PyBullet Quickstart Guide

Erwin Coumans, Yunfei Bai, 2016-2022

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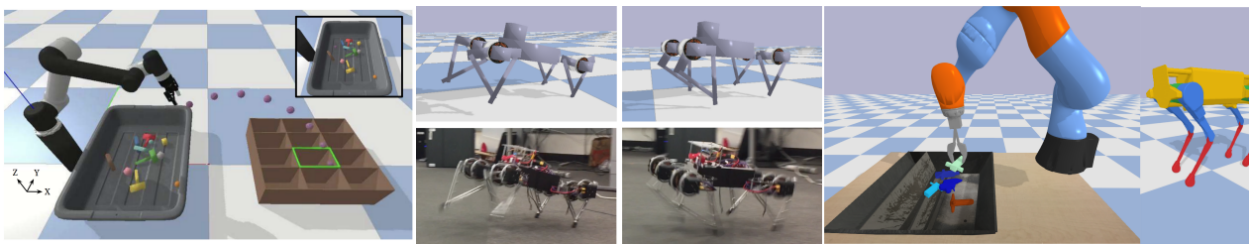
Introduction

PyBullet is a fast and easy to use Python module for robotics simulation and machine learning, with a focus on sim-to-real transfer. 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. Reduced coordinate multibodies, rigidbodies and deformables are handled by a unified LCP constraint solver, similar to the Articulated Islands Algorithm in this thesis, It uses the Articulated Body Algorithm for linear time forward dynamics and creation of the solver A matrix.



Aside from physics simulation, there are bindings to rendering, with a CPU renderer (TinyRenderer) and OpenGL 3.x rendering and 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 OpenAI Gym. Researchers from Google Brain [1,2,3,4], X[1,2], Stanford AI Lab [1,2,3], OpenAI,INRIA [1] and many other labs use PyBullet. If you use PyBullet in your research, please add a citation.

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")
startPos = [0,0,1]
startOrientation = p.getQuaternionFromEuler([0,0,0])
boxId = p.loadURDF("r2d2.urdf",startPos, startOrientation)
#set the center of mass frame (loadURDF sets base link frame)
startPos/Ornp.resetBasePositionAndOrientation(boxId, startPos,
startOrientation)
for i in range (10000):
    p.stepSimulation()
    time.sleep(1./240.)
cubePos, cubeOrn = p.getBasePositionAndOrientation(boxId)
print(cubePos,cubeOrn)
p.disconnect()
```

connect, disconnect, bullet_client

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]

isConnected

isConnected will return true if connected, false otherwise, given a physicsClientId.

setTimeOut

If a command is not processed by the server within a specific time out value, the client will disconnect. Use setTimeOut to specify this value in seconds.

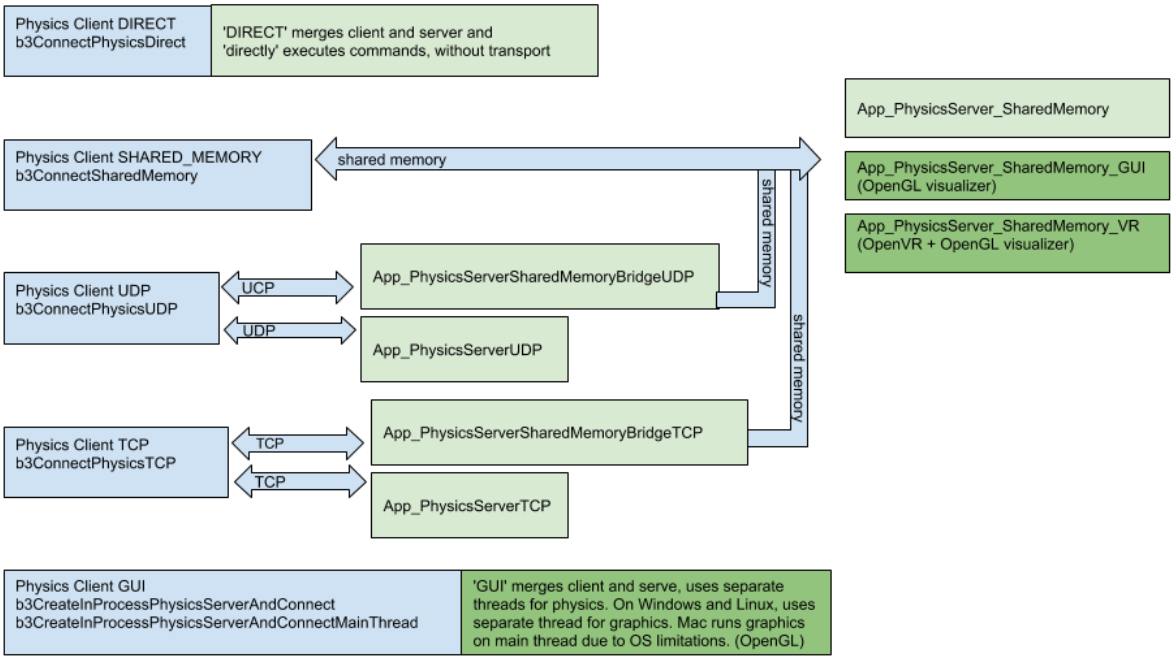


Diagram with various physics client (blue) and physics server (green) options. Dark green servers provide OpenGL debug visualization.

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 GUI_SERVER, SHARED_MEMORY_SERVER, SHARED_MEMORY_GUI	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. GUI_SERVER is similar to GUI but also acts as a serverthat allows external SHARED_MEMORY connections. SHARED_MEMORY_SERVER is similar to DIRECT but also acts as a server that allows external SHARED_MEMORY connections. SHARED_MEMORY_GUI is similar to DIRECT but will attempt to connect to an external graphics server for display. The Bullet ExampleBrowser has an option to act as Physics Server or Graphics Server.
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	hostName (UDP and TCP)	string	IP address or host name, for example "127.0.0.1" or "localhost" or "mymachine.domain.com"
optional	port (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. You can set the background color, with red/green/blue parameters in the range [0..1] as follows: p.connect(p.GUI, options="--background_color_red=1 --background_color_blue=1 --background_color_green=1") Other options are: --mouse_move_multiplier=0.400000 (mouse sensitivity) --mouse_wheel_multiplier=0.400000 (mouse wheel sensitivity) --width=<int> width of the window in pixels --height=<int> height of the window, in pixels. --mp4=moviename.mp4 (records movie, requires ffmpeg) --mp4fps=<int> (for movie recording, set frames per second).

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).

There is also a GRPC client and server support, which is not enabled by default. You can try it out using the premake4 build system using the --enable_grpc option (see Bullet/build3/premake4).

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

bullet_client

If you want to use multiple independent simulations in parallel, you can use pybullet_utils.bullet_client. An instance of bullet_client.BulletClient(connection_mode=pybullet.GUI, options='') has the same API as a pybullet instance. It will automatically add the appropriate physicsClientId to each API call. The PyBullet Gym environments use bullet_client to allow training of multiple environments in parallel, see the implementation in env_bases.py. Another small example shows how to have two separate instances, each with their own objects, see multipleScenes.py.

