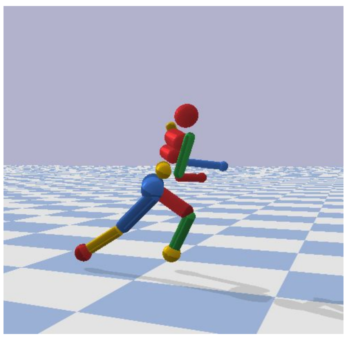
# PyBullet Quickstart Guide

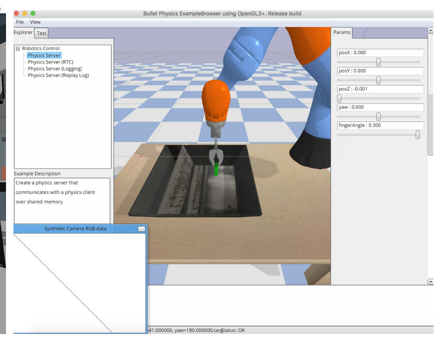
[Erwin Coumans](), [Yunfei Bai](), 2017/2018

Visit the [forums]().

# Introduction

PyBullet is an easy to use Python module for physics simulation for robotics, games, visual effects and machine learning. With PyBullet you can load articulated bodies from URDF, SDF, MJCF and other file formats. PyBullet provides forward dynamics simulation, inverse dynamics computation, forward and inverse kinematics, collision detection and ray intersection queries. The Bullet Physics SDK includes PyBullet robotic examples such as a simulated Minitaur quadruped, humanoids running using TensorFlow inference and KUKA arms grasping objects.





Aside from physics simulation, there are bindings to rendering, with a CPU renderer (TinyRenderer) and OpenGL visualization and support for Virtual Reality headsets such as HTC Vive and Oculus Rift. PyBullet also has functionality to perform collision detection queries (closest points, overlapping pairs, ray intersection test etc) and to add debug rendering (debug lines and text). PyBullet has cross-platform built-in client-server support for shared memory, UDP and TCP networking. So you can run PyBullet on Linux connecting to a Windows VR server.

PyBullet wraps the new Bullet C-API, which is designed to be independent from the underlying physics engine and render engine, so we can easily migrate to newer versions of Bullet, or use a different physics engine or render engine. By default, PyBullet uses the Bullet 2.x API on the CPU. We will expose Bullet 3.x running on GPU using OpenCL as well. There is also a C++ API similar to PyBullet, see b3RobotSimulatorClientAPI.

PyBullet can be easily used with TensorFlow and frameworks such as OpenAI Gym. Researchers from Google Brain [1,2,3,4], X, Stanford AI Lab [1,2,3], OpenAI and INRIA [1] use PyBullet/Bullet C-API.

The installation of PyBullet is as simple as (sudo) pip install PyBullet (Python 2.x), pip3 install PyBullet. This will expose the PyBullet module as well as PyBullet_envs Gym environments.

# Hello PyBullet World

Here is a PyBullet introduction script that we discuss step by step:

```
import pybullet as p
import time
import pybullet_data
physicsClient = p.connect(p.GUI)#or p.DIRECT for non-graphical version
p.setAdditionalSearchPath(pybullet_data.getDataPath()) #optionally
p.setGravity(0,0,-10)
planeId = p.loadURDF("plane.urdf")
cubeStartPos = [0,0,1]
cubeStartOrientation = p.getQuaternionFromEuler([0,0,0])
boxId = p.loadURDF("r2d2.urdf",cubeStartPos, cubeStartOrientation)
for i in range (10000):
    p.stepSimulation()
    time.sleep(1./240.)
cubePos, cubeOrn = p.getBasePositionAndOrientation(boxId)
print(cubePos,cubeOrn)
p.disconnect()
```

## connect, disconnect

After importing the PyBullet module, the first thing to do is 'connecting' to the physics simulation. PyBullet is designed around a client-server driven API, with a client sending commands and a physics server returning the status. PyBullet has some built-in physics servers: DIRECT and GUI. Both GUI and DIRECT connections will execute the physics simulation and rendering in the same process as PyBullet.

Note that in DIRECT mode you cannot access the OpenGL and VR hardware features, as described in the "Virtual Reality" and "Debug GUI, Lines, Text, Parameters" chapters. DIRECT mode does allow rendering of images using the built-in software renderer through the 'getCameraImage' API. This can be useful for running simulations in the cloud on servers without GPU.

You can provide your own data files, or you can use the PyBullet_data package that ships with PyBullet. For this, import pybullet_data and register the directory using pybullet.setAdditionalSearchPath(pybullet_data.getDataPath()).

## getConnectionInfo

Given a physicsClientId will return the list [isConnected, connectionMethod]

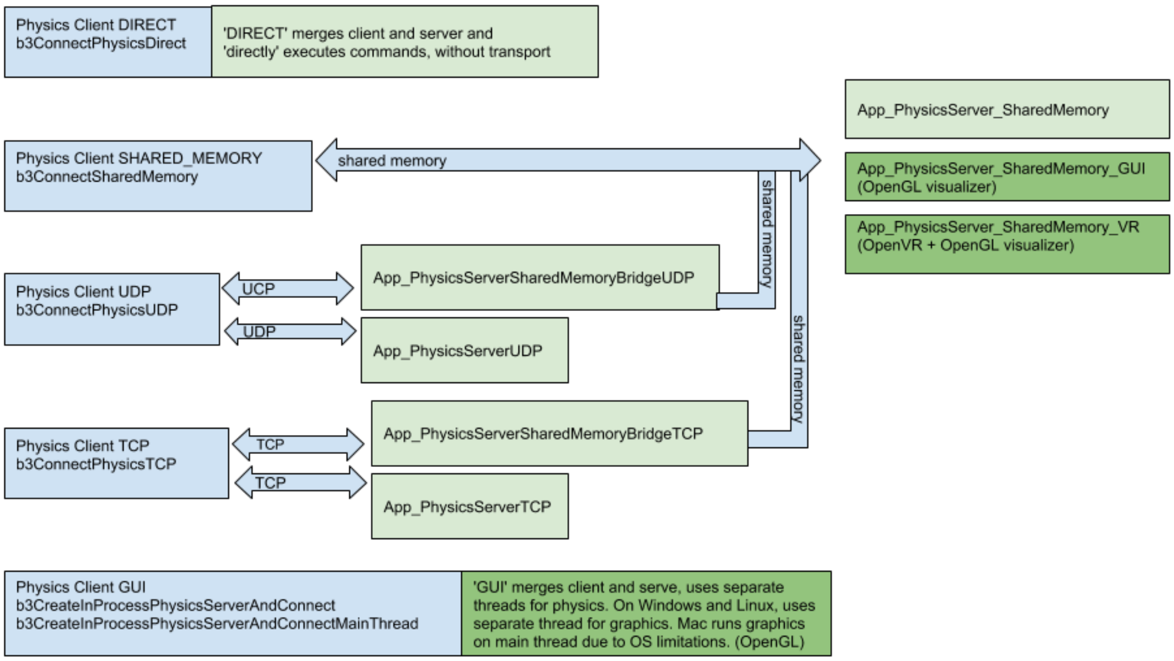



Diagram with various physics client (blue) and physics server (green) options. Dark green servers provide OpenGL debug visualization.

## connect using DIRECT, GUI

The DIRECT connection sends the commands directly to the physics engine, without using any transport layer and no graphics visualization window, and directly returns the status after executing the command.

The GUI connection will create a new graphical user interface (GUI) with 3D OpenGL rendering, within the same process space as PyBullet. On Linux and Windows this GUI runs in a separate thread, while on OSX it runs in the same thread due to operating system limitations. On Mac OSX you may see a spinning wheel in the OpenGL Window, until you run a 'stepSimulation' or other PyBullet command.
The commands and status messages are sent between PyBullet client and the GUI physics simulation server using an ordinary memory buffer.

It is also possible to connect to a physics server in a different process on the same machine or on a remote machine using SHARED_MEMORY, UDP or TCP networking. See the section about Shared Memory, UDP and TCP for details.

Unlike almost all other methods, this method doesn't parse keyword arguments, due to backward compatibility.

The connect input arguments are:

| | | | |
|---|---|---|---|
| required | connection mode | integer: DIRECT, GUI, SHARED_ MEMORY, UDP, TCP | DIRECT mode create a new physics engine and directly communicates with it. GUI will create a physics engine with graphical GUI frontend and communicates with it. SHARED_MEMORY will connect to an existing physics engine process on the same machine, and communicates with it over shared memory. TCP or UDP will connect to an existing physics server over TCP or UDP networking. |
| optional | key | int | in SHARED_MEMORY mode, optional shared memory key. When starting ExampleBrowser or SharedMemoryPhysics_* you can use optional command-line --shared_memory_key to set the key. This allows to run multiple servers on the same machine. |
| optional | UdpNetworkAddress (UDP and TCP) | string | IP address or host name, for example "127.0.0.1" or "localhost" or "mymachine.domain.com" |
| optional | UdpNetworkPort (UDP and TCP) | integer | UDP port number. Default UDP port is 1234, default TCP port is 6667 (matching the defaults in the server) |
| optional | options | string | command-line option passed into the GUI server. At the moment, only the --opengl2 flag is enabled: by default, Bullet uses OpenGL3, but some environments such as virtual machines or remote desktop clients only support OpenGL2. Only one command-line argument can be passed on at the moment. |

connect returns a physics client id or -1 if not connected. The physics client Id is an optional argument to most of the other PyBullet commands. If you don't provide it, it will assume physics client id = 0. You can connect to multiple different physics servers, except for GUI.

For example:

```
pybullet.connect(pybullet.DIRECT)
pybullet.connect(pybullet.GUI, options="--opengl2")
pybullet.connect(pybullet.SHARED_MEMORY,1234)
pybullet.connect(pybullet.UDP,"192.168.0.1")
pybullet.connect(pybullet.UDP,"localhost", 1234)
pybullet.connect(pybullet.TCP,"localhost", 6667)
```

## connect using Shared Memory

There are a few physics servers that allow shared memory connection: the App_SharedMemoryPhysics, App_SharedMemoryPhysics_GUI and the Bullet Example

Browser has one example under Experimental/Physics Server that allows shared memory connection. This will let you execute the physics simulation and rendering in a separate process.

You can also connect over shared memory to the App_SharedMemoryPhysics_VR, the Virtual Reality application with support for head-mounted display and 6-dof tracked controllers such as HTC Vive and Oculus Rift with Touch controllers. Since the Valve OpenVR SDK only works properly under Windows, the App_SharedMemoryPhysics_VR can only be build under Windows using premake (preferably) or cmake.

### connect using UDP or TCP networking

For UDP networking, there is a App_PhysicsServerUDP that listens to a certain UDP port. It uses the open source enet library for reliable UDP networking. This allows you to execute the physics simulation and rendering on a separate machine. For TCP PyBullet uses the clsocket library. This can be useful when using SSH tunneling from a machine behind a firewall to a robot simulation. For example you can run a control stack or machine learning using PyBullet on Linux, while running the physics server on Windows in Virtual Reality using HTC Vive or Rift.

One more UDP application is the App_PhysicsServerSharedMemoryBridgeUDP application that acts as a bridge to an existing physics server: you can connect over UDP to this bridge, and the bridge connects to a physics server using shared memory: the bridge passes messages between client and server. In a similar way there is a TCP version (replace UDP by TCP).

Note: at the moment, both client and server need to be either 32bit or 64bit builds!

### disconnect

You can disconnect from a physics server, using the physics client Id returned by the connect call (if non-negative). A 'DIRECT' or 'GUI' physics server will shutdown. A separate (out-of-process) physics server will keep on running. See also 'resetSimulation' to remove all items.

Parameters of disconnect:

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | if you connect to multiple physics servers, you can pick which one. |

## setGravity

By default, there is no gravitational force enabled. *setGravity* lets you set the default gravity force for all objects.
The setGravity input parameters are: (no return value)

| | | | |
|---|---|---|---|
| required | gravityX | float | gravity force along the X world axis |
| required | gravityY | float | gravity force along the Y world axis |
| required | gravityZ | float | gravity force along the Z world axis |
| optional | physicsClientId | int | if you connect to multiple physics servers, you can pick which one. |

# loadURDF, loadSDF, loadMJCF

The loadURDF will send a command to the physics server to load a physics model from a Universal Robot Description File (URDF). The URDF file is used by the ROS project (Robot Operating System) to describe robots and other objects, it was created by the WillowGarage and the Open Source Robotics Foundation (OSRF). Many robots have public URDF files, you can find a description and tutorial here: [http://wiki.ros.org/urdf/Tutorials](http://wiki.ros.org/urdf/Tutorials)

Important note: most joints (slider, revolute, continuous) have motors enabled by default that prevent free motion. This is similar to a robot joint with a very high-friction harmonic drive. You should set the joint motor control mode and target settings using pybullet.setJointMotorControl2. See the setJointMotorControl2 API for more information.

Warning: by default, PyBullet will cache some files to speed up loading. You can disable file caching using setPhysicsEngineParameter(enableFileCaching=0).

The loadURDF arguments are:

| | | | |
|---|---|---|---|
| required | fileName | string | a relative or absolute path to the URDF file on the file system of the physics server. |
| optional | basePosition | vec3 | create the base of the object at the specified position in world space coordinates [X,Y,Z] |
| optional | baseOrientation | vec4 | create the base of the object at the specified orientation as world space quaternion [X,Y,Z,W] |
| optional | useMaximalCoordinates | int | Experimental. By default, the joints in the URDF file are created using the reduced coordinate method: the joints are simulated using the Featherstone Articulated Body algorithm (btMultiBody in Bullet 2.x). The useMaximalCoordinates option will create a 6 degree of freedom rigid body for each link, and constraints between those rigid bodies are used to model joints. |
| optional | useFixedBase | int | force the base of the loaded object to be static |
| optional | flags | int | URDF_USE_INERTIA_FROM_FILE: by default, Bullet recomputed the inertia tensor based on mass and |

| | | | |
|---|---|---|---|
| | | | volume of the collision shape. If you can provide more accurate inertia tensor, use this flag.<br><br>URDF_USE_SELF_COLLISION: by default, Bullet disables self-collision. This flag let's you enable it. You can customize the self-collision behavior using the following flags:<br>URDF_USE_SELF_COLLISION_EXCLUDE_PARENT will discard self-collision between links that are directly connected (parent and child).<br>URDF_USE_SELF_COLLISION_EXCLUDE_ALL_PARENTS will discard self-collisions between a child link and any of its ancestors (parents, parents of parents, up to the base).<br>URDF_USE_IMPLICIT_CYLINDER, will use a smooth implicit cylinder. By default, Bullet will tesselate the cylinder into a convex hull. |
| optional | globalScaling | float | globalScaling will apply a scale factor to the URDF model. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

loadURDF returns a body unique id, a non-negative integer value. If the URDF file cannot be loaded, this integer will be negative and not a valid body unique id.
By default, loadURDF will use a convex hull for mesh collision detection. For static (mass = 0, not moving) meshes, you can make the mesh concave by adding a tag in the URDF:
`<link concave="yes" name="baseLink">` see [samurai.urdf](samurai.urdf) for an example. There are some other extensions to the URDF format, you can browser the examples to explore. PyBullet doesn't process all information from a URDF file. See the examples and URDF files to get an idea what features are supported. Usually there is a Python API to replace the compensate for lacking URDF support. Each link can only have a single material, so if you have multiple visual shapes with different materials, you need to split them into separate links, connected by fixed joints. You can use the OBJ2SDF utility to do this, part of Bullet.

