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Welcome to the NVIDIA® PhysX® SDK version 3! With this second major rewrite of the SDK, we are excited to bring you a great number of enhancements, including numerous API improvements. Because so much has changed in the API, we recommend even experienced PhysX users to read through this guide to familiarize themselves with the new programming interface.
About this User Guide

This Guide will help the reader to understand the PhysX-3 SDK and its applications. The Guide presents an overview of the features and implementation of the PhysX SDK, and its performance in general use as well as in specific cases.

That is, this Guide covers:
- what PhysX does;
- how PhysX works;
- how well PhysX is expected to perform;
- how to use PhysX by example, and performance in those use cases.

The Guide does not attempt to explain the details of the API, and the interested reader should refer to the PhysX API Reference Documentation. (See PhysX Documentation directory under the main directory where the PhysX SDK was unpacked.) Users migrating from PhysX-2 will find the Migrating From 3.x chapter of particular interest.
Physics vs. PhysX

Physics is a rich and broad scientific pursuit, an attempt to explain the behavior of all matter, everything in the entire universe, using concepts such as time, energy, inertia, momentum and force. In physics, space is assumed to be infinitely in three dimensions, and can be divided into infinitely small units with arbitrarily fine precision. In other words, positions in physics space are described by vectors of single-precision floating point numbers.

Like the dimensions of space, time in physics is described by a real number, its duration divisible into arbitrarily small intervals. Physics promises that if the forces imposed on a system are known throughout some period of time, and the state of the system is known precisely at some instant of time in that period, then the state of the system can be determined precisely for any other instant throughout that period. For example, if one observes a ball falling towards the ground, and measures its position and velocity, one can calculate what the position and velocity of the ball must have been at an earlier time, as well as what they must become at a later time. In contrast, simulation is discrete, not continuous, and it runs only 'forwards'. That is, the simulated system is known only at specific instants in time, usually referred to as 'steps', and the simulation may only step forwards in time, never backwards. Thus, the state of a PhysX system in between time steps is not precisely determined.

Because of such approximations a PhysX simulation is subject to limitations not seen in ordinary physics, and later sections in this Guide will highlight wherever they are likely to concern the user. PhysX is best suited to interactive 3D applications where performance and scalability are more important than precision. Here "quasi-real time" means that advancing a PhysX simulation by a given time step, say 1/60 second, will take less than that amount of time on an observer's clock if the performance of the hardware platform is sufficient for the complexity of the simulation. That the PhysX SDK is more widely used in computer and video game, rather than scientific or engineering applications is both a cause and an effect of these design choices. Consequently this Guide usually refers to PhysX in the context of 'the game world', 'rigid body game objects', 'the character', etc.
World and Objects

The basic concepts of the world within a PhysX simulation are easy to visualize:

- The PhysX world comprises a collection of Scenes, each containing Actors;
- Each Scene defines its own reference frame encompassing all of space and time;
- Actors in different Scenes do not interact with each other;
- The three major types of Actors are rigid bodies, particles and cloth;
- Characters and vehicles are complex specialized objects made from Actors;
- Actors have physical state: position and orientation, velocity, energy, etc;
- Actor physical state may evolve over time due to applied forces, as joints or contacts, and interactions between Actors.

Games are a very visual medium and audible and games usually place requirements on their graphics and sound. Production quality graphics are usually outside the scope of PhysX, but it is enormously valuable to be able to visualize this otherwise hidden world. Some of our example programs come with rudimentary built-in visualization, and we also provide a stand-alone debugging tool called the PhysX Visual Debugger (PVD). PVD provides a graphical view of the PhysX scene together with tools to inspect and visualize variables of every PhysX object. Additionally, PVD can record and visualize memory and timing data. See PhysX Visual Debugger details.
What are PhysX Snippets?

In the context of the PhysX SDK, a 'Snippet' is a simple, minimalistic code sample. PhysX SDK version 3.3.0 offers a collection of Snippets to illustrate usage of the PhysX API in a concise format, free from the complexity of a sample framework or game engine. The Snippets folder is in the top-level directory of the PhysX SDK, along with directories for Documentation, Include, Samples, etc.