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	graX	float	gravity force along the X world axis
required	gravY	float	gravity force along the Y world axis
required	gravZ	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

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]. Note that this position is of the URDF link position. If the inertial frame is non-zero, this is different from the center of mass position. Use resetBasePositionAndOrientation to set the center of mass location/orientation.
optional	baseOrientation	vec4	create the base of the object at the specified orientation as world space quaternion [X,Y,Z,W]. See note in basePosition.
optional	useMaximalCoordinates	int	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 (ABA, 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. Enabling useMaximalCoordinates for bodies that don't have links/joints can improve performance a lot, such as objects picked up by a robot.
optional	useFixedBase	int	force the base of the loaded object to be static
optional	flags	int	The following flags can be combined using a bitwise OR, |: URDF_MERGE_FIXED_LINKS: this will remove fixed links from the URDF file and merge the resulting links. This is good for performance, since various algorithms

			(articulated body algorithm, forward kinematics etc) have linear complexity in the number of joints, including fixed joints. 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. 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: URDF_USE_SELF_COLLISION_INCLUDE_PARENT will enable collision between child and parent, it is disabled by default. Needs to be used together with URDF_USE_SELF_COLLISION flag. 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). Needs to be used together with URDF_USE_SELF_COLLISION. URDF_USE_IMPLICIT_CYLINDER, will use a smooth implicit cylinder. By default, Bullet will tesselate the cylinder into a convex hull. URDF_ENABLE_SLEEPING, will allow to disable simulation after a body hasn't moved for a while. Interaction with active bodies will re-enable simulation. URDF_INITIALIZE_SAT_FEATURES, will create triangle meshes for convex shapes. This will improve visualization and also allow usage of the separating axis test (SAT) instead of GJK/EPA. Requires to enableSAT using setPhysicsEngineParameter. URDF_USE_MATERIAL_COLORS_FROM_MTL, will use the RGB color from the Wavefront OBJ file, instead of from the URDF file. URDF_ENABLE_CACHED_GRAPHICS_SHAPES, will cache and re-use graphics shapes. It will improve loading performance for files with similar graphics assets. URDF_MAINTAIN_LINK_ORDER, will try to maintain the link order from the URDF file. Say in the URDF file, the order is: ParentLink0, ChildLink1 (attached to ParentLink0), ChildLink2 (attached to ParentLink0). Without this flag, the order could be P0, C2, C1.
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 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 instead to control the feature. 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. 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	globalScaling is supported for SDF and URDF, not for MJCF. Every object will be scaled using this scale factor (including links, link frames, joint attachments and linear joint limits). This has no effect on mass, only on the geometry. Use changeDynamics to change the mass if needed.
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.

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.

removeState

removeState allows to remove previously stored states from memory.

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

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, GEOM_HEIGHTFIELD
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	collisionFrameOrientation	vec4	rotational offset (quaternion x,y,z,w) of the collision shape with respect to the link frame
optional	vertices	list of vec3	definition of a heightfield. See the heightfield.py example.
optional	indices	list of int	definition of a heightfield
optional	heightfieldTextureScaling	float	texture scaling of a heightfield

optional	numHeightfieldRows	int	definition of a heightfield
optional	numHeightfieldColumns	int	definition of a heightfield
optional	replaceHeightfieldIndex	int	replacing an existing heightfield (updating its heights) (much faster than removing and re-creating a heightfield)
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.

createCollisionShapeArray

collisionShapeArray is the array version of createCollisionShape. For usage, see the snake.py or createVisualShapeArray.py examples on how to use it.

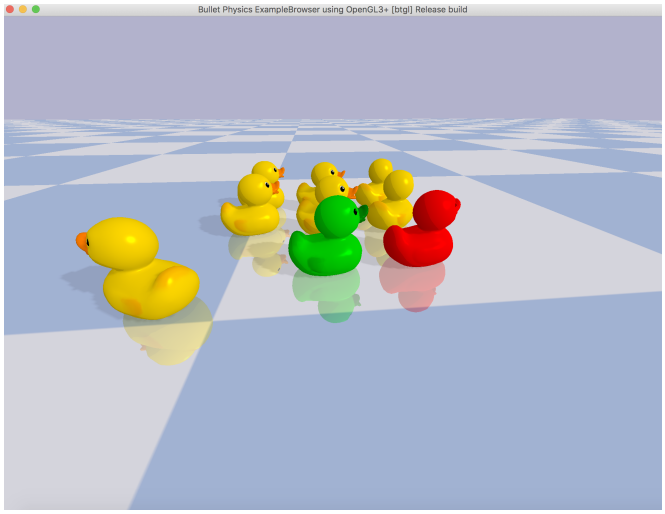
removeCollisionShape

removeCollisionShape will remove an existing collision shape, using its collision shape unique id.

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	vertices	list of vec3	Instead of creating a mesh from obj file, you can provide vertices, indices, uvs and normals.
optional	indices	list of int	triangle indices, should be a multiple of 3
optional	uvs	list of vec2	uv texture coordinates for vertices. Use

			changeVisualShape to choose the texture image. The number of uvs should be equal to number of vertices
optional	normals	list of vec3	vertex normals, number should be equal to number of vertices.
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.
See createVisualShape, createVisualShapeArray and createTexturedMeshVisualShape examples.

createVisualShapeArray

createVisualShapeArray is the array version of createVisualShape. See createVisualShapeArray.py example.

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. JOINT_REVOLUTE, JOINT_PRISMATIC, JOINT_SPHERICAL and JOINT_FIXED types are 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	batchPositions	list of vec3	array of base positions, for fast batch creation of many multibodies.See example.
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.

getMeshData

getMeshData is an experimental undocumented API to return mesh information (vertices, indices) of triangle meshes.

required	bodyUniqueId	int	body unique id

optional	linkIndex	int	link index
optional	collisionShapeIndex	int	index of compound shape, in case of multiple collision shapes in the link (see getCollisionShapeData)
optional	flags	int	By default, PyBullet will return graphics rendering vertices. Since vertices with different normals are duplicated, the can be more vertices than in the original mesh. You can receive the simulation vertices by using flags = pybullet.MESH_DATA_SIMULATION_MESH
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one.

stepSimulation, performCollisionDetection

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.

By default, stepSimulation has no return values.

For experimental/advanced use only: if reportSolverAnalytics is enabled through the setPhysicsEngineParameter API, the following information is returned as a list of island information with the following details:

islandId	int	island unique id
numBodies	list of body unique ids	the body unique ids in this island
numIterationsUsed	int	the number of solver iterations used.
remainingResidual	float	the residual constraint error.

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

performCollisionDetection

The performCollisionDetection api will perform just the collision detection stage of the stepSimulation. The only argument is the physicsClientId. After making this call, you can use getContactPoints.