# loadSDF, loadMJCF

You can also load objects from other file formats, such as .bullet, .sdf and .mjcf. Those file formats support multiple objects, so the return value is a list of object unique ids. The SDF format is explained in detail at [http://sdformat.org](http://sdformat.org). The loadSDF command only extracts some essential parts of the SDF related to the robot models and geometry, and ignores many elements related to cameras, lights and so on. The loadMJCF command performs basic import of MuJoCo MJCF xml files, used in OpenAI Gym. See also the Important note under loadURDF related to default joint motor settings, and make sure to use setJointMotorControl2.

| | | | |
|---|---|---|---|
| required | fileName | string | a relative or absolute path to the URDF file on the file system of the physics server. |
| optional | useMaximalCoordinates | int | Experimental. See loadURDF for more details. |
| optional | globalScaling | float | every object will be scaled using this scale factor (including links, link frames, joint attachments and linear joint limits) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

loadBullet, loadSDF and loadMJCF will return an array of object unique ids:

| | | |
|---|---|---|
| objectUniqueIds | list of int | the list includes the object unique id for each object loaded. |

# saveWorld

You can create an approximate snapshot of the current world as a PyBullet Python file, stored on the server. saveWorld can be useful as a basic editing feature, setting up the robot, joint angles, object positions and environment for example in VR. Later you can just load the PyBullet Python file to re-create the world. The python snapshot contains loadURDF commands together with initialization of joint angles and object transforms. Note that not all settings are stored in the world file.

The input arguments are:

| | | | |
|---|---|---|---|
| required | fileName | string | filename of the PyBullet file. |
| optional | clientServerId | int | if you are connected to multiple servers, you can pick one |

# saveState, saveBullet, restoreState

When you need deterministic simulation after restoring to a previously saved state, all important state information, including contact points, need to be stored. The saveWorld command is not sufficient for this. You can use the restoreState command to restore from a snapshot taken using saveState (in-memory) or saveBullet (on disk).

The saveState command only takes an optional clientServerId as input and returns the state id.
The saveBullet command will save the state to a .bullet file on disk.
The restoreState command input arguments are:

| | | | |
|---|---|---|---|
| optional | fileName | string | filename of the .bullet file created using a saveBullet command. |
| optional | stateId | int | state id returned by saveState |
| optional | clientServerId | int | if you are connected to multiple servers, you can pick one |

Either the filename or state id needs to be valid. Note that restoreState will reset the positions and joint angles of objects to the saved state, as well as restoring contact point information. You need to make sure the objects and constraints are setup before calling restoreState. See the saveRestoreState.py example.

## createCollisionShape/VisualShape

Although the recommended and easiest way to create stuff in the world is using the loading functions (loadURDF/SDF/MJCF/Bullet), you can also create collision and visual shapes programmatically and use them to create a multi body using createMultiBody. See the createMultiBodyLinks.py and createVisualShape.py example in the Bullet Physics SDK.

The input parameters for createCollisionShape are

| | | | |
|---|---|---|---|
| required | shapeType | int | GEOM_SPHERE, GEOM_BOX, GEOM_CAPSULE, GEOM_CYLINDER, GEOM_PLANE, GEOM_MESH |
| optional | radius | float | default 0.5: GEOM_SPHERE, GEOM_CAPSULE, GEOM_CYLINDER |
| optional | halfExtents | vec3 list of 3 floats | default [1,1,1]: for GEOM_BOX |
| optional | height | float | default: 1: for GEOM_CAPSULE, GEOM_CYLINDER |
| optional | fileName | string | Filename for GEOM_MESH, currently only Wavefront .obj. Will create convex hulls for each object (marked as 'o') in the .obj file. |
| optional | meshScale | vec3 list of 3 floats | default: [1,1,1], for GEOM_MESH |
| optional | planeNormal | vec3 list of 3 floats | default: [0,0,1] for GEOM_PLANE |
| optional | flags | int | GEOM_FORCE_CONCAVE_TRIMESH: for GEOM_MESH, this will create a concave static triangle mesh. This should not be used with dynamic / moving objects, only for static (mass = 0) terrain. |
| optional | collisionFramePosition | vec3 | translational offset of the collision shape with respect to the link frame |
| optional | collisionFrameOr | vec4 | rotational offset (quaternion x,y,z,w) of the collision shape with respect |

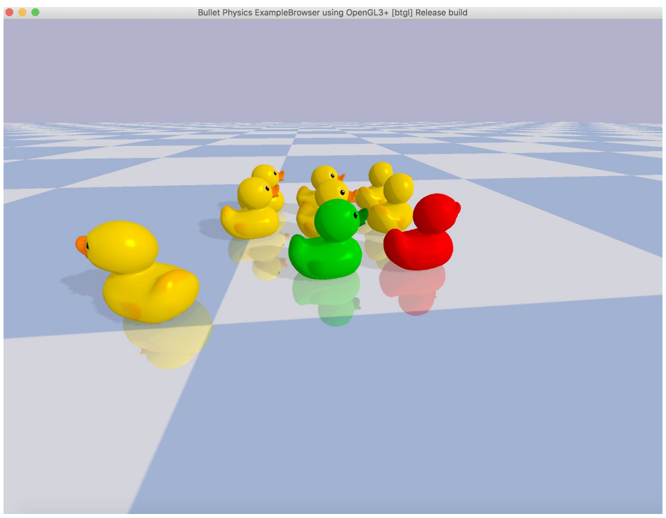
| | | | |
|---|---|---|---|
| | ientation | | to the link frame |
| optional | physicsClientId | int | If you are connected to multiple servers, you can pick one. |

The return value is a non-negative int unique id for the collision shape or -1 if the call failed.

# createVisualShape

You can create a visual shape in a similar way to creating a collision shape, with some additional arguments to control the visual appearance, such as diffuse and specular color. When you use the GEOM_MESH type, you can point to a Wavefront OBJ file, and the visual shape will parse some parameters from the material file (.mtl) and load a texture. Note that large textures (above 1024x1024 pixels) can slow down the loading and run-time performance.

See examples/pybullet/examples/addPlanarReflection.py and createVisualShape.py




The input parameters are

| | | | |
|---|---|---|---|
| required | shapeType | int | GEOM_SPHERE, GEOM_BOX, GEOM_CAPSULE, GEOM_CYLINDER, GEOM_PLANE, GEOM_MESH |
| optional | radius | float | default 0.5: only for GEOM_SPHERE, GEOM_CAPSULE, GEOM_CYLINDER |
| optional | halfExtents | vec3 list of 3 floats | default [1,1,1]: only for GEOM_BOX |
| optional | length | float | default: 1: only for GEOM_CAPSULE, GEOM_CYLINDER (length = height) |
| optional | fileName | string | Filename for GEOM_MESH, currently only Wavefront .obj. Will create convex hulls for each object (marked as 'o') in the |

| | | | |
|---|---|---|---|
| | | | .obj file. |
| optional | meshScale | vec3 list of 3 floats | default: [1,1,1],only for GEOM_MESH |
| optional | planeNormal | vec3 list of 3 floats | default: [0,0,1] only for GEOM_PLANE |
| optional | flags | int | unused / to be decided |
| optional | rgbaColor | vec4, list of 4 floats | color components for red, green, blue and alpha, each in range [0..1]. |
| optional | specularColor | vec3, list of 3 floats | specular reflection color, red, green, blue components in range [0..1] |
| optional | visualFramePosition | vec3, list of 3 floats | translational offset of the visual shape with respect to the link frame |
| optional | visualFrameOrientation | vec4, list of 4 floats | rotational offset (quaternion x,y,z,w) of the visual shape with respect to the link frame |
| optional | physicsClientId | int | If you are connected to multiple servers, you can pick one. |

The return value is a non-negative int unique id for the visual shape or -1 if the call failed.

## createMultiBody

Although the easiest way to create stuff in the world is using the loading functions (loadURDF/SDF/MJCF/Bullet), you can create a multi body using createMultiBody. See the createMultiBodyLinks.py example in the Bullet Physics SDK. The parameters of createMultiBody are very similar to URDF and SDF parameters.

You can create a multi body with only a single base without joints/child links or you can create a multi body with joints/child links. If you provide links, make sure the size of every list is the same (len(linkMasses) == len(linkCollisionShapeIndices) etc). The input parameters for createMultiBody are:

| | | | |
|---|---|---|---|
| optional | baseMass | float | mass of the base, in kg (if using SI units) |
| optional | baseCollisionShapeIndex | int | unique id from createCollisionShape or -1. You can re-use the collision shape for multiple |

| | | | |
|---|---|---|---|
| | | | multibodies (instancing) |
| optional | baseVisualShapeIndex | int | unique id from createVisualShape or -1. You can reuse the visual shape (instancing) |
| optional | basePosition | vec3, list of 3 floats | Cartesian world position of the base |
| optional | baseOrientation | vec4, list of 4 floats | Orientation of base as quaternion [x,y,z,w] |
| optional | baseInertialFramePosition | vec3, list of 3 floats | Local position of inertial frame |
| optional | baseInertialFrameOrientation | vec4, list of 4 floats | Local orientation of inertial frame, [x,y,z,w] |
| optional | linkMasses | list of float | List of the mass values, one for each link. |
| optional | linkCollisionShapeIndices | list of int | List of the unique id, one for each link. |
| optional | linkVisualShapeIndices | list of int | list of the visual shape unique id for each link |
| optional | linkPositions | list of vec3 | list of local link positions, with respect to parent |
| optional | linkOrientations | list of vec4 | list of local link orientations, w.r.t. parent |
| optional | linkInertialFramePositions | list of vec3 | list of local inertial frame pos. in link frame |
| optional | linkInertialFrameOrientations | list of vec4 | list of local inertial frame orn. in link frame |
| optional | linkParentIndices | list of int | Link index of the parent link or 0 for the base. |
| optional | linkJointTypes | list of int | list of joint types, one for each link. Only JOINT_REVOLUTE, JOINT_PRISMATIC, and JOINT_FIXED is supported at the moment. |
| optional | linkJointAxis | list of vec3 | Joint axis in local frame |
| optional | useMaximalCoordinates | int | experimental, best to leave it 0/false. |
| optional | flags | int | similar to the flags passed in loadURDF, for example URDF_USE_SELF_COLLISION. See loadURDF for flags explanation. |
| optional | physicsClientId | int | If you are connected to multiple servers, you can pick one. |

The return value of createMultiBody is a non-negative unique id or -1 for failure. Example:

```
cuid = pybullet.createCollisionShape(pybullet.GEOM_BOX, halfExtents = [1, 1, 1])
mass= 0 #static box
pybullet.createMultiBody(mass,cuid)
```

See also createMultiBodyLinks.py, createObstacleCourse.py and createVisualShape.py in the Bullet/examples/pybullet/examples folder.

# stepSimulation

stepSimulation will perform all the actions in a single forward dynamics simulation step such as collision detection, constraint solving and integration. The default timestep is 1/240 second, it can be changed using the setTimeStep or setPhysicsEngineParameter API.

stepSimulation input arguments are optional:

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

stepSimulation has no return values.

See also setRealTimeSimulation to automatically let the physics server run forward dynamics simulation based on its real-time clock.

# setRealTimeSimulation

By default, the physics server will not step the simulation, unless you explicitly send a 'stepSimulation' command. This way you can maintain control determinism of the simulation. It is possible to run the simulation in real-time by letting the physics server automatically step the simulation according to its real-time-clock (RTC) using the setRealTimeSimulation command. If you enable the real-time simulation, you don't need to call 'stepSimulation'.

Note that setRealTimeSimulation has no effect in DIRECT mode: in DIRECT mode the physics server and client happen in the same thread and you trigger every command. In GUI mode and in Virtual Reality mode, and TCP/UDP mode, the physics server runs in a separate thread from the client (PyBullet), and setRealTimeSimulation allows the physicsserver thread to add additional calls to stepSimulation.

The input parameters are:

| | | | |
|---|---|---|---|
| required | enableRealTimeSimulation | int | 0 to disable real-time simulation, 1 to enable |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

# getBasePositionAndOrientation

getBasePositionAndOrientation reports the current position and orientation of the base (or root link) of the body in Cartesian world coordinates. The orientation is a quaternion in [x,y,z,w] format.

The getBasePositionAndOrientation input parameters are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id, as returned from loadURDF. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getBasePositionAndOrientation returns the position list of 3 floats and orientation as list of 4 floats in [x,y,z,w] order. Use getEulerFromQuaternion to convert the quaternion to Euler if needed.

See also resetBasePositionAndOrientation to reset the position and orientation of the object.

This completes the first PyBullet script. Bullet ships with several URDF files in the Bullet/data folder.

## resetBasePositionAndOrientation

You can reset the position and orientation of the base (root) of each object. It is best only to do this at the start, and not during a running simulation, since the command will override the effect of all physics simulation. The linear and angular velocity is set to zero. You can use resetBaseVelocity to reset to a non-zero linear and/or angular velocity.

The input arguments to resetBasePositionAndOrientation are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id, as returned from loadURDF. |
| required | posObj | vec3 | reset the base of the object at the specified position in world space coordinates [X,Y,Z] |
| required | ornObj | vec4 | reset the base of the object at the specified orientation as world space quaternion [X,Y,Z,W] |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

There are no return arguments.

## Transforms: Position and Orientation

The position of objects can be expressed in Cartesian world space coordinates [x,y,z]. The orientation (or rotation) of objects can be expressed using quaternions [x,y,z,w], euler angles [yaw, pitch, roll] or 3x3 matrices. PyBullet provides a few helper functions to convert between quaternions, euler angles and 3x3 matrices. In additions there are some functions to multiply and invert transforms.

## getQuaternionFromEuler and getEulerFromQuaternion

The PyBullet API uses quaternions to represent orientations. Since quaternions are not very intuitive for people, there are two APIs to convert between quaternions and Euler angles.
The getQuaternionFromEuler input arguments are:

| | | | |
|---|---|---|---|
| required | eulerAngle | vec3: list of 3 floats | The X,Y,Z Euler angles are in radians, accumulating 3 rotations expressing the roll around the X, pitch around Y and yaw around the Z axis. |
| optional | physicsClientId | int | unused, added for API consistency. |

getQuaternionFromEuler returns a quaternion, vec4 list of 4 floating point values [X,Y,Z,W].

