 0.050000 0.025000 1.975000 1.950000 1.950000
0.100000 0.100000 0.100000 0.050000 1.950000 1.900000 1.900000
0.150000 0.150000 0.150000 0.075000 1.925000 1.850000 1.850000
0.200000 0.200000 0.200000 0.100000 1.900000 1.800000 1.800000
0.250000 0.250000 0.250000 0.125000 1.875000 1.750000 1.750000
0.300000 0.300000 0.300000 0.150000 1.850000 1.700000 1.700000
0.350000 0.350000 0.350000 0.155565 1.827215 1.659718 1.648893
0.400000 0.400000 0.400000 0.085599 1.813041 1.657201 1.593480
0.450000 0.450000 0.450000 0.015633 1.798866 1.654684 1.538068
0.500000 0.500000 0.500000 -0.054334 1.784691 1.652167 1.482655
0.550000 0.454424 0.469154 -0.124300 1.770516 1.697439 1.467666
0.600000 0.394305 0.426006 -0.194267 1.756341 1.749981 1.458827
0.650000 0.334186 0.382858 -0.264233 1.742166 1.802524 1.449989
0.700000 0.274067 0.339710 -0.334199 1.727992 1.855067 1.441150
0.750000 0.213948 0.296562 -0.404166 1.713817 1.907609 1.432312
0.800000 0.153829 0.253414 -0.474132 1.699642 1.960152 1.423473
0.850000 0.093709 0.210266 -0.544099 1.685467 2.012695 1.414634
0.900000 0.033590 0.167118 -0.614065 1.671292 2.065238 1.405796
0.950000 -0.026529 0.123970 -0.684032 1.657117 2.117780 1.396957
1.000000 -0.086648 0.080822 -0.753998 1.642943 2.170323 1.388119
```