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	bodyUniqueId	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 a list of 3 floating point values, a vec3. The rotation order is first roll around X, then pitch around Y and finally yaw around Z, as in the ROS URDF rpy convention.

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.

getAxisAngleFromQuaternion

getAxisAngleFromQuaternion will return the axis and angle representation of a given quaternion orientation.

required	quaternion	list of 4 floats	orientation
optional	physicsClientId	int	unused, added for API consistency.

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).

getDifferenceQuaternion

getDifferenceQuaternion will return a quaternion that interpolates from start orientation to end orientation.

required	quaternionStart	list of 4 floats	start orientation
required	quaternionEnd	list of 4 floats	end orientation
optional	physicsClientId	int	unused, added for API consistency.

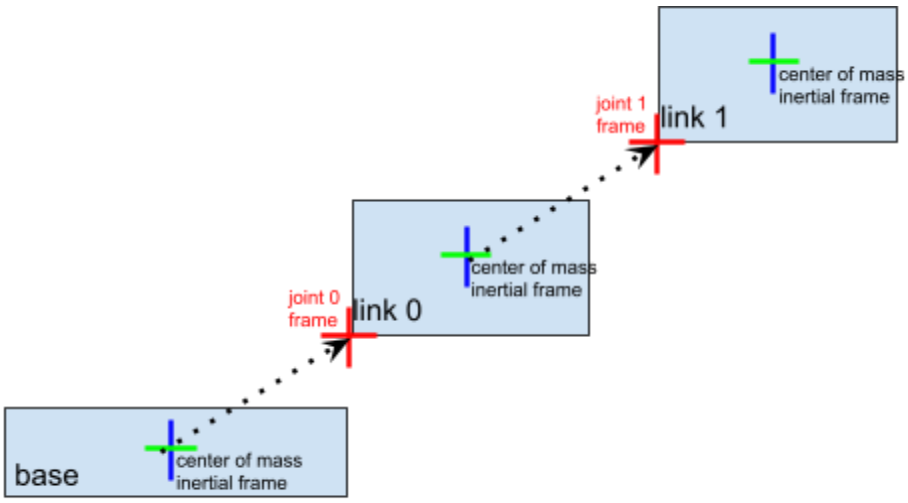
getAPIVersion
You can query for the API version in a year-month-0-day format. You can only connect between physics client/server of the same API version, with the same number of bits (32-bit / 64bit).
There is a optional unused argument physicsClientId, added for API consistency.

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, but most APIs related to links only accept regular links with link index >= 0. 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, as specified in the URDF file.
jointUpperLimit	float	Positional upper limit for slider and revolute joints, as specified in the URDF file. 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	vec4	joint orientation in parent frame (quaternion x,y,z,w)
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.

Important Note: by default, each revolute joint and prismatic joint is motorized using a velocity motor. You can disable those default motor by using a maximum force of 0. This will let you perform torque control.
For example:

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

You can also use a small non-zero force to mimic joint friction.

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 and

			PD_CONTROL. (There is also experimental STABLE_PD_CONTROL for stable(implicit) PD control, which requires additional preparation. See humanoidMotionCapture.py and pybullet_envs.deep_mimc for STABLE_PD_CONTROL examples.) TORQUE_CONTROL will apply a torque instantly, so it only is effective when calling stepSimulation explicitly.
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 PD_CONTROL and POSITION_CONTROL/CONTROL_MODE_POSITION_VELOCITY_PD, the final target velocity is computed using: kp*(erp*(desiredPosition-currentPosition)/dt)+currentVelocity+kd*(m_desiredVelocity - currentVelocity). See also examples/pybullet/examples/pdControl.py
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, PD_CONTROL. (There is also experimental STABLE_PD_CONTROL for stable(implicit) PD control, which requires additional preparation. See humanoidMotionCapture.py and pybullet_envs.deep_mimc for STABLE_PD_CONTROL examples.)
optional	targetPositions	list of float	in POSITION_CONTROL the targetValue is target position of the joint
optional	targetVelocities	list of float	in PD_CONTROL, VELOCITY_CONTROL and POSITION_CONTROL the targetValue is target velocity of the joint, see implementation note below.
optional	forces	list of float	in PD_CONTROL, 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.

setJointMotorControlMultiDof

setJointMotorControlMultiDof is similar to setJointMotorControl2, but it support the spherical (multiDof) joint, This is used for the deep_mimic environment (in pybullet_envs) and humanoidMotionCapture.py example. Instead of a single float, targetPosition, targetVelocity and force arguments accept a list of 1 float or list of 3 floats to support a spherical joint.

The input arguments to setJointMotorControlMultiDof 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 and PD_CONTROL. (There is also experimental STABLE_PD_CONTROL for stable(implicit) PD control, which requires additional preparation. See humanoidMotionCapture.py and pybullet_envs.deep_mimc for STABLE_PD_CONTROL examples.)
optional	targetPosition	list of 1 or 3 floats	in POSITION_CONTROL the targetValue is target position of the joint
optional	targetVelocity	list of 1 or 3 floats	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 PD_CONTROL and POSITION_CONTROL/CONTROL_MODE_POSITION_VELOCITY_PD, the final target velocity is computed using: kp*(erp*(desiredPosition-currentPosition)/dt)+currentVelocity+kd*(m_desiredVelocity - currentVelocity). See also examples/pybullet/examples/pdControl.py
optional	force	list of 1 or 3 floats	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.

setJointMotorControlMultiDofArray

setJointMotorControlMultiDofArray is a more efficient version of setJointMotorControlMultiDof, passing in multiple control targets to avoid/reduce calling overhead between Python and PyBullet C++ extension. See humanoidMotionCapture.py for an example.

The input arguments to setJointMotorControlMultiDofArray are:

required	bodyUniqueId	int	body unique id as returned from loadURDF etc.
required	jointIndices	list of 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 and PD_CONTROL. (There is also experimental STABLE_PD_CONTROL for stable(implicit) PD control, which requires additional preparation. See humanoidMotionCapture.py and pybullet_envs.deep_mimc for STABLE_PD_CONTROL examples.)
optional	targetPositions	list of float or vec3	in POSITION_CONTROL the targetValue is target position of the joint
optional	targetVelocities	list of 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 PD_CONTROL and POSITION_CONTROL/CONTROL_MODE_POSITION_VELOCITY_PD, the final target velocity is computed using: kp*(erp*(desiredPosition-currentPosition)/dt)+currentVelocity+kd*(m_desiredVelocity - currentVelocity). See also examples/pybullet/examples/pdControl.py
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 in setJointMotorControl2
optional	velocityGains	list of float	See implementation note in setJointMotorControl2
optional	maxVelocities	list of 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.

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

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

getJointStateMultiDof

There is also getJointStateMultiDof for spherical joints.

getJointState output

jointPosition	list of 1 or 4 float	The position value of this joint (as jonit angle/position or joint orientation quaternion)
jointVelocity	list of 1 or 3 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.

getJointStatesMultiDof

getJointStatesMultiDof allows to query multiple joint states, including multiDof (spherical) joints.