## getEulerFromQuaternion

The getEulerFromQuaternion input arguments are:

| | | | |
|---|---|---|---|
| required | quaternion | vec4: list of 4 floats | The quaternion format is [x,y,z,w] |
| optional | physicsClientId | int | unused, added for API consistency. |

getEulerFromQuaternion returns alist of 3 floating point values, a vec3.

## getMatrixFromQuaternion

getMatrixFromQuaternion is a utility API to create a 3x3 matrix from a quaternion. The input is a quaternion and output a list of 9 floats, representing the matrix.

## multiplyTransforms, invertTransform

PyBullet provides a few helper functions to multiply and inverse transforms. This can be helpful to transform coordinates from one to the other coordinate system.

The input parameters of multiplyTransforms are:

| | | | |
|---|---|---|---|
| required | positionA | vec3, list of 3 floats | |

| | | | |
|---|---|---|---|
| required | orientationA | vec4, list of 4 floats | quaternion [x,y,z,w] |
| required | positionB | vec3, list of 3 floats | |
| required | orientationB | vec4, list of 4 floats | quaternion [x,y,z,w] |
| optional | physicsClientId | int | unused, added for API consistency. |

The return value is a list of position (vec3) and orientation (vec4, quaternion x,y,x,w).

The input and output parameters of invertTransform are:

| | | | |
|---|---|---|---|
| required | position | vec3, list of 3 floats | |
| required | orientation | vec4, list of 4 floats | quaternion [x,y,z,w] |

The output of invertTransform is a position (vec3) and orientation (vec4, quaternion x,y,x,w).

## getAPIVersion

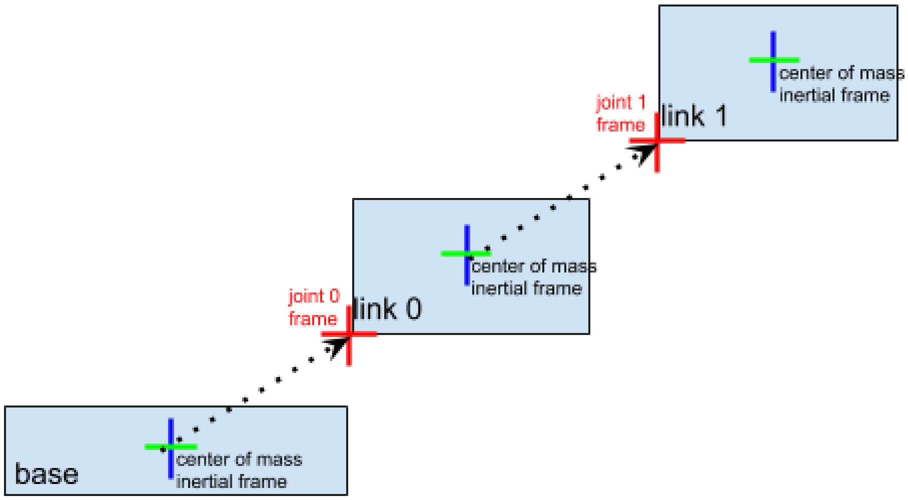
You can query for the API version in a year-month-0-day format. You can only connect between physics client/server of the same API version, with the same number of bits (32-bit / 64bit). There is a optional unused argument physicsClientId, added for API consistency.

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | unused, added for API consistency. |

# Controlling a robot

In the Introduction we already showed how to initialize PyBullet and load some objects. If you replace the file name in the loadURDF command with "r2d2.urdf" you can simulate a R2D2 robot from the ROS tutorial. Let's control this R2D2 robot to move, look around and control the gripper. For this we need to know how to access its joint motors.

## Base, Joints, Links




A simulated robot as described in a URDF file has a base, and optionally links connected by joints. Each joint connects one parent link to a child link. At the root of the hierarchy there is a single root parent that we call base. The base can be either fully fixed, 0 degrees of freedom, or fully free, with 6 degrees of freedom. Since each link is connected to a parent with a single joint, the number of joints is equal to the number of links. Regular links have link indices in the range [0..getNumJoints()] Since the base is not a regular 'link', we use the convention of -1 as its link index. We use the convention that joint frames are expressed relative to the parents center of mass inertial frame, which is aligned with the principle axis of inertia.

## getNumJoints, getJointInfo

After you load a robot you can query the number of joints using the getNumJoints API. For the r2d2.urdf this should return 15.

getNumJoints input parameters:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | the body unique id, as returned by loadURDF etc. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getNumJoints returns an integer value representing the number of joints.

## getJointInfo

For each joint we can query some information, such as its name and type.

getJointInfo input parameters

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | the body unique id, as returned by loadURDF etc. |

| | | | |
|---|---|---|---|
| required | jointIndex | int | an index in the range [0 .. getNumJoints(bodyUniqueId)) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getJointInfo returns a list of information:

| | | |
|---|---|---|
| jointIndex | int | the same joint index as the input parameter |
| jointName | string | the name of the joint, as specified in the URDF (or SDF etc) file |
| jointType | int | type of the joint, this also implies the number of position and velocity variables. JOINT_REVOLUTE, JOINT_PRISMATIC, JOINT_SPHERICAL, JOINT_PLANAR, JOINT_FIXED. See the section on Base, Joint and Links for more details. |
| qIndex | int | the first position index in the positional state variables for this body |
| uIndex | int | the first velocity index in the velocity state variables for this body |
| flags | int | reserved |
| jointDamping | float | the joint damping value, as specified in the URDF file |
| jointFriction | float | the joint friction value, as specified in the URDF file |
| jointLowerLimit | float | Positional lower limit for slider and revolute (hinge) joints. |
| jointUpperLimit | float | Positional upper limit for slider and revolute joints. Values ignored in case upper limit <lower limit. |
| jointMaxForce | float | Maximum force specified in URDF (possibly other file formats) Note that this value is not automatically used. You can use maxForce in 'setJointMotorControl2'. |
| jointMaxVelocity | float | Maximum velocity specified in URDF. Note that the maximum velocity is not used in actual motor control commands at the moment. |
| linkName | string | the name of the link, as specified in the URDF (or SDF etc.) file |
| jointAxis | vec3 | joint axis in local frame (ignored for JOINT_FIXED) |
| parentFramePos | vec3 | joint position in parent frame |
| parentFrameOrn | vec3 | joint orientation in parent frame |
| parentIndex | int | parent link index, -1 for base |

# setJointMotorControl2/Array

Note: *setJointMotorControl is obsolete and replaced by setJointMotorControl2 API. (Or even better use setJointMotorControlArray).*

We can control a robot by setting a desired control mode for one or more joint motors. During the stepSimulation the physics engine will simulate the motors to reach the given target value that can be reached within the maximum motor forces and other constraints. Each revolute joint and prismatic joint is motorized by default. There are 3 different motor control modes: position control, velocity control and torque control.

You can effectively disable the motor by using a force of 0. You need to disable motor in order to use direct torque control. For example:

```
maxForce = 0
mode = p.VELOCITY_CONTROL
p.setJointMotorControl2(objUid, jointIndex,
     controlMode=mode, force=maxForce)
```

If you want a wheel to maintain a constant velocity, with a max force you can use:

```
maxForce = 500
p.setJointMotorControl2(bodyUniqueId=objUid,
                jointIndex=0,
                controlMode=p.VELOCITY_CONTROL,
                targetVelocity = targetVel,
                force = maxForce)
```

The input arguments to setJointMotorControl2 are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned from loadURDF etc. |
| required | jointIndex | int | link index in range [0..getNumJoints(bodyUniqueId) (note that link index == joint index) |
| required | controlMode | int | POSITION_CONTROL (which is in fact CONTROL_MODE_POSITION_VELOCITY_PD), VELOCITY_CONTROL, TORQUE_CONTROL |
| optional | targetPosition | float | in POSITION_CONTROL the targetValue is target position of the joint |
| optional | targetVelocity | float | in VELOCITY_CONTROL and POSITION_CONTROL the targetVelocity is the desired velocity of the joint, see implementation note below. Note that the targetVelocity is not the maximum joint velocity. In POSITION_CONTROL/CONTROL_MODE_POSITION_VELOCITY_PD, the final target velocity is computed using: kp*(erp*(desiredPosition-currentPosition)/dt)+currentVelocity+kd*(m_desiredVelocity - currentVelocity)<br><br>. |
| optional | force | float | in POSITION_CONTROL and VELOCITY_CONTROL this is the maximum motor force used to reach the target value. In TORQUE_CONTROL this is the force/torque to be applied each simulation step. |

| | | | |
|---|---|---|---|
| optional | positionGain | float | See implementation note below |
| optional | velocityGain | float | See implementation note below |
| optional | maxVelocity | float | in POSITION_CONTROL this limits the velocity to a maximum |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

Note: the actual implementation of the joint motor controller is as a constraint for POSITION_CONTROL and VELOCITY_CONTROL, and as an external force for TORQUE_CONTROL:

| method | implementation | component | constraint error to be minimized |
|---|---|---|---|
| POSITION_CONTROL | constraint | velocity and position constraint | error = position_gain*(desired_position-actual_position)+velocity_gain*(desired_velocity-actual_velocity) |
| VELOCITY_CONTROL | constraint | pure velocity constraint | error = desired_velocity - actual_velocity |
| TORQUE_CONTROL | external force | | |

Generally it is best to start with VELOCITY_CONTROL or POSITION_CONTROL. It is much harder to do TORQUE_CONTROL (force control) since simulating the correct forces relies on very accurate URDF/SDF file parameters and system identification (correct masses, inertias, center of mass location, joint friction etc).

## setJointMotorControlArray

Instead of making individual calls for each joint, you can pass arrays for all inputs to reduce calling overhead dramatically.

setJointMotorControlArray takes the same parameters as setJointMotorControl2, except replacing integers with lists of integers.

The input arguments to setJointMotorControlArray are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned from loadURDF etc. |
| required | jointIndices | list of int | index in range [0..getNumJoints(bodyUniqueId) (note that link index == joint index) |
| required | controlMode | int | POSITION_CONTROL, VELOCITY_CONTROL, TORQUE_CONTROL |
| optional | targetPositions | list of float | in POSITION_CONTROL the targetValue is target position of the joint |

| | | | |
|---|---|---|---|
| optional | targetVelocities | list of float | in VELOCITY_CONTROL and POSITION_CONTROL the targetValue is target velocity of the joint, see implementation note below. |
| optional | forces | list of float | in POSITION_CONTROL and VELOCITY_CONTROL this is the maximum motor force used to reach the target value. In TORQUE_CONTROL this is the force/torque to be applied each simulation step. |
| optional | positionGains | list of float | See implementation note below |
| optional | velocityGains | list of float | See implementation note below |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

See bullet3/examples/pybullet/tensorflow/humanoid_running.py for an example of using setJointMotorControlArray.

# getJointState(s), resetJointState

We can query several state variables from the joint using getJointState, such as the joint position, velocity, joint reaction forces and joint motor torque.

getJointState input parameters

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned by loadURDF etc |
| required | jointIndex | int | link index in range [0..getNumJoints(bodyUniqueId)] |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getJointState output

| | | |
|---|---|---|
| jointPosition | float | The position value of this joint. |
| jointVelocity | float | The velocity value of this joint. |
| jointReactionForces | list of 6 floats | These are the joint reaction forces, if a torque sensor is enabled for this joint it is [Fx, Fy, Fz, Mx, My, Mz]. Without torque sensor, it is [0,0,0,0,0,0]. |
| appliedJointMotorTorque | float | This is the motor torque applied during the last stepSimulation. Note that this only applies in VELOCITY_CONTROL and POSITION_CONTROL. If you use TORQUE_CONTROL then the applied joint motor torque is exactly what you provide, so there is no need to report it separately. |

getJointStates is the array version of getJointState. Instead of passing in a single jointIndex, you pass in a list of jointIndices.

## resetJointState

You can reset the state of the joint. It is best only to do this at the start, while not running the simulation: resetJointState overrides all physics simulation. Note that we only support 1-DOF motorized joints at the moment, sliding joint or revolute joints.

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned by loadURDF etc |
| required | jointIndex | int | joint index in range [0..getNumJoints(bodyUniqueId)] |
| required | targetValue | float | the joint position (angle in radians or position) |
| optional | targetVelocity | float | the joint velocity (angular or linear velocity) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

## enableJointForceTorqueSensor

You can enable or disable a joint force/torque sensor in each joint. Once enabled, if you perform a stepSimulation, the 'getJointState' will report the joint reaction forces in the fixed degrees of freedom: a fixed joint will measure all 6DOF joint forces/torques. A revolute/hinge joint force/torque sensor will measure 5DOF reaction forces along all axis except the hinge axis. The applied force by a joint motor is available in the appliedJointMotorTorque of getJointState.

The input arguments to enableJointForceTorqueSensor are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned by loadURDF etc |
| required | jointIndex | int | joint index in range [0..getNumJoints(bodyUniqueId)] |
| optional | enableSensor | int | 1/True to enable, 0/False to disable the force/torque sensor |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

## getLinkState

You can also query the Cartesian world position and orientation for the center of mass of each link using getLinkState. It will also report the local inertial frame of the center of mass to the URDF link frame, to make it easier to compute the graphics/visualization frame.

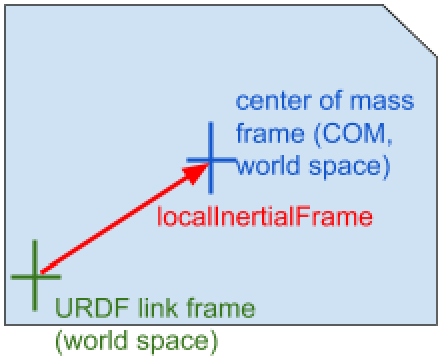
getLinkState input parameters

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id as returned by loadURDF etc |
| required | linkIndex | int | link index |
| optional | computeLinkVelocity | int | If set to 1, the Cartesian world velocity will be computed and returned. |
| optional | computeForwardKinematics | int | if set to 1 (or True), the Cartesian world position/orientation will be recomputed using forward kinematics. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getLinkState return values

| | | |
|---|---|---|
| linkWorldPosition | vec3, list of 3 floats | Cartesian position of center of mass |
| linkWorldOrientation | vec4, list of 4 floats | Cartesian orientation of center of mass, in quaternion [x,y,z,w] |
| localInertialFramePosition | vec3, list of 3 floats | local position offset of inertial frame (center of mass) expressed in the URDF link frame |
| localInertialFrameOrientation | vec4, list of 4 floats | local orientation (quaternion [x,y,z,w]) offset of the inertial frame expressed in URDF link frame. |
| worldLinkFramePosition | vec3, list of 3 floats | world position of the URDF link frame |
| worldLinkFrameOrientation | vec4, list of 4 floats | world orientation of the URDF link frame |
| worldLinkLinearVelocity | vec3, list of 3 floats | Cartesian world velocity. Only returned if computeLinkVelocity non-zero. |
| worldLinkAngularVelocity | vec3, list of 3 floats | Cartesian world velocity. Only returned if computeLinkVelocity non-zero. |

The relationship between URDF link frame and the center of mass frame (both in world space) is: urdfLinkFrame = comLinkFrame * localInertialFrame.inverse(). For more information about the link and inertial frame, see the ROS URDF tutorial.