The folder `{SDK Root}/Snippets/compiler/{platform}` contains the Snippets solution file, e.g., `Snippets/compiler/vc14win64/Snippets.sln`.

Although a few of the Snippets support rendering (Win32, Win64, OSX only), most Snippets do not provide rendering, require no input, and provide limited output through messages. Although Snippets can be run from a command prompt or by double-clicking the executable icon, the best way to explore Snippets is by viewing the code in the Visual Studio IDE, and running the program in the debugger.
**HelloWorld: PhysX Basics**

SnippetHelloWorld illustrates basic use of PhysX, from startup to shutdown of a scene, and is a good place to start learning the PhysX API. The snippets comprise a single source file, but SnippetHelloWorld, among others, supports optional rendering through a second source file. SnippetHelloWorld creates stacks on a plane, and if rendering is enabled, allows the user to create and fire a ball from the camera position.

The primary code for SnippetHelloWorld is found in `{SDK Root}/Snippets/SnippetHelloWorld/SnippetHelloWorld.cpp`. 
Using PhysX Visual Debugger with SnippetHelloWorld

As is the case with any Snippet built against PROFILE, CHECKED or DEBUG configurations of the PhysX runtime, HelloWorld will automatically connect to the Visual Debugger if that application is already running when the Snippet is launched. For Snippets without rendering, PVD provides an easy way to visualize the contents of the PhysX scene presented in the Snippet. In the screenshot below, PhysX Visual Debugger appears on the right hand side, while Visual Studio and Snippet Hello World are on the left.
On Windows, PhysX requires Visual Studio 2013 or later versions.
Build Settings

The PhysX headers should compile cleanly at the highest typical warning levels: -Wall -Wextra -pedantic for gcc- and clang-based compilers. Stricter warning settings may result in a small number of benign informational warnings.

The PhysX source projects and snippets will compile cleanly using the makefiles supplied.
Build Configurations

The SDK has four build configurations available, designed for different stages of development and deployment.

- the *debug* build can be useful for error analysis, but contains asserts which some customers may find too intrusive. Optimizations are turned off for this configuration.
- the *checked* build contains code to detect invalid parameters, API misuse, and other incorrect uses of the API which might otherwise cause run-time crashes or failures in simulation.
- the *profile* build omits the checks, but still has PVD and memory instrumentation.
- the *release* build is built for minimal footprint and maximum speed. It omits most of the checks and instrumentation.

Simulation works the same way in all of them, and all are compiled with high optimization levels (except debug configuration).

**Note:** We strongly recommend that you use the checked build as the primary configuration for day-to-day development and QA.

**Note:** PhysX libraries of different build configurations (e.g. the DEBUG version of PhysXVehicle and the CHECKED version of PhysXVisualDebuggerSDK) should never be mixed in an application because this will result a CRT conflict.
Header Files

To build your own PhysX app, you will need to add some include paths to your project makefile or IDE.

Users should specify the root "Include" and "Lib" folders in the additional include and library directories respectively. There is a combined include header available as:

```
#include "PxPhysicsAPI.h"
```

This will include the entire PhysX API including core, extensions, vehicles, etc. It is also possible to include subsets of the SDK if preferred, for example:

```
#include "vehicle/PxVehicleSDK.h"
```
Libraries

At a minimum, applications need to link against the following libraries with a platform extension (e.g. ".lib" or ".a") and with * being a x86 or x64 for Windows platforms:

- PhysX3_*\.lib
- PhysX3Common_*\.lib
- PxFoundation_*\.lib

**Note:** The static libraries we provide with the Windows binary distribution are linked against the Multi-Threaded static C Run-Time (CRT) libraries. This means your application must also use the same CRT flavor. If you need to use a different version, you must upgrade to our source license. The source distribution can simply be recompiled using different CRT settings.
Redistribution

On the Windows platform, you need to redistribute some of our DLLs to end users as part of your application:

- PhysX3Common_*.dll - will always be needed.
- PhysX3_*.dll - will always be needed.
- PxFoundation_*.dll - will always be needed.
- PhysX3Cooking_*.dll - you only need to bundle if your application cooks geometry data on the fly.
- PhysX3GPU_*.dll - is only needed if your application runs some GPU.
- PhysX3CharacterKinematic_*.dll - is only needed if your application uses a character controller.
- PxPvdSDK_*.dll - is only needed if your application uses PVD.