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.

resetJointState(s)MultiDof

There is also resetJointStateMultiDof for spherical joints. See humanoidMotionCapture for an example of resetJointStateMultiDof. Also a resetJointStatesMultiDof to reset multiple joints at a time.

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(s)

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.

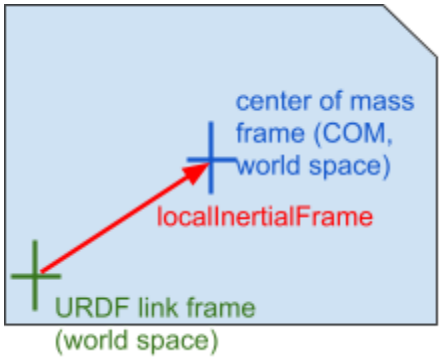
getLinkState return values

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.

getLinkStates

getLinkStates will return the information for multiple links. Instead of linkIndex it will accept linkIndices as a list of int. This can improve performance by reducing calling overhead of multiple calls to getLinkState.



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 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, and body name as extracted from the URDF, SDF, MJCF or other file.

syncBodyInfo

syncBodyInfo will synchronize the body information (getBodyInfo) in case of multiple clients connected to one physics server changing the world (loadURDF, removeBody etc).

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	gearRatio	float	the ratio between the rates at which the two gears rotate
optional	gearAuxLink	int	In some cases, such as a differential drive, a third (auxilary) link is used as reference pose. See racecar_differential.py

optional	relativePositionTarget	float	the relative position target offset between two gears
optional	erp	float	constraint error reduction parameter
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
gearRatio	float	See createConstraint
gearAuxLink	int	See createConstraint
relativePositionTarget	float	See createConstraint
erp	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.
body type	int	1=rigid body, 2 = multi body, 3 = soft body
collision margin	double	advanced/internal/unsupported info. collision margin of the collision shape. collision margins depend on the shape type, it is not consistent.

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 (keep this value very close to zero, otherwise the simulation can become very unrealistic.
optional	restitution	double	bouncyness of contact. Keep it a bit less than 1,

			preferably closer to 0.
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: friction drift 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.
optional	ccdSweptSphereRadius	float	radius of the sphere to perform continuous collision detection. See Bullet/examples/pybullet/examples/experimentalCcdSphereRadius.py for an example.
optional	contactProcessingThreshold	float	contacts with a distance below this threshold will be processed by the constraint solver. For example, if contactProcessingThreshold = 0, then contacts with distance 0.01 will not be processed as a constraint.
optional	activationState	int	When sleeping is enabled, objects that don't move (below a threshold) will be disabled as sleeping, if all other objects that influence it are also ready to sleep. pybullet.ACTIVATION_STATE_SLEEP pybullet.ACTIVATION_STATE_ENABLE_SLEEPING pybullet.ACTIVATION_STATE_DISABLE_WAKEUP You can also use flags = pybullet.URDF_ENABLE_SLEEPING in loadURDF to enable sleeping. See sleeping.py example.
optional	jointDamping	double	Joint damping coefficient applied at each joint. This coefficient is read from URDF joint damping field. Keep the value close to 0. Joint damping force = -damping_coefficient * joint_velocity.
optional	anisotropicFriction	double	anisotropicFriction coefficient to allow scaling of friction in different directions.
optional	maxJointVelocity	double	maximum joint velocity for a given joint, if it is exceeded during constraint solving, it is clamped to avoid crashing the simulation. Make sure your simulation doesn't exceed the maxJointVelocity.

			Default maximum joint velocity is 100 units.
optional	collisionMargin	double	unsupported. change the collision margin. dependent on the shape type, it may or may not add some padding to the inside or outside of the collision shape.
optional	jointLowerLimit	double	change the lower limit of a joint, also requires jointUpperLimit otherwise it is ignored. NOTE that at the moment, the joint limits are not updated in 'getJointInfo'!
optional	jointUpperLimit	double	change the upper limit of a joint, also requires jointLowerLimit otherwise it is ignored. NOTE that at the moment, the joint limits are not updated in 'getJointInfo'!
optional	jointLimitForce	double	change the maximum force applied to satisfy a joint limit.
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one.

setTimeStep

Warning: in many cases it is best to leave the timeStep to default, which is 240Hz. Several parameters are tuned with this value in mind. For example the number of solver iterations and the error reduction parameters (erp) for contact, friction and non-contact joints are related to the time step. If you change the time step, you may need to re-tune those values accordingly, especially the erp values.

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	See the warning in the setTimeStep section. physics engine timestep in fraction of seconds, each time you call 'stepSimulation' simulated time will progress this amount. 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). NOTE: Although enabled by default, it is worth trying to disable this feature, in case there are friction artifacts.
optional	deterministicOverlappingPairs	int	Set to 1 to enable and 0 to disable sorting of overlapping pairs (backward compatibility setting).
optional	allowedCcdPenetration	float	If continuous collision detection (CCD) is enabled, CCD will not be used if the penetration is below this threshold.
optional	jointFeedbackMode	int	Speficy joint feedback frame: JOINT_FEEDBACK_IN_WORLD_SPACE JOINT_FEEDBACK_IN_JOINT_FRAME
optional	solverResidualThreshold	double	velocity threshold, if the maximum velocity-level error for each constraint is below this threshold the solver will terminate (unless the solver hits the numSolverIterations). Default value is 1e-7.
optional	contactSlop	float	Position correction of contacts is not resolved below this threshold, to allow more stable contact.
optional	enableSAT	int	if true/1, enable separating axis theorem based convex collision detection, if features are available (instead of using GJK and EPA). Requires URDF_INITIALIZE_SAT_FEATURES in loadURDF. See satCollision.py example.
optional	constraintSolverType	int	Experimental (best to ignore): allow to use a direct LCP solver, such as Dantzig. See switchConstraintSolverType.py example.
optional	globalCFM	float	Experimental (best to ignore) global default constraint force mixing parameter.
optional	minimumSolverIslandSize	int	Experimental (best to ignore), minimum size of constraint solving islands, to avoid very small islands of independent constraints.
optional	reportSolverAnalytics	int	when true/1, additional solve analytics is available.
optional	warmStartingFactor	float	fraction of previous-frame force/impulse that is used to initialize the initial solver solution
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.

optional	flags	int	Experimental flags, best to ignore. RESET_USE_SIMPLE_BROADPHASE RESET_USE_DEFORMABLE_WORLD RESET_USE_DISCRETE_DYNAMICS_WORLD
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one.

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. 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). STATE_LOGGING_GENERIC_ROBOT: This will log a log of the data of either all objects or selected ones (if objectUniqueIds is provided). 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. STATE_LOGGING_CONTACT_POINTS STATE_LOGGING_VR_CONTROLLERS. STATE_LOGGING_PROFILE_TIMINGS 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

submitProfileTiming allows to insert start and stop timings to profile Python code. See profileTiming.py example.