Example scripts (could be out-of-date, check actual Bullet/examples/pybullet/examples folder.)

| | |
|---|---|
| examples/pybullet/tensorflow/humanoid_running.py | load a humanoid and use a trained neural network to control the running using TensorFlow, trained by OpenAI |
| examples/pybullet/gym/pybullet_envs/bullet/minitaur.py and minitaur_gym_env.py | Minitaur environment for OpenAI GYM and TensorFlow<br>You can also use python -m pybullet_envs.examples.minitaur_gym_env_example after you did pip install pybullet to see the Minitaur in action. |
| examples/pybullet/examples/quadruped.py | load a quadruped from URDF file, step the simulation, control the motors for a simple hopping gait based on sine waves.Will also log the state to file using p.startStateLogging. See video. |
| examples/quadruped_playback.py | Create a quadruped (Minitaur), read log file and set positions as motor control targets. |
| examples/pybullet/examples/testrender.py | load a URDF file and render an image, get the pixels (RGB, depth, segmentation mask) and display the image using MatPlotLib. |
| examples/pybullet/examples/testrender_np.py | Similar to testrender.py, but speed up the pixel transfer using NumPy arrays. Also includes simple benchmark/timings. |
| examples/pybullet/examples/saveWorld.py | Save the state (position, orientation) of objects into a pybullet Python scripts. This is mainly useful to setup a scene in VR and save the initial state. Not all state is serialized. |
| examples/pybullet/examples/inverse_kinematics.py | Show how to use the calculateInverseKinematics command, creating a Kuka ARM clock |
| examples/pybullet/examples/rollPitchYaw.py | Show how to use slider GUI widgets |
| examples/pybullet/examples/constraint.py | Programmatically create a constraint between links. |
| examples/pybullet/examples/vrhand.py | Control a hand using a VR glove, tracked by a VR controller. See video. |

## getBaseVelocity, resetBaseVelocity

You get access to the linear and angular velocity of the base of a body using getBaseVelocity. The input parameters are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id, as returned from the load* methods. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

This returns a list of two vector3 values (3 floats in a list) representing the linear velocity [x,y,z] and angular velocity [wx,wy,wz] in Cartesian worldspace coordinates.

You can reset the linear and/or angular velocity of the base of a body using resetBaseVelocity. The input parameters are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | body unique id, as returned from the load* methods. |
| optional | linearVelocity | vec3, list of 3 floats | linear velocity [x,y,z] in Cartesian world coordinates. |
| optional | angularVelocity | vec3, list of 3 floats | angular velocity [wx,wy,wz] in Cartesian world coordinates. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

## applyExternalForce/Torque

You can apply a force or torque to a body using applyExternalForce and applyExternalTorque. Note that this method will only work when explicitly stepping the simulation using stepSimulation, in other words: setRealTimeSimulation(0). After each simulation step, the external forces are cleared to zero. If you are using 'setRealTimeSimulation(1), applyExternalForce/Torque will have undefined behavior (either 0, 1 or multiple force/torque applications).

The input parameters are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id as returned by load methods. |
| required | linkIndex | int | link index or -1 for the base. |
| required | forceObj | vec3, list of 3 floats | force/torque vector to be applied [x,y,z]. See flags for coordinate system. |
| required | posObj | vec3, list of 3 floats | position on the link where the force is applied. Only for applyExternalForce. See flags for coordinate system. |

| | | | |
|---|---|---|---|
| required | flags | int | Specify the coordinate system of force/position: either WORLD_FRAME for Cartesian world coordinates or LINK_FRAME for local link coordinates. |
| optional | physicsClientId | int | |

## getNumBodies, getBodyInfo, getBodyUniqueId, removeBody

getNumBodies will return the total number of bodies in the physics server.
If you used 'getNumBodies' you can query the body unique ids using 'getBodyUniqueId'. Note that all APIs already return body unique ids, so you typically never need to use getBodyUniqueId if you keep track of them.

**getBodyInfo** will return the base name, as extracted from the URDF, SDF, MJCF or other file.
**removeBody** will remove a body by its body unique id (from loadURDF, loadSDF etc).

## createConstraint, removeConstraint, changeConstraint

URDF, SDF and MJCF specify articulated bodies as a tree-structures without loops. The 'createConstraint' allows you to connect specific links of bodies to close those loops. See Bullet/examples/pybullet/examples/quadruped.py how to connect the legs of a quadruped 5-bar closed loop linkage. In addition, you can create arbitrary constraints between objects, and between an object and a specific world frame. See Bullet/examples/pybullet/examples/constraint.py for an example.
It can also be used to control the motion of physics objects, driven by animated frames, such as a VR controller. It is better to use constraints, instead of setting the position or velocity directly for such purpose, since those constraints are solved together with other dynamics constraints.

createConstraint has the following input parameters:

| | | | |
|---|---|---|---|
| required | parentBodyUniqueId | int | parent body unique id |
| required | parentLinkIndex | int | parent link index (or -1 for the base) |
| required | childBodyUniqueId | int | child body unique id, or -1 for no body (specify a non-dynamic child frame in world coordinates) |
| required | childLinkIndex | int | child link index, or -1 for the base |
| required | jointType | int | joint type: JOINT_PRISMATIC, JOINT_FIXED, |

| | | | |
|---|---|---|---|
| | | | JOINT_POINT2POINT, JOINT_GEAR |
| required | jointAxis | vec3, list of 3 floats | joint axis, in child link frame |
| required | parentFramePosition | vec3, list of 3 floats | position of the joint frame relative to parent center of mass frame. |
| required | childFramePosition | vec3, list of 3 floats | position of the joint frame relative to a given child center of mass frame (or world origin if no child specified) |
| optional | parentFrameOrientation | vec4, list of 4 floats | the orientation of the joint frame relative to parent center of mass coordinate frame |
| optional | childFrameOrientation | vec4, list of 4 floats | the orientation of the joint frame relative to the child center of mass coordinate frame (or world origin frame if no child specified) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

createConstraint will return an integer unique id, that can be used to change or remove the constraint. See examples/pybullet/examples/mimicJointConstraint.py for an example of a JOINT_GEAR and examples/pybullet/examples/minitaur.py for a JOINT_POINT2POINT and examples/pybullet/examples/constraint.py for JOINT_FIXED.

# changeConstraint

changeConstraint allows you to change parameters of an existing constraint. The input parameters are:

| | | | |
|---|---|---|---|
| required | userConstraintUniqueId | int | unique id returned by createConstraint |
| optional | jointChildPivot | vec3, list of 3 floats | updated child pivot, see 'createConstraint' |
| optional | jointChildFrameOrientation | vec4, list of 4 floats | updated child frame orientation as quaternion |
| optional | maxForce | float | maximum force that constraint can apply |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

See also Bullet/examples/pybullet/examples/constraint.py

removeConstraint will remove a constraint, given by its unique id. Its input parameters are:

| | | | |
|---|---|---|---|
| required | userConstraintUniqueId | int | unique id as returned by createConstraint |

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | unique id as returned by 'connect' |

## getNumConstraints, getConstraintUniqueId

You can query for the total number of constraints, created using 'createConstraint'. Optional parameter is the int physicsClientId.

## getConstraintUniqueId

getConstraintUniqueId will take a serial index in range 0..getNumConstraints, and reports the constraint unique id. Note that the constraint unique ids may not be contiguous, since you may remove constraints. The input is the integer serial index and optionally a physicsClientId.

## getConstraintInfo/State

You can query the constraint info give a constraint unique id.
The input parameters are

| | | | |
|---|---|---|---|
| required | constraintUniqueId | int | unique id as returned by createConstraint |
| optional | physicsClientId | int | unique id as returned by 'connect' |

The output list is:

| | | |
|---|---|---|
| parentBodyUniqueId | int | See createConstraint |
| parentJointIndex | int | See createConstraint |
| childBodyUniqueId | int | See createConstraint |
| childLinkIndex | int | See createConstraint |
| constraintType | int | See createConstraint |
| jointAxis | vec3, list of 3 floats | See createConstraint |
| jointPivotInParent | vec3, list of 3 floats | See createConstraint |
| jointPivotInChild | vec3, list of 3 floats | See createConstraint |
| jointFrameOrientationParent | vec4, list of 4 floats | See createConstraint |
| jointFrameOrientationChild | vec4, list of 4 floats | See createConstraint |
| maxAppliedForce | float | See createConstraint |

## getConstraintState

Give a constraint unique id, you can query for the applied constraint forces in the most recent simulation step. The input is a constraint unique id and the output is a vector of constraint forces, its dimension is the degrees of freedom that are affected by the constraint (a fixed constraint affects 6 DoF for example).

## getDynamicsInfo/changeDynamics

You can get information about the mass, center of mass, friction and other properties of the base and links.

The input parameters to getDynamicsInfo are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | object unique id, as returned by loadURDF etc. |
| required | linkIndex | int | link (joint) index or -1 for the base. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The return information is limited, we will expose more information when we need it:

| | | |
|---|---|---|
| mass | double | mass in kg |
| lateral_friction | double | friction coefficient |
| local inertia diagonal | vec3, list of 3 floats | local inertia diagonal. Note that links and base are centered around the center of mass and aligned with the principal axes of inertia. |
| local inertial pos | vec3 | position of inertial frame in local coordinates of the joint frame |
| local inertial orn | vec4 | orientation of inertial frame in local coordinates of joint frame |
| restitution | double | coefficient of restitution |
| rolling friction | double | rolling friction coefficient orthogonal to contact normal |
| spinning friction | double | spinning friction coefficient around contact normal |
| contact damping | double | -1 if not available. damping of contact constraints. |
| contact stiffness | double | -1 if not available. stiffness of contact constraints. |

# changeDynamics

You can change the properties such as mass, friction and restitution coefficients using changeDynamics.

The input parameters are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | object unique id, as returned by loadURDF etc. |
| required | linkIndex | int | link index or -1 for the base |
| optional | mass | double | change the mass of the link (or base for linkIndex -1) |
| optional | lateralFriction | double | lateral (linear) contact friction |
| optional | spinningFriction | double | torsional friction around the contact normal |
| optional | rollingFriction | double | torsional friction orthogonal to contact normal |
| optional | restitution | double | bouncyness of contact. Keep it a bit less than 1. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |
| optional | linearDamping | double | linear damping of the link (0.04 by default) |
| optional | angularDamping | double | angular damping of the link (0.04 by default) |
| optional | contactStiffness | double | stiffness of the contact constraints, used together with contactDamping. |
| optional | contactDamping | double | damping of the contact constraints for this body/link. Used together with contactStiffness. This overrides the value if it was specified in the URDF file in the contact section. |
| optional | frictionAnchor | int | enable or disable a friction anchor: positional friction correction (disabled by default, unless set in the URDF contact section) |
| optional | localInertiaDiagnoal | vec3 | diagonal elements of the inertia tensor. Note that the base and links are centered around the center of mass and aligned with the principal axes of inertia so there are no off-diagonal elements in the inertia tensor. |

# setTimeStep

You can set the physics engine timestep that is used when calling 'stepSimulation'. It is best to only call this method at the start of a simulation. Don't change this time step regularly. setTimeStep can also be achieved using the new setPhysicsEngineParameter API.

The input parameters are:

| | | | |
|---|---|---|---|
| required | timeStep | float | Each time you call 'stepSimulation' the timeStep will proceed with 'timeStep'. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

# setPhysicsEngineParameter

You can set physics engine parameters using the setPhysicsEngineParameter API. The following input parameters are exposed:

| | | | |
|---|---|---|---|
| optional | fixedTimeStep | float | physics engine timestep in fraction of seconds, each time you call 'stepSimulation'. Same as 'setTimeStep' |
| optional | numSolverIterations | int | Choose the maximum number of constraint solver iterations. If the solverResidualThreshold is reached, the solver may terminate before the numSolverIterations. |
| optional | useSplitImpulse | int | Advanced feature, only when using maximal coordinates: split the positional constraint solving and velocity constraint solving in two stages, to prevent huge penetration recovery forces. |
| optional | splitImpulsePenetrationThreshold | float | Related to 'useSplitImpulse': if the penetration for a particular contact constraint is less than this specified threshold, no split impulse will happen for that contact. |
| optional | numSubSteps | int | Subdivide the physics simulation step further by 'numSubSteps'. This will trade performance over accuracy. |
| optional | collisionFilterMode | int | Use 0 for default collision filter: (group A&maskB) AND (groupB&maskA). Use 1 to switch to the OR collision filter: (group A&maskB) OR (groupB&maskA) |
| optional | contactBreakingThreshold | float | Contact points with distance exceeding this threshold are not processed by the LCP solver. In addition, AABBs are extended by this number. Defaults to 0.02 in Bullet 2.x. |
| optional | maxNumCmdPer1ms | int | Experimental: add 1ms sleep if the number of commands executed exceed this threshold. |

| | | | |
|---|---|---|---|
| optional | enableFileCaching | int | Set to 0 to disable file caching, such as .obj wavefront file loading |
| optional | restitutionVelocityThreshold | float | If relative velocity is below this threshold, restitution will be zero. |
| optional | erp | float | constraint error reduction parameter (non-contact, non-friction) |
| optional | contactERP | float | contact error reduction parameter |
| optional | frictionERP | float | friction error reduction parameter (when positional friction anchors are enabled) |
| optional | enableConeFriction | int | Set to 0 to disable implicit cone friction and use pyramid approximation (cone is default) |
| optional | deterministicOverlappingPairs | int | Set to 1 to enable and 0 to disable sorting of overlapping pairs (backward compatibility setting). |
| optional | solverResidualThreshold | double | velocity threshold, if the maximum error for each constraint is below this threshold the solver will terminate (unless the solver hits the numSolverIterations) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

setDefaultContactERP is an API to set the default contact parameter setting. It will be rolled into the setPhysicsEngineParameter API.

## getPhysicsEngineParameters

You can query some current physics engine parameters using the getPhysicsEngineParameters command, using the optional 'physicsClientId'. This will return named tuples of parameters.

## resetSimulation

resetSimulation will remove all objects from the world and reset the world to initial conditions. It takes one optional parameter: the physics client Id (in case you created multiple physics server connections).