Where * is a platform specific suffix, e.g. x86 or x64. You will need depending on whether your application is built in 64 bit mode.
**Introduction**

This chapter covers the basic patterns common to the PhysX application programming interface (API.) We are committed to keeping this API stable and backwards-compatible from one minor release to the next, to protect the investment you make in your code.

The PhysX API is composed primarily of abstract interface enumerations and functions defined by the API have the prefix Px.

**Note:** There is currently one section of the public API which does not have the Px prefix: the PhysX Visual Debugger connection library which has the prefix Pvd.

The PhysX libraries also expose some classes and functions that are not part of the public API. These are primarily containers and platform abstractions that are required to build the PhysX libraries which are distributed as source, and are also used in the samples. They can be recognized because they do not have the Px prefix. Even though in principle accessible to users, they are largely undocumented and we do not maintain compatibility of this code between PhysX versions. For that reason we recommend strongly against their use in applications.
Memory Management

PhysX performs all allocations via the `PxAllocatorCallback` interface. You must implement this interface in order to initialize PhysX:

```cpp
class PxAllocatorCallback
{
public:
    virtual ~PxAllocatorCallback() {};
    virtual void* allocate(size_t size, const char* typeName, const int line) = 0;
    virtual void deallocate(void* ptr) = 0;
};
```

The size of the request is specified in bytes, and PhysX requires that the memory returned be 16-byte aligned. On many platforms `malloc()` returns memory that is 16-byte aligned, and on Windows the system function `_aligned_malloc()` provides this capability. The other parameters to `allocate()` are a string which identifies the type of allocation, the `__FILE__` and `__LINE__` location inside PhysX code where the allocation was made. Refer to `PxAllocatorCallback::allocate()` to find out more about them.

A simple implementation of the allocator callback class can be found in PhysX Extensions library, see class `PxDefaultAllocatorCallback`.

**Note:** On some platforms PhysX uses system library calls to determine the type name, and the system function that returns the type name may call the system memory allocator. If you are instrumenting system memory allocations, you may observe unexpected behavior. To prevent PhysX requesting type names, disable allocation names using the method `PxFoundation::setReportAllocationNames()`.

You can place PhysX objects in memory owned by the application using PhysX's binary deserialization mechanism. See `Serialization` for details.

As an alternative to instrumenting the allocator, you can obtain detailed information about memory allocation in the PhysX Visual Debugger (see: `PhysX Visual Debugger (PVD)`).
Error Reporting

PhysX logs all error messages through the `PxErrorCallback` interface. You must implement this interface in order to initialize PhysX:

```cpp
class UserErrorCallback : public PxErrorCallback
{
public:
    virtual void reportError(PxErrorCode::Enum code, const char* message, int line)
    {
        // error processing implementation
        ...
    }
};
```

There is only a single function to implement, `reportError`. This function should log the passed message, or print it on the application's output console. For the error codes `eABORT`, `eINVALID_PARAMETER`, `eINVALID_OPERATION`, `eINTERNAL_ERROR` and `eOUT_OF_MEMORY`, breaking into the debugger may be a more appropriate choice. Whatever you do, do not just ignore the messages.

A simple implementation of the error callback class can be found in the PhysX Extensions library, see class `PxDefaultErrorCallback`. 
Math Classes

The common math classes used in PhysX are PxVec2, PxVec3, PxMat44, PxTransform, PxPlane and PxQuat, which are defined in their respective header files, e.g. (SDKRoot)/Include/foundation/PxVec3.h. The types support standard operator overloads and typical math operations. Zero and identity objects can be constructed by passing the arguments PxZero and PxIdentity respectively.

Some points to note are:

- PxTransform is a representation of a rigid body transform as a rotation quaternion and a position vector, and PhysX functions which take transforms all use this type.
- PxPlane is a homogeneous plane equation: that is, the constructor \( \text{PxPlane}(n, d) \) represents the equation \( n \cdot x + d = 0 \).