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:

Deformables and Cloth (FEM, PBD)

Aside from articulated multi body and rigid body dynamics, PyBullet also implements deformable and cloth simulation, using Finite Element Method (FEM) mass spring systems as well as using Position Based Dynamics (PBD). Some research papers using the implementation are Learning to Rearrange Deformable Cables, Fabrics, and Bags with Goal-Conditioned Transporter Networks (using FEM, ICRA2021), Sim-to-Real Reinforcement Learning for Deformable Object Manipulation (using PBD) and Assistive Gym: A Physics Simulation Framework for Assistive Robotics. (using PBD).

PyBullet implements two-way coupling between multibody/rigidbody and deformables. Two-way coupling works for collisions as well as manual created attachments (see createSoftBodyAnchor below).

By default, PyBullet will use position based dynamics (PBD). You can enable Finite Element Method (FEM) based simulation by resetting the world as follows:

pybullet.resetSimulation(p.RESET_USE_DEFORMABLE_WORLD)

See also deformable_torus.py as an example.

loadSoftBody/loadURDF

There are a few ways to create deformable objects, both cloth or volumetric.
loadSoftBody lets you load a deformable object from a VTK or OBJ file.

The following arguments can be used for loadSoftBody. Note that several parameters assume you use the FEM model and have no effect for PBD simulation.

required	fileName	string	filename of the deformable. Can be in the Wavefront .obj format or VTK format.
optional	basePosition	vec3	initial position of the deformable object
optional	baseOrientation	vec4	initial orientation (quaternion x,y,z,w) of the deformable object
optional	scale	double	scaling factor to resize the deformable (default = 1)
optional	mass	double	total mass of the deformable, the mass is equally distributed among all vertices
optional	collisionMargin	double	a collision margin extends the deformable, it can help avoiding penetrations, especially for thin (cloth) deformables
optional	useMassSpring	bool	using mass spring
optional	useBendingSprings	bool	create bending springs to control bending of deformables
optional	useNeoHookean	bool	enable the Neo Hookean simulation
optional	springElasticStiffness	double	stiffness parameter
optional	springDampingStiffness	double	damping parameter

optional	springDampingAllDirections	double	spring damping parameter
optional	springBendingStiffness	double	parameters of bending stiffness
optional	NeoHookeanMu	double	parameters of the Neo Hookean model
optional	NeoHookeanLambda	double	parameters of the Neo Hookean model
optional	NeoHookeanDamping	double	parameters of the Neo Hookean model
optional	frictionCoeff	double	contact friction for deformables
optional	useFaceContact	bool	enable collisions internal to faces, not just at vertices.
optional	useSelfCollision	bool	enable self collision for a deformable
optional	repulsionStiffness	double	a parameter that helps avoiding penetration.

loadURDF

PyBullet also extends the URDF format to specify deformable objects using the 'deformable' tag. See for example deformable_torus.urdf:

```
<robot name="torus">
 <deformable name="torus">
   <inertial>
     <mass value="1" />
     <inertia ixx="0.0" ixy="0" ixz="0" iyy="0" iyz="0" izz="0" />
   </inertial>
   <collision_margin value="0.006"/>
   <repulsion_stiffness value="800.0"/>
   <friction value= "0.5"/>
   <neohookean mu= "60" lambda= "200" damping= "0.01" />
   <visual filename="torus.vtk"/>
 </deformable>
</robot>
```

createSoftBodyAnchor

You can pin vertices of a deformable object to the world, or attach a vertex of a deformable to a multi body using the createSoftBodyAnchor. This will return a constraint unique id. You can remove this constraint using the removeConstraint API.

See the deformable_anchor.py for an example.

You can access the vertices of a deformable using the getMeshData API.

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. On Linux, you can also enable hardware accelerated OpenGL rendering without a X11 context, for example for cloud rendering on the Google Cloud Platform or in a Colab. See the eglRenderTest.py example how to use it, as described in the 'Plugins' section.

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.

Check out this article about intrinsic camera matrix with links to OpenGL camera information.

computeView/ProjectionMatrix

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	lightDirection specifies the world position of the light source, the direction is from the light source position to the origin of the world frame.
optional	lightColor	vec3, list of 3 floats	directional light color in [RED,GREEN,BLUE] in range 0..1, only applies to ER_TINY_RENDERER
optional	lightDistance	float	distance of the light along the normalized lightDirection, only applies to ER_TINY_RENDERER
optional	shadow	int	1 for shadows, 0 for no shadows, only applies to ER_TINY_RENDERER
optional	lightAmbientCoeff	float	light ambient coefficient, only applies to ER_TINY_RENDERER
optional	lightDiffuseCoeff	float	light diffuse coefficient, only applies to ER_TINY_RENDERER
optional	lightSpecularCoeff	float	light specular coefficient, only applies to ER_TINY_RENDERER
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. Use ER_NO_SEGMENTATION_MASK to avoid calculating the segmentation mask.
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. Bullet uses OpenGL to render, and the convention is non-linear z-buffer. See https://stackoverflow.com/questions/6652253/getting-the-true-z-value-from-the-depth-buffer far=1000.//depends on projection matrix, this is default near=0.01//depends on projection matrix depth = far * near / (far - (far - near) * depthImg)//depthImg is the depth from Bullet 'getCameraImage' See also PyBullet https://github.com/bulletphysics/bullet3/blob/master/examples/pybullet/examples/pointCloudFromCameraImage.py
segmentationMaskBuffer	list of int [0..width*height]	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: value = objectUniqueId + (linkIndex+1)<<24. See example. 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.

isNumpyEnabled

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(). pip install pybullet has NumPy enabled, if available on the system. At the moment, only getCameraImage is accelerated using numpy.

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. You can also use getMeshData, in particular for deformable objects, to receive data about vertex locations.

The input parameters are:

required	objectUniqueId	int	object unique id, as returned by a load method.
optionsl	flags	int	`VISUAL_SHAPE_DATA_TEXTURE_UNIQUE_IDS will also provide textureUniqueId`
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
textureUniqueId	int	(field only exists if using `VISUAL_SHAPE_DATA_TEXTURE_UNIQUE_IDS flags`)Texture unique id of the shape, or -1 if none

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, the RGBA color and other properties.

required	objectUniqueId	int	object unique id, as returned by load method.
required	linkIndex	int	link index
optional	shapeIndex	int	Experimental for internal use, recommended ignore shapeIndex or leave it -1. Intention is 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. Note that TinyRenderer doesn't support transparancy, but the GUI/EGL OpenGL3 renderer does.