## startStateLogging/stopStateLogging

State logging lets you log the state of the simulation, such as the state of one or more objects after each simulation step (after each call to stepSimulation or automatically after each simulation step when setRealTimeSimulation is enabled). This allows you to record trajectories of objects. There is also the option to log the common state of bodies such as base position and orientation, joint positions (angles) and joint motor forces.

All log files generated using startStateLogging can be read using C++ or Python scripts. See quadruped_playback.py and kuka_with_cube_playback.py for Python scripts reading the log files. You can use bullet3/examples/Utils/RobotLoggingUtil.cpp/h to read the log files in C++.

For MP4 video recording you can use the logging option STATE_LOGGING_VIDEO_MP4. We plan to implement various other types of logging, including logging the state of VR controllers.

As a special case, we implemented the logging of the Minitaur robot. The log file from PyBullet simulation is identical to the real Minitaur quadruped log file. See Bullet/examples/pybullet/examples/logMinitaur.py for an example.

Important: various loggers include their own internal timestamp that starts at zero when created. This means that you need to start all loggers at the same time, to be in sync. You need to make sure to that the simulation is not running in real-time mode, while starting the loggers: use pybullet.setRealTimeSimulation(0) before creating the loggers.

| | | | |
|---|---|---|---|
| required | loggingType | int | There are various types of logging implemented.<br><br>STATE_LOGGING_MINITAUR: This will require to load the quadruped/quadruped.urdf and object unique id from the quadruped. It logs the timestamp, IMU roll/pitch/yaw, 8 leg motor positions (q0-q7), 8 leg motor torques (u0-u7), the forward speed of the torso and mode (unused in simulation).<br><br>STATE_LOGGING_GENERIC_ROBOT: This will log a log of the data of either all objects or selected ones (if objectUniqueIds is provided).<br><br>STATE_LOGGING_VIDEO_MP4: this will open an MP4 file and start streaming the OpenGL 3D visualizer pixels to the file using an ffmpeg pipe. It will require ffmpeg installed. You can also use avconv (default on Ubuntu), just create a symbolic link so that ffmpeg points to avconv. On Windows, ffmpeg has some issues that cause tearing/color artifacts in some cases.<br><br>STATE_LOGGING_CONTACT_POINTS<br><br>STATE_LOGGING_VR_CONTROLLERS.<br><br>STATE_LOGGING_PROFILE_TIMINGS<br>This will dump a timings file in JSON format that can be opened using Google Chrome about://tracing LOAD. |
| required | fileName | string | file name (absolute or relative path) to store the log file data. |
| optional | objectUniqueIds | list of int | If left empty, the logger may log every object, otherwise the logger just logs the objects in the objectUniqueIds list. |

| | | | |
|---|---|---|---|
| optional | maxLogDof | int | Maximum number of joint degrees of freedom to log (excluding the base dofs). This applies to STATE_LOGGING_GENERIC_ROBOT_DATA. Default value is 12. If a robot exceeds the number of dofs, it won't get logged at all. |
| optional | bodyUniqueIdA | int | Applies to STATE_LOGGING_CONTACT_POINTS. If provided,only log contact points involving bodyUniqueIdA. |
| optional | bodyUniqueIdB | int | Applies to STATE_LOGGING_CONTACT_POINTS. If provided,only log contact points involving bodyUniqueIdB. |
| optional | linkIndexA | int | Applies to STATE_LOGGING_CONTACT_POINTS. If provided,only log contact points involving linkIndexA for bodyUniqueIdA. |
| optional | linkIndexB | int | Applies to STATE_LOGGING_CONTACT_POINTS. If provided,only log contact points involving linkIndexB for bodyUniqueIdA. |
| optional | deviceTypeFilter | int | deviceTypeFilter allows you to select what VR devices to log: VR_DEVICE_CONTROLLER, VR_DEVICE_HMD ,VR_DEVICE_GENERIC_TRACKER or any combination of them. Applies to STATE_LOGGING_VR_CONTROLLERS. Default values is VR_DEVICE_CONTROLLER. |
| optional | logFlags | int | (upcoming PyBullet 1.3.1). STATE_LOG_JOINT_TORQUES, to log joint torques due to joint motors. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The command will return a non-negative int loggingUniqueId, that can be used with stopStateLogging.

Todo: document the data that is logged for each logging type. For now, use the log reading utilities to find out, or check out the C++ source code of the logging or Python dumpLog.py script.

## stopStateLogging

You can stop a logger using its loggingUniqueId.

submitProfileTiming

PyBullet and Bullet have instrumented many functions so you can see where the time is spend. You can dump those profile timings in a file, that can be viewed with Google Chrome in the about://tracing window using the LOAD feature. In the GUI, you can press 'p' to start/stop the profile dump. In some cases you may want to instrument the timings of your client code. You can submit profile timings using PyBullet. Here is an example output:

# Synthetic Camera Rendering

PyBullet has both a build-in OpenGL GPU visualizer and a build-in CPU renderer based on TinyRenderer. This makes it very easy to render images from an arbitrary camera position.

The synthetic camera is specified by two 4 by 4 matrices: the view matrix and the projection matrix. Since those are not very intuitive, there are some helper methods to compute the view and projection matrix from understandable parameters.

## computeViewMatrix

The computeViewMatrix input parameters are

| | | | |
|---|---|---|---|
| required | cameraEyePosition | vec3, list of 3 floats | eye position in Cartesian world coordinates |
| required | cameraTargetPosition | vec3, list of 3 floats | position of the target (focus) point, in Cartesian world coordinates |
| required | cameraUpVector | vec3, list of 3 floats | up vector of the camera, in Cartesian world coordinates |
| optional | physicsClientId | int | unused,added for API consistency |

Output is the 4x4 view matrix, stored as a list of 16 floats.

## computeViewMatrixFromYawPitchRoll

The input parameters are

| | | | |
|---|---|---|---|
| required | cameraTargetPosition | list of 3 floats | target focus point in Cartesian world coordinates |
| required | distance | float | distance from eye to focus point |
| required | yaw | float | yaw angle in degrees left/right around up-axis. |
| required | pitch | float | pitch in degrees up/down. |
| required | roll | float | roll in degrees around forward vector |
| required | upAxisIndex | int | either 1 for Y or 2 for Z axis up. |
| optional | physicsClientId | int | unused, added for API consistency. |

Output is the 4x4 view matrix, stored as a list of 16 floats.

## computeProjectionMatrix

The input parameters are

| | | | |
|---|---|---|---|
| required | left | float | left screen (canvas) coordinate |
| required | right | float | right screen (canvas) coordinate |
| required | bottom | float | bottom screen (canvas) coordinate |
| required | top | float | top screen (canvas) coordinate |
| required | near | float | near plane distance |
| required | far | float | far plane distance |
| optional | physicsClientId | int | unused, added for API consistency. |

Output is the 4x4 projection matrix, stored as a list of 16 floats.

## computeProjectionMatrixFOV

This command also will return a 4x4 projection matrix, using different parameters. You can check out OpenGL documentation for the meaning of the parameters.
The input parameters are:

| | | | |
|---|---|---|---|
| required | fov | float | field of view |
| required | aspect | float | aspect ratio |
| required | nearVal | float | near plane distance |
| required | farVal | float | far plane distance |
| optional | physicsClientId | int | unused, added for API consistency. |

## getCameraImage

The getCameraImage API will return a RGB image, a depth buffer and a segmentation mask buffer with body unique ids of visible objects for each pixel. Note that PyBullet can be compiled using the numpy option: using numpy will improve the performance of copying the camera pixels from C to Python. Note: the old renderImage API is obsolete and replaced by getCameraImage.

getCameraImage input parameters:

| | | | |
|---|---|---|---|
| required | width | int | horizontal image resolution in pixels |
| required | height | int | vertical image resolution in pixels |
| optional | viewMatrix | 16 floats | 4x4 view matrix, see computeViewMatrix* |
| optional | projectionMatrix | 16 floats | 4x4 projection matrix, see computeProjection* |
| optional | lightDirection | vec3, list of 3 floats | light direction |
| optional | lightColor | vec3, list of 3 floats | directional light color in [RED,GREEN,BLUE] in range 0..1 |
| optional | lightDistance | float | distance of the light along the normalized lightDirection |
| optional | shadow | int | 1 for shadows, 0 for no shadows |
| optional | lightAmbientCoeff | float | light ambient coefficient |
| optional | lightDiffuseCoeff | float | light diffuse coefficient |
| optional | lightSpecularCoeff | float | light specular coefficient |
| optional | renderer | int | ER_BULLET_HARDWARE_OPENGL or ER_TINY_RENDERER. Note that DIRECT mode has no OpenGL, so it requires ER_TINY_RENDERER. |
| optional | flags | int | ER_SEGMENTATION_MASK_OBJECT_AND_LINKINDEX, See below in description of segmentationMaskBuffer and example code. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getCameraImage returns a list of parameters:

| | | |
|---|---|---|
| width | int | width image resolution in pixels (horizontal) |
| height | int | height image resolution in pixels (vertical) |
| rgbPixels | list of [char RED,char GREEN,char BLUE, char ALPHA] [0..width*height] | list of pixel colors in R,G,B,A format, in range [0..255] for each color |
| depthPixels | list of float [0..width*height] | depth buffer |
| segmentationMaskBuffer | list of int [0..width*height] | Only available when using ER_TINY_RENDERER.<br>For each pixels the visible object |

| | | |
|---|---|---|
| | | unique id. If ER_SEGMENTATION_MASK_OBJECT_AND_LINKINDEX is used, the segmentationMaskBuffer combines the object unique id and link index as follows:<br>value = objectUniqueId + (linkIndex+1)<<24. See example.<br><br>So for a free floating body without joints/links, the segmentation mask is equal to its body unique id, since its link index is -1. |

Note that copying pixels from C/C++ to Python can be really slow for large images, unless you compile PyBullet using NumPy. You can check if NumPy is enabled using PyBullet.isNumpyEnabled().

## getVisualShapeData

You can access visual shape information using getVisualShapeData. You could use this to bridge your own rendering method with PyBullet simulation, and synchronize the world transforms manually after each simulation step.

The input parameters are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id, as returned by a load method. |
| optional | physicsClientId | int | physics client id as returned by 'connect' |

The output is a list of visual shape data, each visual shape is in the following format:

| | | |
|---|---|---|
| objectUniqueId | int | object unique id, same as the input |
| linkIndex | int | link index or -1 for the base |
| visualGeometryType | int | visual geometry type (TBD) |
| dimensions | vec3, list of 3 floats | dimensions (size, local scale) of the geometry |
| meshAssetFileName | string, list of chars | path to the triangle mesh, if any. Typically relative to the URDF, SDF or MJCF file location, but could be absolute. |
| localVisualFrame position | vec3, list of 3 floats | position of local visual frame, relative to link/joint frame |
| localVisualFrame orientation | vec4, list of 4 floats | orientation of local visual frame relative to link/joint frame |
| rgbaColor | vec4, list of 4 floats | URDF color (if any specified) in red/green/blue/alpha |

The physics simulation uses center of mass as a reference for the Cartesian world transforms, in getBasePositionAndOrientation and in getLinkState. If you implement your own rendering, you need to transform the local visual transform to world space, making use of the center of mass world transform and the (inverse) localInertialFrame. You can access the localInertialFrame using the getLinkState API.

## changeVisualShape, loadTexture

You can use changeVisualShape to change the texture of a shape. This texture will currently only affect the software renderer (see getCameraImage), not the OpenGL visualization window (yet).

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id, as returned by load method. |
| required | jointIndex | int | link index |
| optional | shapeIndex | int | Experimental for internal use, recommended ignore shapeIndex or leave it -1. Intention was to let you pick a specific shape index to modify, since URDF (and SDF etc) can have more than 1 visual shape per link. This shapeIndex matches the list ordering returned by getVisualShapeData. |
| optional | textureUniqueId | int | texture unique id, as returned by 'loadTexture' method |
| optional | rgbaColor | vec4, list of 4 floats | color components for RED, GREEN, BLUE and ALPHA, each in range [0..1]. Alpha has to be 0 (invisible) or 1 (visible) at the moment (no transparancy yet). |
| optional | specularColor | vec3 | specular color components, RED, GREEN and BLUE, can be from 0 to large number (>100). |
| required | physicsClientId | int | physics client id as returned by 'connect' |

## loadTexture

Load a texture from file and return a non-negative texture unique id if the loading succeeds. This unique id can be used with changeVisualShape.

# Collision Detection Queries

You can query the contact point information that existed during the last 'stepSimulation'. To get the contact points you can use the 'getContactPoints' API. Note that the 'getContactPoints' will not recompute any contact point information.

# getOverlappingObjects, getAABB

This query will return all the unique ids of objects that have axis aligned bounding box overlap with a given axis aligned bounding box. Note that the query is conservative and may return additional objects that don't have actual AABB overlap. This happens because the acceleration structures have some heuristic that enlarges the AABBs a bit (extra margin and extruded along the velocity vector).

The getOverlappingObjects input parameters are:

| | | | |
|---|---|---|---|
| required | aabbMin | vec3, list of 3 floats | minimum coordinates of the aabb |
| required | aabbMax | vec3, list of 3 floats | maximum coordinates of the aabb |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The getOverlappingObjects will return a list of object unique ids.

## getAABB

You can query the axis aligned bounding box (in world space) given an object unique id, and optionally a link index. (when you don't pass the link index, or use -1, you get the AABB of the base).

The input parameters are

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | object unique id as returned by creation methods. |
| optional | linkIndex | int | link index in range [0..getNumJoints(..)] |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The return structure is a list of vec3, aabbMin (x,y,z) and aabbMax (x,y,z) in world space coordinates.

See also the getAABB.py example.

# getContactPoints, getClosestPoints

The getContactPoints API returns the contact points computed during the most recent call to stepSimulation. Its input parameters are as follows:

| | | | |
|---|---|---|---|
| optional | bodyA | int | only report contact points that involve body A |
| optional | bodyB | int | only report contact points that involve body B |
| optional | linkIndexA | int | Only report contact points that involve linkIndexA of bodyA |
| optional | linkIndexB | int | Only report contact points that involve linkIndexB of bodyB |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getContactPoints will return a list of contact points. Each contact point has the following fields:

| | | |
|---|---|---|
| contactFlag | int | reserved |
| bodyUniqueIdA | int | body unique id of body A |
| bodyUniqueIdB | int | body unique id of body B |
| linkIndexA | int | link index of body A, -1 for base |
| linkIndexB | int | link index of body B, -1 for base |
| positionOnA | vec3, list of 3 floats | contact position on A, in Cartesian world coordinates |
| positionOnB | vec3, list of 3 floats | contact position on B, in Cartesian world coordinates |
| contactNormalOnB | vec3, list of 3 floats | contact normal on B, pointing towards A |
| contactDistance | float | contact distance, positive for separation, negative for penetration |
| normalForce | float | normal force applied during the last 'stepSimulation' |

# getClosestPoints

It is also possible to compute the closest points, independent from stepSimulation. This also lets you compute closest points of objects with an arbitrary separating distance. In this query there will be no normal forces reported.

getClosestPoints input parameters:

| | | | |
|---|---|---|---|
| required | bodyA | int | object unique id for first object (A) |

| | | | |
|---|---|---|---|
| required | bodyB | int | object unique id for second object (B) |
| required | distance | float | If the distance between objects exceeds this maximum distance, no points may be returned. |
| optional | linkIndexA | int | link index for object A (-1 for base) |
| optional | linkIndexB | int | link index for object B (-1 for base) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

getClosestPoints returns a list of closest points in the same format as getContactPoints (but normalForce is always zero in this case)

# rayTest, rayTestBatch

You can perform a single raycast to find the intersection information of the first object hit.