PxMat33 and PxMat44 matrices represent transformations with basis vectors in the columns (pre-multiply with matrix on the left hand side) and are stored in column-major order. This format is layout compatible with popular graphics APIs such as OpenGL and Direct3D. For example, to set the model transformation for a rigid body in OpenGL:

```cpp
// retrieve world space transform of rigid body
PxTransform t = rigidActor.getGlobalPose();

// convert to matrix form
PxMat44 m = PxMat44(t);

// set to OpenGL
glMatrixMode(GL_MODELVIEW);
glPushMatrix();

// PxMat44::front() returns a pointer to the first matrix element
glMultMatrixf(m.front());

// draw model
glPopMatrix()
```
DirectX uses row-major storage for matrices by default (D3DMATRIX), basis vectors in rows (post-multiply on the right), so PxMat44 may be D3DXMATRIX types directly.
Connecting PhysX Objects with User Application Objects

Often an application needs to associate PhysX objects with application logic or rendering purposes. An easy way to connect a single user application object with a PhysX object is to use the `userData` member provided by the most important PhysX classes (`PxActor::userData`, `PxShape::userData`, `PxMaterial::userData`, ...). The member is a `void*` pointer which is reserved for application use. Each `userData` field, so to manage multiple associations another mechanism
Type Casting

PhysX API interface classes inherit from a top-level interface called PxBase, which provides mechanisms for type-safe down-casting between interface types. For example, to cast from a PxActor to a PxRigidDynamic, use the following idiom:

```cpp
PxActor* actor = <...>
PxRigidDynamic* myActor = actor->is<PxRigidDynamic>();
```

This pattern can be used to cast to intermediate types in the hierarchy such as PxRigidActor, but this is somewhat slower than casting to concrete types. PxBase provides the following capabilities:

- `getConcreteType()` provides an integer value which corresponds to the type of an object
- `getConcreteTypeName()` provides a string name of the concrete type
- `isKindOf()` provides string-based testing of inheritance
Reference Counting

Some PhysX objects are designed to be shared and referenced multiple times in a scene graph. For example, a PxConvexMesh may be referenced by multiple objects, each sharing the same geometry but associated with different actors. Types are PxTriangleMesh, PxHeightField, PxConvexMesh, PxMaterial, and PxShape. Each object of these types has a reference count. The rules for reference counting are as follows:

- when an object is created from PxPhysics, it has a reference count of 1.
- when an object’s reference count reaches 0, the object is destroyed.
- when a new counted reference is created, the reference count is incremented.

Counted references are as follows:

- when a PxShape references a PxConvexMesh, PxTriangleMesh.
- when a PxShape references a PxMaterial.
- when a PxRigidActor references a PxShape.
- when a PxCloth references a PxClothFabric.

- when a counted reference is destroyed, or the object’s release() method is called, the reference count is decremented.
- when an object is created through deserialization, its reference count is 1, plus the number of counted references that exist to the object.

The initial reference count of 1 ensures the object is not destroyed until the application allows it by calling release() - thereafter it will be destroyed when no references to it exist.

For example, if you create a shape using PxPhysics::createShape() and attach it to an actor with PxRigidActor::attachShape(), it has a reference count of 2. Calling the shape’s release() method, it has a reference count of 1. When the actor is destroyed, the shape is detached from the actor, the reference count is decremented to 0, and the shape is destroyed.
The acquireReference() method increments the reference count of an object. For example, when a spatial query returns a reference to a mesh shape, and you want to pass that result to another thread for deferred processing, incrementing the reference count will ensure that even if the shape referencing the mesh is released, the mesh continues to exist.

**Note:** subtypes of PxGeometry do not have counted references to the meshes they point, e.g. when PxConvexMeshGeometry points to a PxConvexMesh, a counted reference exists only when the geometry is within a PxShape.

**Note:** shapes are often created using the utility method PxRigidActorExt::createExclusiveShape(). Take special care when deserializing such actors (see *Shapes* and *Reference Counting of Deserialized Objects*).
Using Different Units

PhysX is designed to produce correct results regardless of the units of length or mass, as long as inputs use those units consistently. However, there are certain tolerances whose defaults need to be adjusted depending on the units. In order to ensure that these tolerances default to reasonable values, adjust the values in PxTolerancesScale when creating the PxPhysics and PxCooking interfaces. Tolerances for objects are set at creation time, and may then be overridden by the application.