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' or 'performCollisionDetection'. 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 or performCollisionDetection. Note that if you change the state of the simulation after stepSimulation or performCollisionDetection, the 'getContactPoints' is not updated and potentially invalid. 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. Important: you need to have a valid bodyA if you provide 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'
lateralFriction1	float	lateral friction force in the lateralFrictionDir1 direction
lateralFrictionDir1	vec3, list of 3 floats	first lateral friction direction
lateralFriction2	float	lateral friction force in the lateralFrictionDir2 direction
lateralFrictionDir2	vec3, list of 3 floats	second lateral friction direction

getClosestPoints

It is also possible to compute the closest points, independent from stepSimulation or performCollisionDetection. 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 rayTestBatch 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	parentObjectUniqueId	int	ray from/to is in local space of a parent object
optional	parentLinkIndex	int	ray from/to is in local space of a parent object
optional	numThreads	int	use multiple threads to compute ray tests (0 = use all threads available, positive number = exactly this amoung of threads, default =-1 = single-threaded)
optional	reportHitNumber	int	instead of first closest hit, you can report the n-th hit
optional	collisionFilterMask	int	only test hits if the bitwise and between collisionFilterMask and body collision filter group is non-zero. See setCollisionFilterGroupMask on how to modify the body filter mask/group.
optional	fractionEpsilon	float	only useful when using reportHitNumber: ignore duplicate hits if the fraction is similar to an existing hit within this fractionEpsilon when hitting the same body. For example, a ray may hit many co-planar triangles of one body, you may only be interested in one of those hits.
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. See batchRayTest.py example how to use it.

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 frame orn	vec4	Local orientation of the collision frame with respect to the inertial frame.

Enable/Disable Collisions

By default, collision detection is enabled between different dynamic moving bodies. Self-collision between links of the same body can be enabled using flags such as 'URDF_USE_SELF_COLLISION' flag in loadURDF (see the loadURDF command for more info).

You can enable and disable collision detection between groups of objects using the setCollisionFilterGroupMask API.

V-HACD

PyBullet includes an implementation of Volumetric Hierarchical Approximate Decomposition (vhacd), by Khaled Mamou. This can import a concave Wavefront .obj file and export a new Wavefront obj file that contains the convex decomposed parts. This can be used in PyBullet to efficiently deal with concave moving geometry.

For static (non-moving) concave triangle mesh environments, you can tag triangle meshes as concave using a tag in URDF files (<link concave="yes" name="baseLink">) or using createCollisionShape with flags=p.GEOM_FORCE_CONCAVE_TRIMESH.

required	fileNameIn	string	source (concave) Wavefront obj file name
required	fileNameOut	string	destination (convex decomposition) Wavefront obj file name
required	fileNameLog	string	log file name
optional	concavity	double	Maximum allowed concavity (default=0.0025, range=0.0-1.0)
optional	alpha	double	Controls the bias toward clipping along symmetry planes (default=0.05, range=0.0-1.0)
optional	beta	double	Controls the bias toward clipping along revolution axes (default=0.05, range=0.0-1.0)
optional	gamma	double	Controls the maximum allowed concavity during the merge stage (default=0.00125, range=0.0-1.0)
optional	minVolumePerCH	double	Controls the adaptive sampling of the generated convex-hulls (default=0.0001, range=0.0-0.01)
optional	resolution	int	Maximum number of voxels generated during the voxelization stage (default=100,000, range=10,000-16,000,000)
optional	maxNumVerticesPerCH	int	Controls the maximum number of triangles per convex-hull (default=64, range=4-1024)
optional	depth	int	Maximum number of clipping stages. During each split stage, parts with a concavity higher than the user defined threshold are clipped according the best clipping plane (default=20, range=1-32)
optional	planeDownsampling	int	Controls the granularity of the search for the \"best\" clipping plane (default=4, range=1-16
optional	convexhullDownsampling	int	Controls the precision of the convex-hull generation process during the clipping plane selection stage (default=4, range=1-16)
optional	pca	int	Enable/disable normalizing the mesh before applying the convex decomposition (default=0, range={0,1})
optional	mode	int	0: voxel-based approximate convex decomposition, 1: tetrahedron-based approximate convex decomposition (default=0, range={0,1})
optional	convexhullApproximation	int	Enable/disable approximation when computing convex-hulls (default=1, range={0,1})
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one. Note: vhacd decomposition happens on the client side at the moment.

Example usage:

```
import pybullet as p
import pybullet_data as pd
import os
```

```
p.connect(p.DIRECT)
name_in = os.path.join(pd.getDataPath(), "duck.obj")
name_out = "duck_vhacd2.obj"
name_log = "log.txt"
p.vhacd(name_in, name_out, name_log)
```

setCollisionFilterGroupMask

Each body is part of a group. It collides with other bodies if their group matches the mask, and vise versa. The following check is performed using the group and mask of the two bodies involved. It depends on the collision filter mode.

required	bodyUniqueId	int	bodyUniqueId of the body to be configured
required	linkIndexA	int	link index of the body to be configured
required	collisionFilterGroup	int	bitwise group of the filter, see below for explanation
required	collisionFilterMask	int	bitwise mask of the filter, see below for explanation
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one.

You can have more fine-grain control over collision detection between specific pairs of links. There using the setCollisionFilterPair API: you can enable or disable collision detection. setCollisionFilterPair will override the filter group/mask and other logic.

setCollisionFilterPair

required	bodyUniqueIdA	int	bodyUniqueId of body A to be filtered
required	bodyUniqueIdB	int	bodyUniqueId of body B to be filtered, A==B implies self-collision
required	linkIndexA	int	linkIndex of body A
required	linkIndexB	int	linkIndex of body B
required	enableCollision	int	1 to enable collision, 0 to disable collision

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

There is a plugin API to write your own collision filtering implementation as well, see the collisionFilterPlugin implementation.

Inverse Dynamics, Kinematics

calculateInverseDynamics(2)

calculateInverseDynamics will compute the forces needed to reach the given joint accelerations, starting from specified joint positions and velocities. The inverse dynamics is computed using the recursive Newton Euler algorithm (RNEA).

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.
Note that when multidof (spherical) joints are involved, the calculateInverseDynamics uses a different code path and is a bit slower. Also note that calculateInverseDynamics ignores the joint/link damping, while forward dynamics (in stepSimulation) includes those damping terms. So if you want to compare the inverse dynamics and forward dynamics, make sure to set those damping terms to zero using changeDynamics with jointDamping and link damping through linearDamping and angularDamping.

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. The composite rigid body algorithm (CBRA) is used to compute the mass matrix.

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.

Note that when multidof (spherical) joints are involved, calculateMassMatrix will use a different code path, that is a bit slower.

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(2)

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 (its link coordinate, not center of mass coordinate!). 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,z,w]. 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. Default is 20 iterations.
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.

calculateInverseKinematics2

Similar to calculateInverseKinematics, but it takes a list of end-effector indices and their target positions (no orientations at the moment).

required	bodyUniqueId	int	body unique id, as returned by loadURDF
required	endEffectorLinkIndices	list of int	end effector link index
required	targetPositions	list of vec3	target position of the end effector (its link coordinate, not center of mass coordinate!). By default this is in Cartesian world space,

			unless you provide currentPosition joint angles.
...	For other arguments, see calculateInverseKinematics		

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.