The rayTest input parameters are:

| | | | |
|---|---|---|---|
| required | rayFromPosition | vec3, list of 3 floats | start of the ray in world coordinates |
| required | rayToPosition | vec3, list of 3 floats | end of the ray in world coordinates |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The raytest query will return the following information in case of an intersection:

| | | |
|---|---|---|
| objectUniqueId | int | object unique id of the hit object |
| linkIndex | int | link index of the hit object, or -1 if none/parent. |
| hit fraction | float | hit fraction along the ray in range [0,1] along the ray. |
| hit position | vec3, list of 3 floats | hit position in Cartesian world coordinates |
| hit normal | vec3, list of 3 floats | hit normal in Cartesian world coordinates |

# rayTestBatch

This is similar to the rayTest, but allows you to provide an array of rays, for faster execution. The size of 'rayFromPositions' needs to be equal to the size of 'rayToPositions'. You can one ray result per ray, even if there is no intersection: you need to use the objectUniqueId field to check if the ray has hit anything: if the objectUniqueId is -1, there is no hit. In that case, the 'hit fraction' is 1. The maximum number of rays per batch is pybullet.MAX_RAY_INTERSECTION_BATCH_SIZE.

The rayTest input parameters are:

| | | | |
|---|---|---|---|
| required | rayFromPositions | list of vec3, list of list of 3 floats | list of start points for each ray, in world coordinates |
| required | rayToPositions | list of vec3, list of list of 3 floats | list of end points for each ray in world coordinates |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

Output is one ray intersection result per input ray, with the same information as in above rayTest query.

## getCollisionShapeData

You can query the collision geometry type and other collision shape information of existing body base and links using this query. It works very similar to getVisualShapeData.

The input parameters for getCollisionShapeData are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | object unique id, received from loadURDF etc |
| required | linkIndex | int | link index or -1 for the base |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The return value is a list with following contents:

| | | |
|---|---|---|
| object unique id | int | object unique id |
| linkIndex | int | link index or -1 for the base |
| geometry type | int | geometry type: GEOM_BOX, GEOM_SPHERE, GEOM_CAPSULE, GEOM_MESH, GEOM_PLANE |
| dimensions | vec3 | depends on geometry type: for GEOM_BOX: extents, for GEOM_SPHERE dimensions[0] = radius, for GEOM_CAPSULE and GEOM_CYLINDER, dimensions[0] = height (length), dimensions[1] = radius. For GEOM_MESH, dimensions is the scaling factor. |
| filename | string | Only for GEOM_MESH: file name (and path) of the collision mesh asset |

| | | |
|---|---|---|
| local frame pos | vec3 | Local position of the collision frame with respect to the center of mass/inertial frame. |
| local fram orn | vec4 | Local orientation of the collision frame with respect to the inertial frame. |

# Inverse Dynamics, Kinematics

## calculateInverseDynamics

calculateInverseDynamics will compute the forces needed to reach the given joint accelerations, starting from specified joint positions and velocities.

The calculateInverseDynamics input parameters are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id, as returned by loadURDF etc. |
| required | objPositions | list of float | joint positions (angles) for each degree of freedom (DoF). Note that fixed joints have 0 degrees of freedom. The base is skipped/ignored in all cases (floating base and fixed base). |
| required | objVelocities | list of float | joint velocities for each degree of freedom (DoF) |
| required | objAccelerations | list of float | desired joint accelerations for each degree of freedom (DoF) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

calculateInverseDynamics returns a list of joint forces for each degree of freedom.

## calculateJacobian, MassMatrix

calculateJacobian will compute the translational and rotational jacobians for a point on a link, e.g. x_dot = J * q_dot. The returned jacobians are slightly different depending on whether the root link is fixed or floating. If floating, the jacobians will include columns corresponding to the root link degrees of freedom; if fixed, the jacobians will only have columns associated with the joints. The function call takes the full description of the kinematic state, this is because calculateInverseDynamics is actually called first and the desired jacobians are extracted from this; therefore, it is reasonable to pass zero vectors for joint velocities and accelerations if desired.

The calculateJacobian input parameters are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id, as returned by loadURDF etc. |
| required | linkIndex | int | link index for the jacobian. |

| | | | |
|---|---|---|---|
| required | localPosition | list of float | the point on the specified link to compute the jacobian for, in link local coordinates around its center of mass. |
| required | objPositions | list of float | joint positions (angles) |
| required | objVelocities | list of float | joint velocities |
| required | objAccelerations | list of float | desired joint accelerations |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

calculateJacobian returns:

| | | | |
|---|---|---|---|
| required | linearJacobian | mat3x ((dof), (dof), (dof)) | the translational jacobian, x_dot = J_t * q_dot. |
| required | angularJacobian | mat3x ((dof), (dof), (dof)) | the rotational jacobian, r_dot = J_r * q_dot. |

## calculateMassMatrix

calculateMassMatrix will compute the system inertia for an articulated body given its joint positions.

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id, as returned by loadURDF etc. |
| required | objPositions | array of float | jointPositions for each link. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The result is the square mass matrix with dimensions dofCount * dofCount, stored as a list of dofCount rows, each row is a list of dofCount mass matrix elements.

# Inverse Kinematics

You can compute the joint angles that makes the end-effector reach a given target position in Cartesian world space. Internally, Bullet uses an improved version of Samuel Buss Inverse Kinematics library. At the moment only the Damped Least Squares method with or without Null Space control is exposed, with a single end-effector target. Optionally you can also specify the target orientation of the end effector. In addition, there is an option to use the null-space to specify joint limits and rest poses. This optional null-space support requires all 4 lists (lowerLimits, upperLimits, jointRanges, restPoses), otherwise regular IK will be used. See also inverse_kinematics.py example in Bullet/examples/pybullet/examples folder for details.

# calculateInverseKinematics

calculateInverseKinematics input parameters are:

| | | | |
|---|---|---|---|
| required | bodyUniqueId | int | body unique id, as returned by loadURDF |
| required | endEffectorLinkIndex | int | end effector link index |
| required | targetPosition | vec3, list of 3 floats | target position of the end effector. By default this is in Cartesian world space, unless you provide currentPosition joint angles. |
| optional | targetOrientation | vec3, list of 4 floats | target orientation in Cartesian world space, quaternion [x,y,w,z]. If not specified, pure position IK will be used. |
| optional | lowerLimits | list of floats [0..nDof] | Optional null-space IK requires all 4 lists (lowerLimits, upperLimits, jointRanges, restPoses). Otherwise regular IK will be used. Only provide limits for joints that have them (skip fixed joints), so the length is the number of degrees of freedom. Note that lowerLimits, upperLimits, jointRanges can easily cause conflicts and instability in the IK solution. Try first using a wide range and limits, with just the rest pose. |
| optional | upperLimits | list of floats [0..nDof] | Optional null-space IK requires all 4 lists (lowerLimits, upperLimits, jointRanges, restPoses). Otherwise regular IK will be used.. lowerLimit and upperLimit specify joint limits |
| optional | jointRanges | list of floats [0..nDof] | Optional null-space IK requires all 4 lists (lowerLimits, upperLimits, jointRanges, restPoses). Otherwise regular IK will be used. |
| optional | restPoses | list of floats [0..nDof] | Optional null-space IK requires all 4 lists (lowerLimits, upperLimits, jointRanges, restPoses). Otherwise regular IK will be used.. Favor an IK solution closer to a given rest pose |
| optional | jointDamping | list of floats [0..nDof] | jointDamping allow to tune the IK solution using joint damping factors |
| optional | solver | int | p.IK_DLS or p.IK_SDLS, Damped Least Squares or Selective Damped Least Squares, as described in the paper by Samuel Buss "Selectively Damped Least Squares for Inverse Kinematics". |
| optional | currentPosition | list of floats [0..nDof] | list of joint positions. By default PyBullet uses the joint positions of the body. If provided, the targetPosition and targetOrientation is in local space! |

| | | | |
|---|---|---|---|
| optional | maxNumIterations | int | Refine the IK solution until the distance between target and actual end effector position is below this threshold, or the maxNumIterations is reached. |
| optional | residualThreshold | double | Refine the IK solution until the distance between target and actual end effector position is below this threshold, or the maxNumIterations is reached. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

calculateInverseKinematics returns a list of joint positions for each degree of freedom, so the length of this list is the number of degrees of freedom of the joints (The base and fixed joints are skipped). See Bullet/examples/pybullet/inverse_kinematics.py for an example.

By default, the IK will refine the solution until the distance between target end effector and actual end effector is below a residual threshold (1e-4) or the maximum number of iterations is reached.

# Reinforcement Learning Gym Envs

A suite of RL Gym Environments are installed during "pip install pybullet". This includes PyBullet versions of the OpenAI Gym environments such as ant, hopper, humanoid and walker. There are also environments that apply in simulation as well as on real robots, such as the Ghost Robotics Minitaur quadruped, the MIT racecar and the KUKA robot arm grasping environments.

The source code of pybullet, pybullet_envs, pybullet_data and the examples are here: [https://github.com/bulletphysics/bullet3/tree/master/examples/pybullet/gym](https://github.com/bulletphysics/bullet3/tree/master/examples/pybullet/gym).

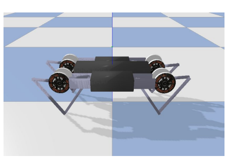
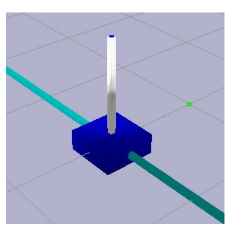
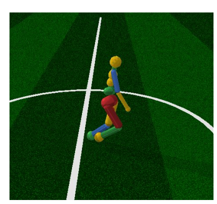
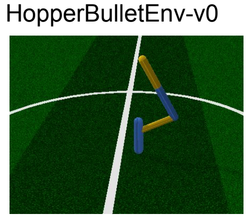
You can train the environments with RL training algorithms such as DQN, PPO, TRPO and DDPG. Several  pre-trained examples are available, you can enjoy them like this:

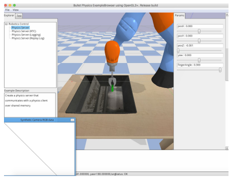
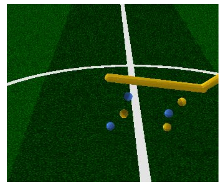
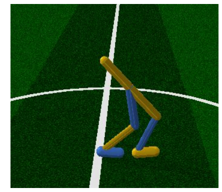
```
pip install pybullet, tensorflow, gym
python -m pybullet_envs.examples.enjoy_TF_HumanoidBulletEnv_v0_2017may
python -m pybullet_envs.examples.kukaGymEnvTest
```

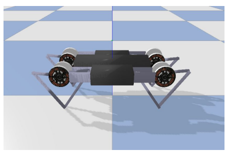
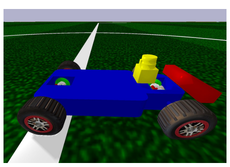
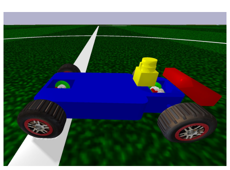
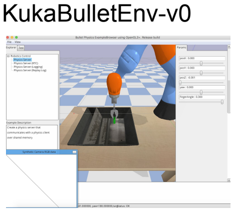
## Environments and Data

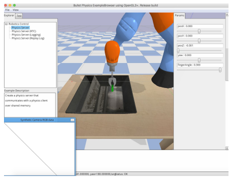
After you "sudo pip install pybullet", the pybullet_envs and pybullet_data packages are available. Importing the pybullet_envs package will register the environments automatically to OpenAI Gym.

You can get a list of the Bullet environments in gym using the following Python line:
print(

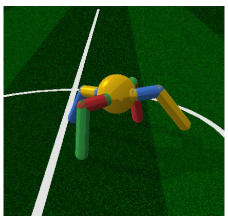
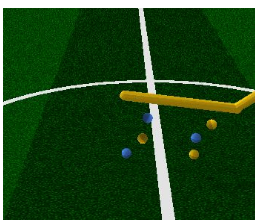
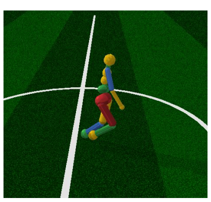
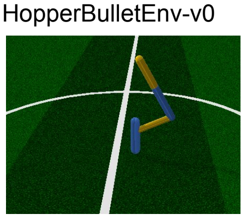
| | | |
|---|---|---|
| MinitaurBulletEnv-v0  | CartPoleBulletEnv-v0  | HumanoidBulletEnv-v0  |
| RacecarBulletEnv-v0  | AntBulletEnv-v0  | HopperBulletEnv-v0  |

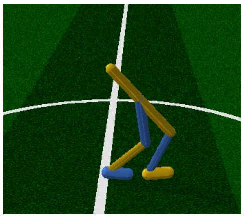
| | | |
|---|---|---|
| KukaBulletEnv-v0  | HalfCheetahBulletEnv-v0  | Walker2DBulletEnv-v0  |

| Environment Name | Description |
|---|---|
| MinitaurBulletEnv-v0  | Simulation of the Ghost Robotics Minitaur quadruped on a flat ground. Reward based on distance traveled. Create the class using Gym:<br><br>env = gym.make('MinitaurBulletEnv-v0')<br><br>or create the environment using the class directly, with parameters:<br><br>import pybullet_envs.bullet.minitaur_gym_env as e<br>env = e.MinitaurBulletEnv(render=True) |
| RacecarBulletEnv-v0  | Simulation of the MIT RC Racecar. Reward based on distance to the randomly placed ball. Observations are ball position (x,y) in camera frame. The action space of the environment can be discrete (for DQN) or continuous (for PPO, TRPO and DDPG).<br><br>import pybullet_envs.bullet.racecarGymEnv as e<br>env = e.RacecarGymEnv(isDiscrete=False ,renders=True)<br>env.reset() |
| RacecarZedBulletEnv-v0  | Same as the RacecarBulletEnv-v0, but observations are camera pixels. |
| KukaBulletEnv-v0  | Simulation of the KUKA Iiwa robotic arm, grasping an object in a tray. The main reward happens a the end, when the gripped can grasp the object above a certain height. Some very small reward/cost happens each step: cost of action and distance between gripper and object. Observation includes the x,y position of the object.<br><br>Note: this environment has issues training at the moment, we look into it. |
| KukaCamBulletEnv-v0 | Same as KukaBulletEnv-v0, but observation are camera pixels. |

| | |
|---|---|
|  | |

We ported the [Roboschool environments] to pybullet. The Roboschool environments are harder than the MuJoCo Gym environments.

| | |
|---|---|
| AntBulletEnv-v0<br> | Ant is heavier, encouraging it to typically have two or more legs on the ground. |
| HalfCheetahBulletEnv-v0<br> | |
| HumanoidBulletEnv-v0<br> | Humanoid benefits from more realistic energy cost (= torque × angular velocity) subtracted from reward. |
| HopperBulletEnv-v0<br> | |
| Walker2DBulletEnv-v0 | |

| | |
|---|---|
|  | |
| InvertedPendulumBulletEnv-v0 | |
| InvertedDoublePendulumBulletEnv-v0 | |
| InvertedPendulumSwingupBulletEnv-v0 | |

It is also possible to access the data, such as URDF/SDF robot assets, Wavefront .OBJ files from the pybullet_data package. Here is an example how to do this:

```
import pybullet
import pybullet_data
datapath = pybullet_data.getDataPath()
pybullet.connect(pybullet.GUI)
pybullet.setAdditionalSearchPath(datapath)
pybullet.loadURDF("r2d2.urdf",[0,0,1])
```

Alternatively, manually append the datapath to the filename in the loadURDF/SDF commands.

# Train and Enjoy: DQN, PPO, ES

For discrete Gym environments such as the KukaBulletEnv-v0 and RacecarBulletEnv-v0 you can use OpenAI Baselines DQN to train the model using a discrete action space. Some examples are provided how to train and enjoy those discrete environments:

```
python -m pybullet_envs.baselines.train_pybullet_cartpole
python -m pybullet_envs.baselines.train_pybullet_racecar
```

OpenAI Baselines will save a .PKL file at specified intervals when the model improves. This .PKL file is used in the enjoy scripts:

```
python -m pybullet_envs.baselines.enjoy_pybullet_cartpole
python -m pybullet_envs.baselines.enjoy_pybullet_racecar
```

There are also some pre-trained models that you can enjoy out-of-the-box. Here is a list of pretrained environments to enjoy:

python -m pybullet_envs.examples.enjoy_TF_AntBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_HalfCheetahBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_AntBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_HopperBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_HumanoidBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_InvertedDoublePendulumBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_InvertedPendulumBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_InvertedPendulumSwingupBulletEnv_v0_2017may
python -m pybullet_envs.examples.enjoy_TF_Walker2DBulletEnv_v0_2017may

# Train using TensorFlow & PyTorch

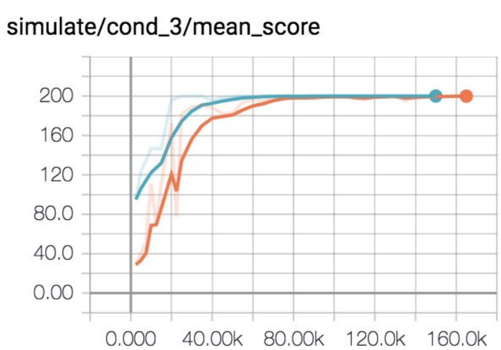
You can train various pybullet environments using TensorFlow Agents PPO. First install the required Python packages: pip install gym, tensorflow, agents, pybullet, ruamel.yaml

Then for training use:

python -m pybullet_envs.agents.train_ppo --config=pybullet_pendulum --logdir=pendulum

The following environments are available as Agents config:
pybullet_pendulum
pybullet_doublependulum
pybullet_pendulumswingup
pybullet_cheetah
pybullet_ant
pybullet_racecar
pybullet_minitaur

You can use tensorboard to see the progress of the training:
tensorboard --logdir=pendulum --port=2222
Open a web browser and visit localhost:2222 page. Here is an example graph from Tensorboard for the pendulum training:




After training, you can visualize the trained model, creating a video or visualizing it using a physics server (python -m pybullet_envs.examples.runServer or ExampleBrowser in physics server mode or in Virtual Reality). If you start a local GUI physics server, the visualizer (bullet_client.py) will automatically connect to it, and use OpenGL hardware rendering to create the video. Otherwise it will use the CPU tinyrenderer instead. To generate the video, use:

```
python -m pybullet_envs.agents.visualize_ppo --logdir=pendulum/xxxxx --outdir=pendulum_video
```

In a similar way you can train and visualize the Minitaur robot:

```
python -m pybullet_envs.agents.train_ppo --config=pybullet_minitaur --logdir=pybullet_minitaur
```

Here is an example video of the Minitaur gait: https://www.youtube.com/watch?v=tfqCHDoFHRQ

## Evolution Strategies (ES)

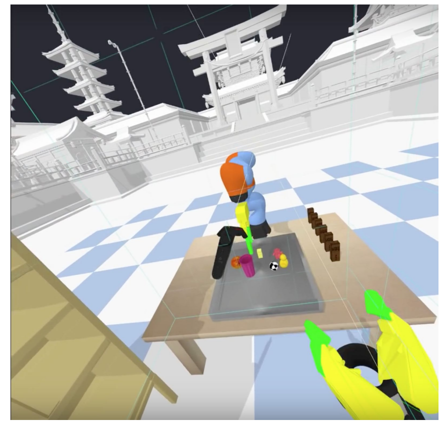
There is an blog article by David Ha (hardmaru) how to train PyBullet environments using Evolution Strategies at http://blog.otoro.net/2017/11/12/evolving-stable-strategies
.

## Train using PyTorch PPO

We will add some description how to get started with PyTorch and pybullet. In the meanwhile, see this repository: https://github.com/ikostrikov/pytorch-a2c-ppo-acktr

# Virtual Reality

See also the vrBullet quickstart guide.



The VR physics server uses the OpenVR API for HTC Vive and Oculus Rift Touch controller support. OpenVR is currently working on Windows, Valve is also working on a Linux version.

See also https://www.youtube.com/watch?v=VMJyZtHQL50 for an example video of the VR example, part of Bullet, that can be fully controlled using PyBullet over shared memory, UDP or TCP connection.

For VR on Windows, it is recommended to compile the Bullet Physics SDK using Microsoft Visual Studio (MSVC). Generate MSVC project files by running the "build_visual_studio_vr_pybullet_double.bat" script. You can customize this small script to point to the location of Python etc. Make sure to switch to 'Release' configuration of MSVC and build and run the App_PhysicsServer_SharedMemory_VR*.exe. By default, this VR application will present an empty world showing trackers/controllers (if available).

## getVREvents,setVRCameraState

getVREvents will return a list events for a selected VR devices that changed state since the last call to getVREvents. When not providing any deviceTypeFilter, the default is to only report VR_DEVICE_CONTROLLER state. You can choose any combination of devices including VR_DEVICE_CONTROLLER, VR_DEVICE_HMD (Head Mounted Device) and VR_DEVICE_GENERIC_TRACKER (such as the HTC Vive Tracker).

Note that VR_DEVICE_HMD and VR_DEVICE_GENERIC_TRACKER only report position and orientation events.
getVREvents has the following parameters:

| | | | |
|---|---|---|---|
| optional | deviceTypeFilter | int | default is VR_DEVICE_CONTROLLER<br>. You can also choose VR_DEVICE_HMD<br>or VR_DEVICE_GENERIC_TRACKER or any combination of them. |
| optional | allAnalogAxes | int | 1 for all analogue axes, 0 with just a single axis |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one. |

The output parameters are:

| | | |
|---|---|---|
| controllerId | int | controller index (0..MAX_VR_CONTROLLERS) |
| controllerPosition | vec3, list of 3 floats | controller position, in world space Cartesian coordinates |
| controllerOrientation | vec4, list of 4 floats | controller orientation quaternion [x,y,z,w] in world space |
| controllerAnalogueAxis | float | analogue axis value |
| numButtonEvents | int | number of button events since last call to getVREvents |
| numMoveEvents | int | number of move events since last call to getVREvents |
| buttons | int[64], list of button states (OpenVR has a maximum of 64 buttons) | flags for each button: VR_BUTTON_IS_DOWN (currently held down), VR_BUTTON_WAS_TRIGGERED (went down at least once since last cal to getVREvents, VR_BUTTON_WAS_RELEASED (was released at least once since last call to getVREvents). Note that only VR_BUTTON_IS_DOWN reports actual current state. For example if the button went down and up, you can tell from the RELEASE/TRIGGERED flags, even though IS_DOWN is still false. Note that in the log file, those buttons are packed with 10 buttons in 1 integer (3 bits per button). |
| deviceType | int | type of device: VR_DEVICE_CONTROLLER, VR_DEVICE_HMD or VR_DEVICE_GENERIC_TRACKER |
| allAnalogAxes (only if explicitly requested!) | list of 10 floats | currently, MAX_VR_ANALOGUE_AXIS is 5, for each axis x and y value. |

See Bullet/examples/pybullet/examples/vrEvents.py for an example of VR drawing and Bullet/examples/pybullet/examples/vrTracker.py to track HMD and generic tracker.

## setVRCameraState

setVRCameraState allows to set the camera root transform offset position and orientation. This allows to control the position of the VR camera in the virtual world. It is also possible to let the VR Camera track an object, such as a vehicle.

setVRCameraState has the following arguments (there are no return values):

| | | | |
|---|---|---|---|
| optional | rootPosition | vec3, vector of 3 floats | camera root position |
| optional | rootOrientation | vec4, vector of 4 floats | camera root orientation in quaternion [x,y,z,w] format. |
| optional | trackObject | vec3, vector of 3 floats | the object unique id to track |
| optional | trackObjectFlag | int | flags.VR_CAMERA_TRACK_OBJECT_ORIENTATION (if enabled, both position and orientation is tracked) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick |

| | | | |
|---|---|---|---|
| | | | one. |

# Debug GUI, Lines, Text, Parameters

PyBullet has some functionality to make it easier to debug, visualize and tune the simulation. This feature is only useful if there is some 3D visualization window, such as GUI mode or when connected to a separate physics server (such as Example Browser in 'Physics Server' mode or standalone Physics Server with OpenGL GUI).

## addUserDebugLine, Text

You can add a 3d line specified by a 3d starting point (from) and end point (to), a color [red,green,blue], a line width and a duration in seconds. The arguments to addUserDebugline are:

| | | | |
|---|---|---|---|
| required | lineFromXYZ | vec3, list of 3 floats | starting point of the line in Cartesian world coordinates |
| required | lineToXYZ | vec3, list of 3 floats | end point of the line in Cartesian world coordinates |
| optional | lineColorRGB | vec3, list of 3 floats | RGB color [Red, Green, Blue] each component in range [0..1] |
| optional | lineWidth | float | line width (limited by OpenGL implementation) |
| optional | lifeTime | float | use 0 for permanent line, or positive time in seconds (afterwards the line with be removed automatically) |
| optional | parentObjectUniqueId | int | new in upcoming PyBullet 1.0.8: draw line in local coordinates of a parent object/link. |
| optional | parentLinkIndex | int | new in upcoming PyBullet 1.0.8: draw line in local coordinates of a parent object/link. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

addUserDebugLine will return a non-negative unique id, that lets you remove the line using removeUserDebugItem.

## addUserDebugText

You can add some 3d text at a specific location using a color and size. The input arguments are:

| | | | |
|---|---|---|---|
| required | text | text | text represented as a string (array of characters) |
| required | textPosition | vec3, list of 3 floats | 3d position of the text in Cartesian world coordinates [x,y,z] |
| optional | textColorRGB | vec3, list of 3 floats | RGB color [Red, Green, Blue] each component in range [0..1] |
| optional | textSize | float | Text size |
| optional | lifeTime | float | use 0 for permanent text, or positive time in seconds (afterwards the text with be removed automatically) |
| optional | textOrientation | vec4, list of 4 floats | By default, debug text will always face the camera, automatically rotation. By specifying a text orientation (quaternion), the orientation will be fixed in world space or local space (when parent is specified). Note that a different implementation/shader is used for camera facing text, with different appearance: camera facing text uses bitmap fonts, text with specified orientation uses TrueType fonts.. |
| optional | parentObjectUniqueId | int | new in upcoming PyBullet 1.0.8: draw line in local coordinates of a parent object/link. |
| optional | parentLinkIndex | int | new in upcoming PyBullet 1.0.8: draw line in local coordinates of a parent object/link. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

addUserDebugText will return a non-negative unique id, that lets you remove the line using removeUserDebugItem. See also pybullet/examples/debugDrawItems.py

## addUserDebugParameter

addUserDebugParameter lets you add custom sliders to tune parameters. It will return a unique id. This lets you read the value of the parameter using readUserDebugParameter. The input parameters of addUserDebugParameter are:

| | | | |
|---|---|---|---|
| required | paramName | string | name of the parameter |
| required | rangeMin | float | minimum value |
| required | rangeMax | float | maximum value |
| required | startValue | float | starting value |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

The input parameters of readUserDebugParameter are:

| | | | |
|---|---|---|---|
| required | itemUniqueId | int | the unique id returned by 'addUserDebugParameter) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

Return value is the most up-to-date reading of the parameter.

## removeUserDebugItem/All

The functions to add user debug lines, text or parameters will return a non-negative unique id if it succeeded. You can remove the debug item using this unique id using the removeUserDebugItem method.The input parameters are:

| | | | |
|---|---|---|---|
| required | itemUniqueId | int | unique id of the debug item to be removed (line, text etc) |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

## removeAllUserDebugItems

This API will remove all debug items (text, lines etc).

## setDebugObjectColor

The built-in OpenGL visualizers have a wireframe debug rendering feature: press 'w' to toggle. The wireframe has some default colors. You can override the color of a specific object and link using setDebugObjectColor. The input parameters are:

| | | | |
|---|---|---|---|
| required | objectUniqueId | int | unique id of the object |
| required | linkIndex | int | link index |
| optional | objectDebugColorRGB | vec3, list of 3 floats | debug color in [Red,Green,Blue]. If not provided, the custom color will be removed. |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

## addUserData

In development, pull request here. In a nutshell, add, remove and query user data, at the moment text strings, attached to any link of a body. See the userData.py example on how to use it. Note that this API may still change a little bit.