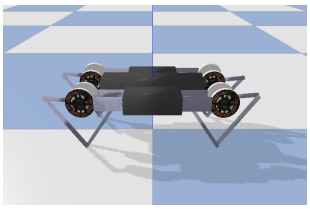
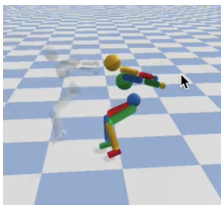
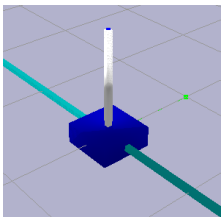
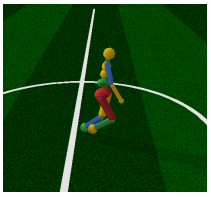
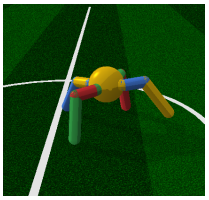
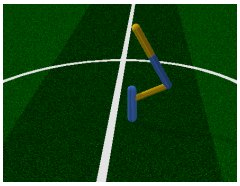
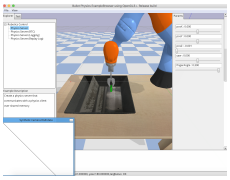
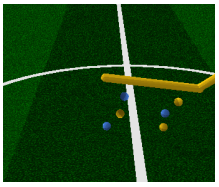
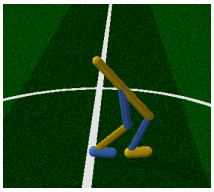
You can train the environments with RL training algorithms such as DQN, PPO, TRPO and DDPG. Several pre-trained examples are available, you can enjoy them like this:

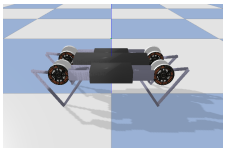
pip install pybullet, tensorflow, gym
python -m pybullet_envs.examples.enjoy_TF_HumanoidBulletEnv_v0_2017may
python -m pybullet_envs.examples.kukaGymEnvTest

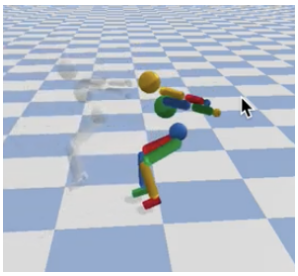
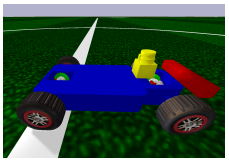
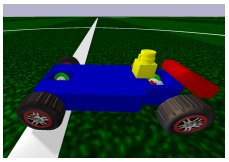
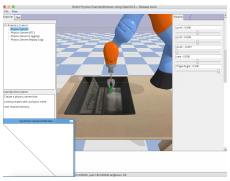
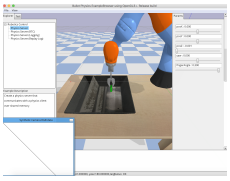
Environments and Data

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(

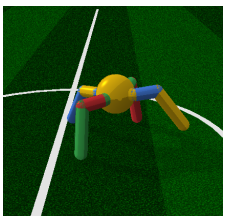
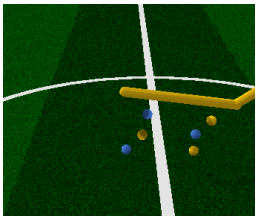
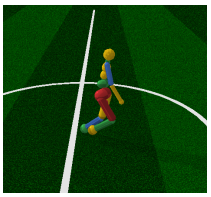
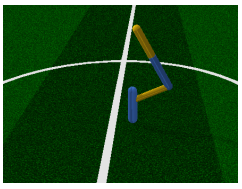
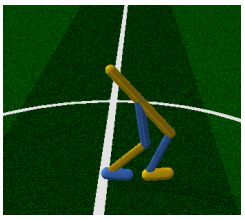
MinitaurBulletEnv-v0 	HumanoidDeepMimic*BulletEnv-v1 	CartPoleContinuousBulletEnv-v0 
HumanoidBulletEnv-v0 	AntBulletEnv-v0 	HopperBulletEnv-v0 
KukaBulletEnv-v0 	HalfCheetahBulletEnv-v0 	Walker2DBulletEnv-v0 

Environment Name	Description
MinitaurBulletEnv-v0 	Simulation of the Ghost Robotics Minitaur quadruped on a flat ground. This environment was used for the RSS 2018 "Sim-to-Real: Learning Agile Locomotion For Quadruped Robots", see paper on arxiv. Reward based on distance traveled. Create the class using Gym: env = gym.make('MinitaurBulletEnv-v0') or create the environment using the class directly, with parameters: import pybullet_envs.bullet.minitaur_gym_env as e env = e.MinitaurBulletEnv(render=True)
HumanoidDeepMimicBackflipBulletEnv-v1 and HumanoidDeepMimicWalkBulletEnv-v1	A re-implementation of the DeepMimic paper in PyBullet: a simulation of a Humanoid mimic a reference motion. The implementation allows selecting the reference motion. The backflip and walk reference motion are turned into a Gym environment. Pre-trained models of various motions are available as part of PyBullet: requires Tensorflow 1.x (1.14): python3 -m pybullet_envs.deep_mimic.testrl --arg_file run_humanoid3d_backflip_args.txt

 See VIDEO. and an example using the Human 3.6 dataset.	python3 -m pybullet_envs.deep_mimic.testrl --arg_file run_humanoid3d_walk_args.txt You can also train using the included DeepMimic MPI parallelized PPO implementation: python3 mpi_run.py --arg_file train_humanoid3d_walk_args.txt --num_workers 16 (change the number of cores 16 dependent on your machine) For playback of your trained policy you need to copy the weights.
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). import pybullet_envs.bullet.racecarGymEnv as e env = e.RacecarGymEnv(isDiscrete=False ,renders=True) 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. 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	Ant is heavier,

	encouraging it to typically have two or more legs on the ground.
HalfCheetahBulletEnv-v0 	
HumanoidBulletEnv-v0 	Humanoid benefits from more realistic energy cost (= torque × angular velocity) subtracted from reward.
HopperBulletEnv-v0 	
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.

Stable Baselines & ARS, ES,...

For continuous control Gym environments such as the HalfCheetah (HalfCheetahBulletEnv-v0), Ant (AntBulletEnv_v0), (Hopper) HopperBulletEnv_v0, CartPoleContinuousBulletEnv-v0, you can use Stable Baselines. Here is an example:

```
pip3 install stable_baselines --user
pip3 install pybullet --user
python3 -m pybullet_envs.stable_baselines.train --algo sac --env HalfCheetahBulletEnv-v0
```

To enjoy the trained environment, copy/rename the weights file to sac_HalfCheetahBulletEnv-v0.zip (remove the _best part)

```
python3 -m pybullet_envs.stable_baselines.enjoy --algo sac --env HalfCheetahBulletEnv-v0
--n-episodes 5
```

Stable Baselines Zoo provides pretrained PyBullet environments.