## configureDebugVisualizer

You can configure some settings of the built-in OpenGL visualizer, such as enabling or disabling wireframe, shadows and GUI rendering. This is useful since some laptops or Desktop GUIs have performance issues with our OpenGL 3 visualizer.

| | | | |
|---|---|---|---|
| required | flag | int | The feature to enable or disable, such as COV_ENABLE_WIREFRAME, COV_ENABLE_SHADOWS,COV_ENABLE_GUI, COV_ENABLE_VR_PICKING, COV_ENABLE_VR_TELEPORTING, COV_ENABLE_RENDERING, COV_ENABLE_TINY_RENDERER, COV_ENABLE_VR_RENDER_CONTROLLERS, COV_ENABLE_KEYBOARD_SHORTCUTS, COV_ENABLE_MOUSE_PICKING, COV_ENABLE_Y_AXIS_UP (Z is default world up axis),COV_ENABLE_RGB_BUFFER_PREVIEW, COV_ENABLE_DEPTH_BUFFER_PREVIEW, COV_ENABLE_SEGMENTATION_MARK_PREVIEW |
| required | enable | int | 0 or 1 |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

Example:
pybullet.configureDebugVisualizer(pybullet.COV_ENABLE_WIREFRAME,1)

## get/resetDebugVisualizerCamera

Warning: the return arguments of getDebugVisualizerCamera are in a different order than resetDebugVisualizerCamera. Will be fixed in a future API revision.

## resetDebugVisualizerCamera

You can reset the 3D OpenGL debug visualizer camera distance (between eye and camera target position), camera yaw and pitch and camera target position.

| | | | |
|---|---|---|---|
| required | cameraDistance | float | distance from eye to camera target position |
| required | cameraYaw | float | camera yaw angle (in degrees) left/right |

| | | | |
|---|---|---|---|
| required | cameraPitch | float | camera pitch angle (in degrees) up/down |
| required | cameraTargetPosition | vec3, list of 3 floats | cameraTargetPosition is the camera focus point |
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

Example: pybullet.resetDebugVisualizerCamera( cameraDistance=3, cameraYaw=30, cameraPitch=52, cameraTargetPosition=[0,0,0])

## getDebugVisualizerCamera

You can get the width and height (in pixels) of the camera, its view and projection matrix using this command. Input parameter is the optional physicsClientId. Output information is:

| | | |
|---|---|---|
| width | int | width of the camera image in pixels |
| height | int | height of the camera image in pixels |
| viewMatrix | float16, list of 16 floats | view matrix of the camera |
| projectionMatrix | float16, list of 16 floats | projection matrix of the camera |
| cameraUp | float3, list of 3 floats | up axis of the camera, in Cartesian world space coordinates |
| cameraForward | float3, list of 3 floats | forward axis of the camera, in Cartesian world space coordinates |
| horizontal | float3, list of 3 floats | TBD. This is a horizontal vector that can be used to generate rays (for mouse picking or creating a simple ray tracer for example) |
| vertical | float3, list of 3 floats | TBD.This is a vertical vector that can be used to generate rays(for mouse picking or creating a simple ray tracer for example). |
| yaw | float | yaw angle of the camera, in Cartesian local space coordinates |
| pitch | float | pitch angle of the camera, in Cartesian local space coordinates |
| dist | float | distance between the camera and the camera target |
| target | float3, list of 3 floats | target of the camera, in Cartesian world space coordinates |

## getKeyboardEvents, getMouseEvents

You can receive all keyboard events that happened since the last time you called 'getKeyboardEvents'. Each event has a keycode and a state. The state is a bit flag combination of KEY_IS_DOWN, KEY_WAS_TRIGGERED and KEY_WAS_RELEASED. If a key is going from 'up' to 'down' state, you receive the KEY_IS_DOWN state, as well as the KEY_WAS_TRIGGERED state. If a key was pressed and released, the state will be KEY_IS_DOWN and KEY_WAS_RELEASED.

Some special keys are defined: B3G_F1 … B3G_F12, B3G_LEFT_ARROW, B3G_RIGHT_ARROW, B3G_UP_ARROW, B3G_DOWN_ARROW, B3G_PAGE_UP, B3G_PAGE_DOWN, B3G_PAGE_END, B3G_HOME, B3G_DELETE, B3G_INSERT, B3G_ALT, B3G_SHIFT, B3G_CONTROL, B3G_RETURN.

The input of getKeyboardEvents is an optional physicsClientId:

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

The output is a dictionary of keycode 'key' and keyboard state 'value'.
For example

```
qKey = ord('q')
keys = p.getKeyboardEvents()
if qKey in keys and keys[qKey]&p.KEY_WAS_TRIGGERED:
   break;
```

## getMouseEvents

Similar to getKeyboardEvents, you can get the mouse events that happened since the last call to getMouseEvents. All the mouse move events are merged into a single mouse move event with the most up-to-date position. In addition, all mouse button events for a given button are merged. If a button went down and up, the state will be 'KEY_WAS_TRIGGERED '. We reuse the KEY_WAS_TRIGGERED /KEY_IS_DOWN /KEY_WAS_RELEASED for the mouse button states.

Input arguments to getMouseEvents are:

| | | | |
|---|---|---|---|
| optional | physicsClientId | int | if you are connected to multiple servers, you can pick one |

The output is a list of mouse events in the following format:

| | | |
|---|---|---|
| eventType | int | MOUSE_MOVE_EVENT=1, MOUSE_BUTTON_EVENT=2 |
| mousePosX | float | x-coordinates of the mouse pointer |
| mousePosY | float | y-coordinates of the mouse pointer |
| buttonIndex | int | button index for left/middle/right mouse button |
| buttonState | int | flag KEY_WAS_TRIGGERED /KEY_IS_DOWN /KEY_WAS_RELEASED |

# Build and install PyBullet

There are a few different ways to install PyBullet on Windows, Mac OSX and Linux. We use Python 2.7 and Python 3.5.2, but expect most Python 2.x and Python 3.x versions should work. The easiest to get PyBullet to work is using pip or python setup.py:

## Using Python pip

Make sure Python and pip is installed, and then run:

pip install pybullet

Note that if you used pip to install PyBullet, it is still beneficial to also install the C++ Bullet Physics SDK: it includes data files, physics servers and tools useful for PyBullet.
You can also run 'python setup.py build' and 'python setup.py install' in the root of the Bullet Physics SDK (get the SDK from [http://github.com/bulletphysics/bullet3](http://github.com/bulletphysics/bullet3))

See also [https://pypi.python.org/pypi/pybullet](https://pypi.python.org/pypi/pybullet)

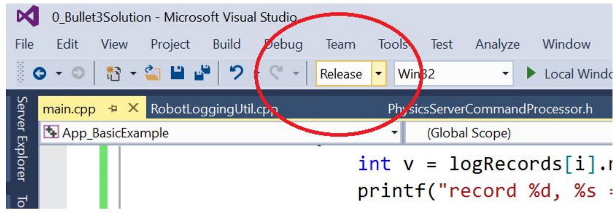
Alternatively you can install PyBullet from source code using premake (Windows) or cmake:

## Using premake for Windows

Make sure some Python version is installed in c:\python-3.5.2 (or other version folder name)

First get the source code from github, using
git clone [https://github.com/bulletphysics/bullet3](https://github.com/bulletphysics/bullet3)

Click on build_visual_studio_vr_pybullet_double.bat and open the 0_Bullet3Solution.sln project in Visual Studio, convert projects if needed.
Switch to Release mode, and compile the 'pybullet' project.




Then there are a few options to import pybullet in a Python interpreter:

1) Rename pybullet_vs2010..dll to pybullet.pyd and start the Python.exe interpreter using bullet/bin as the current working directory. Optionally for debugging: rename bullet/bin/pybullet_vs2010_debug.dll to pybullet_d.pyd and start python_d.exe)
2) Rename bullet/bin/pybullet_vs2010..dll to pybullet.pyd and use command prompt: set PYTHONPATH=c:\develop\bullet3\bin (replace with actual folder where Bullet is located) or create this PYTHONPATH environment variable using Windows GUI
3) create an administrator prompt (cmd.exe) and create a symbolic link as follows

cd c:\python-3.5.2\dlls

mklink pybullet.pyd c:\develop\bullet3\bin\pybullet_vs2010.dll

Then run python.exe and import pybullet should work.

# Using cmake on Linux and Mac OSX

Note that the recommended way is to use sudo pip install pybullet (or pip3). Using cmake or premake or other build systems is only for developers who know what they are doing, and is unsupported in general.

First get the source code from github, using
git clone https://github.com/bulletphysics/bullet3

1) Download and install cmake
2) Run the shell script in the root of Bullet:
   build_cmake_pybullet_double.sh
3) Make sure Python finds our pybullet.so module:
   export PYTHONPATH = /your_path_to_bullet/build_cmake/examples/pybullet

That's it. Test pybullet by running a python interpreter and enter 'import pybullet' to see if the module loads. If so, you can play with the pybullet scripts in Bullet/examples/pybullet.

## Possible Mac OSX Issues

- If you have any issues importing pybullet on Mac OSX, make sure you run the right Python interpreter, matching the include/libraries set in -DPYTHON_INCLUDE_DIR and -DPYTHON_LIBRARY (using cmake). It is possible that you have multiple Python interpreters installed, for example when using homebrew. See this comment for an example.

## Possible Linux Issues

- Make sure OpenGL is installed
- When using Anaconda as Python distribution, conda install libgcc so that 'GLIBCXX' is found (see http://askubuntu.com/questions/575505/glibcxx-3-4-20-not-found-how-to-fix-this-error)
- It is possible that cmake cannot find the python libs when using Anaconda as Python distribution. You can add them manually by going to the ../build_cmake/CMakeCache.txt file and changing following line: 'PYTHON_LIBRARY:FILEPATH=/usr/lib/python2.7/config-x86_64-linux-gnu/libpython2.7.so'

## GPU or virtual machine lacking OpenGL 3

- By default PyBullet uses OpenGL 3. Some remote desktop environments and GPUs don't support OpenGL 3, leading to artifacts (grey screen) or even crashes. You can use the --opengl2 flag to fall back to OpenGL 2. This is not fully supported, but it give you some way to view the scene.:
  - pybullet.connect(pybullet.GUI,options="--opengl2")
- Alternatively, you can run the physics server on the remote machine, with UDP or TCP bridge, and connect from local laptop to the remote server over UDP tunneling. (todo: describe steps in detail)

# Support, Tips, Citation

Question: Where do we go for support and to report issues?
Answer: There is a discussion forum at http://pybullet.org/Bullet and an issue tracker at https://github.com/bulletphysics/bullet3

Question: How do we add a citation to PyBullet in our academic paper?
Answer:
```
@MISC{coumans2018,
    author =   {Erwin Coumans and Yunfei Bai},
    title =    {PyBullet, a Python module for physics simulation for games, robotics
    and machine learning},
    howpublished = {\url{http://pybullet.org}},
```

year = {2016--2018}
}

Question: What happens to Bullet 2.x and the Bullet 3 OpenCL implementation?
Answer: PyBullet is wrapping the Bullet C-API. We will put the Bullet 3 OpenCL GPU API (and future Bullet 4.x API) behind this C-API. So if you use PyBullet or the C-API you are future-proof. Not to be confused with the Bullet 2.x C++ API.

Question: Should I use torque/force control or velocity/position control mode?
In general it is best to start with position or velocity control.
It will take much more effort to get force/torque control working reliably.

Question: How to turn off gravity only for some parts of a robot (for example the arm)?
Answer:

At the moment this is not exposed, so you would need to either turn of gravity acceleration for all objects, and manually apply gravity for the objects that need it. Or you can actively compute gravity compensation forces, like happens on a real robot. Since Bullet has a full constraint system, it would be trivial to compute those anti-gravity forces: You could run a second simulation (PyBullet lets you connect to multiple physics servers) and position the robot under gravity, set joint position control to keep the position as desired, and gather those 'anti-gravity' forces. Then apply those in the main simulation.

Question: How to scale up/down objects?
Answer: You can use the globalScaleFactor value as optional argument to loadURDF and loadSDF. Otherwise scaling of visual shapes and collision shapes is part of most file formats, such as URDF and SDF. At the moment you cannot rescale objects.

Question: How can I get textures in my models?
Answer: You can use the Wavefront .obj file format. This will support material files (.mtl). There are various examples using textures in the Bullet/data folder. You can change the texture for existing textured objects using the 'changeTexture' API.

Question: Which texture file formats are valid for PyBullet?
Answer: Bullet uses stb_image to load texture files, which loads PNG, JPG,TGA, GIF etc. see stb_image.h for details.
Question: How can I improve the performance and stability of the collision detection?
Answer: There are many ways to optimize, for example:
shape type

1) Choose one or multiple primitive collision shape types such as box, sphere, capsule, cylinder to approximate an object, instead of using convex or concave triangle meshes.
2) If you really need to use triangle meshes, create a convex decomposition using Hierarchical Approximate Convex Decomposition (v-HACD). The test_hacd utility

converts convex triangle mesh in an OBJ file into a new OBJ file with multiple convex hull objects. See for example Bullet/data/teddy_vhacd.urdf pointing to Bullet/data/teddy2_VHACD_CHs.obj, or duck_vhacd.urdf pointing to duck_vhacd.obj.

3) Reduce the number of vertices in a triangle mesh. For example Blender 3D has a great mesh decimation modifier that interactively lets you see the result of the mesh simplification.
4) Use rolling friction and spinning friction for round objects such as sphere and capsules and robotic grippers using the <rolling_friction> and <spinning_friction> nodes inside <link><contact> nodes. See for example Bullet/data/sphere2.urdf
5) Use a small amount of compliance for wheels using the <stiffness value="30000"/> <damping value="1000"/> inside the URDF <link><contact> xml node. See for example the Bullet/data/husky/husky.urdf vehicle.
6) Use the double precision build of Bullet, this is good both for contact stability and collision accuracy. Choose some good constraint solver setting and time step.
7) Decouple the physics simulation from the graphics. PyBullet already does this for the GUI and various physics servers: the OpenGL graphics visualization runs in its own thread, independent of the physics simulation.

Question: What are the options for friction handling?

Answer: by default, Bullet and PyBullet uses an exact implicit cone friction for the Coulomb friction model. In addition, You can enable rolling and spinning friction by adding a <rolling_friction> and <spinning_friction> node inside the <link><contact> node, see the Bullet/data/sphere2.urdf for example. Instead of the cone friction, you can enable pyramidal approximation.

Question: What kind of constant or threshold inside Bullet, that makes high speeds impossible?

Answer: By default, Bullet relies on discrete collision detection in combination with penetration recovery. Relying purely on discrete collision detection means that an object should not travel faster than its own radius within one timestep. PyBullet uses 1./240 as a default timestep. Time steps larger than 1./60 can introduce instabilities for various reasons (deep penetrations, numerical integrator). Bullet has is an option for continuous collision detection to catch collisions for objects that move faster than their own radius within one timestep. Unfortunately, this continuous collision detection can introduce its own issues (performance and non-physical response, lack of restitution), hence this experimental feature is not enabled by default.