You can also train and enjoy PyBullet environments using Stable Baselines in a Google Colab notebook, see this Colab example of training a cartpole.

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

PyBullet also comes with 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

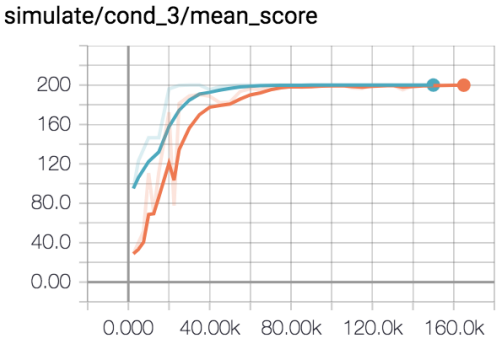
You can train various pybullet environments using TensorFlow Agents PPO. First install the required Python packages: pip install gym, tensorflow, agents, pybullet, ruamel.yaml

Then for training use:

dir

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 . You can also choose VR_DEVICE_HMD 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, Parameter

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	replaceItemUniqueId	int	replace an existing line (to improve performance and to avoid flickering of remove/add) See also the f10_racecar.py example.
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. (when using 'replaceItemUniqueId' it will return replaceItemUniqueId).

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	replaceItemUniqueId	int	replace an existing text item (to avoid flickering of remove/add)
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 and buttons 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. If Minimum value > maximum value a button instead of slider will appear
required	rangeMax	float	maximum value

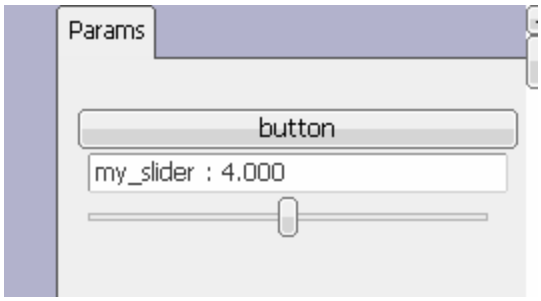
required	startValue	float	starting value
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one

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, for a slider. For a button, the value of getUserDebugParameter for a button increases 1 at each button press.

Example:
p.addUserDebugParameter("button",1,0,1)
p.addUserDebugParameter("my_slider",3,5,4)



removeAllUserParameters

This will remove all sliders and buttons.

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

removeUserDebugItem/All

The functions to add user debug lines, text 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 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. It will return a userDataId. Note that you can also add user data in a urdf file.

getUserData

getUserData will receive user data given the userDataId returned by addUserData. See userData.py for example usage.

syncUserData

syncUserData will synchronize the user data (getUserData) in case multiple clients change the user data (addUserData etc).

removeUserData

removeUserData will remove user data previously added, given a userDataId.

getUserDataId and getNumUserData

getNumUserData will return the number of user data entries given a bodyUniqueId.

getUserDataInfo

getUserDataInfo retrieves the key and the identifier of a user data as (userDataId, key, bodyUniqueId, linkIndex, visualShapeIndex)

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	lightPosition	vec3	position of the light for the visualizer
optional	shadowMapResolution	int	size of the shadow map texture, typically a power of 2 for many GPUs. Default is 4096. Modern GPUs can handle 16384 or 32768 or higher.
optional	shadowMapWorldSize	int	size of the shadow map in world space (units in meter, default is 10)
optional	shadowMapIntensity	float	visibility of the shadow, 0 = invisible, 1 = fully visible
optional	rgbBackground	vec3	background color [red, green, blue]
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 (major new version).

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

See createVisualShape.py for an example of mouse events, to select/color objects.

Plugins

PyBullet allows you to write plugins in C or C++ to add customize features. Some core features of PyBullet are written as plugins, such as PD control, rendering, gRPC server, collision filtering and Virtual Reality sync. Most plugins that are core part of PyBullet are statically linked by default, so you don't need to manually load and unload them.

On Linux, the eglPlugin is an example of a plugin that ships with PyBullet by default. It can be enabled to use hardware OpenGL 3.x rendering without a X11 context, for example for cloud rendering on the Google Cloud Platform. See the eglRenderTest.py example how to use it.

PyBullet also comes with a fileIOPlugin that can load files from a zip file directly and allows file caching. See the fileIOPlugin.py example how to use it.

loadPlugin,executePluginCommand

You can load a PyBullet plugin using the loadPlugin command:

required	pluginPath	string	path, location on disk where to find the plugin
required	postFix	string	postfix name of the plugin that is appended to each API
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one

loadPlugin will return a pluginUniqueId integer. If this pluginId is negative, the plugin is not loaded. Once a plugin is loaded, you can send commands to the plugin using

executePluginCommand:

required	pluginUniqueId	int	The unique id of the plugin, returned by loadPlugin
optional	textArgument	string	optional text argument, to be interpreted by plugin
optional	intArgs	list of int	optional list of integers, to be interpreted by plugin
optional	floatArgs	list of float	optional list of floats, to be interpreted by plugin
optional	physicsClientId	int	if you are connected to multiple servers, you can pick one

unloadPlugin

You can unload a plugin using the pluginId.

The plugin API shares the same underlying C API than PyBullet and has the same features as PyBullet.

You can browser the plugin implementation of PyBullet to get an idea what is possible.

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

You may need to use *sudo pip install pybullet* or *pip install pybullet --user*.
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)

See also https://pypi.python.org/pypi/pybullet

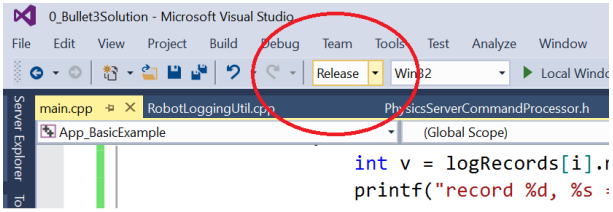
Alternatively you can install PyBullet from source code using premake (Windows) or cmake:

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

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.
- Try using CFLAGS='-stdlib=libc++' pip install pybullet, see this issue.

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{coumans2020,
        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--2020}
}
```

Question: Can PyBullet be used in Google Colab?
Answer: Yes, we provide precompiled manylinux wheels that can be used in Colab.
Also GPY rendering works using EGL. See an example Colab here.
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: The velocity of objects seems to be smaller than expected. Does PyBullet apply some default damping? Also the velocity doesn't exceed 100 units.

Answer: Yes, PyBullet applies some angular and linear damping to increase stability. You can modify/disable this damping using the 'changeDynamics' command, using linearDamping=0 and angularDamping=0 as arguments.
The maximum linear/angular velocity is clamped to 100 units for stability.

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 small positive values for rolling friction (0.01 for example) 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. Check out the experimentalCcdSphereRadius.py example how to enable it.

Question: Some APIs are not documented. Usually this means that either (1) we haven't updated the Quickstart Guide yet or (2) the feature is too experimental to document. You can file an issue in the tracker if you really want to know about a specific undocumented API.