You should set tolerances based on the typical size of objects in your simulation. For example, if you are working with objects of size approximately one meter, but in units of centimeters, you should set the scale as follows:

```cpp
PxFoundation* foundation = ...;
PxTolerancesScale scale;
scale.length = 100;       // typical length of an object
scale.speed = 981;        // typical speed of an object, gravity
PxPhysics *p = PxCreatePhysics(PX_PHYSICS_VERSION, *foundation, scale);
```

This will result in the defaults for values like PxShape::contactDistance being scaled appropriately for your objects.

You can also set the typical object mass in PxTolerancesScale.

It is important to use the same PxTolerances value for initialization of PxPhysics, and also when creating PxSceneDesc objects.
PhysX uses the PX_DEBUG macro to enable or disable assertions. The macro is not set in the PhysXCore and PhysXCommon libraries, and so by default the trigger assertions, however you may configure the libraries provided a them. When an assert is triggered, PhysX calls an assert handler. By handler will trigger a debug breakpoint. However, you may PxSetAssertHandler() to customize the assert handler.
Determinism

PhysX is deterministic in the sense it will produce identical simulation results from the same sequence of API calls applied from the point where a scene is created (and the same responses from simulation callbacks which modify data). Note that removing all the objects from a scene is not in general sufficient to reinitialize it for this purpose.

PhysX simulation behavior is not sensitive to the number of CPU worker threads.

An important caveat to determinism is the state of the x87 FPU on 32-bit Intel/AMD platforms. Some compilers produce x87 floating point instructions even when configured to prefer SSE instructions, and the results of those operations may depend on the x87 control word. Since it is too expensive to modify the x87 FPU state at every PhysX entry point, this is delegated to the application if necessary. PhysX operations do not result in changes to the x87 control word, but certain other libraries (including DirectX) may modify it.

Configurations in which this is known to be a issue are all 32-bit MSVC configurations, and all MSVC 32-bit checked, release and profile configurations prior to Visual Studio 2012.
The first step in using the PhysX SDK in a program is the initialization of objects. These objects can be released when PhysX is no longer needed to free resources. This chapter describes how to do this.
Foundation and Physics

First, in some startup code, create a $PxFoundation$ object:

```c
static PxDefaultErrorCallback gDefaultErrorCallback;
static PxDefaultAllocator gDefaultAllocatorCallback;

mFoundation = PxCreateFoundation(PX_FOUNDATION_VERSION, gDefaultAllocatorCallback);
if(!mFoundation)
    fatalError("PxCreateFoundation failed!");
```

Every PhysX module requires a PxFoundation instance to be available. The required parameters are a version ID, an allocator callback and an error callback. $PX_PHYSICS_VERSION$, is a macro predefined in our headers to enable check for a version mismatch between the headers and the corresponding SDK DLLs.

Usually, the allocator callback and error callback are specific to the application, but PhysX provides default implementations that make it easy to get started. See Management and Error Reporting for more details of these callbacks. (The actual sample code supports an advanced memory allocator that tracks allocations instead of the default, but we have omitted that detail here.)

Now create the top-level $PxPhysics$ object:

```c
bool recordMemoryAllocations = true;

mPvd = PxCreatePvd(*gFoundation);
PxPvdTransport* transport = PxDefaultPvdSocketTransportCreate(PVD_HOST);
mPvd->connect(*transport,PxPvdInstrumentationFlag::eALL);

mPhysics = PxCreatePhysics(PX_PHYSICS_VERSION, *mFoundation,
    PxTolerancesScale(), recordMemoryAllocations, mPvd);
if(!mPhysics)
    fatalError("PxCreatePhysics failed!");
```

Again, the version ID has to be passed in. The PxTolerancesScale parameter...
easier to author content at different scales and still have PhysX work and get started simply pass a default object of this type. The recordMemoryAllocations parameter specifies whether to perform memory profiling. The optional PVD instance enables the debugging and profiling with the PhysX Visual Debugger.
Cooking

The PhysX cooking library provides utilities for creating, converting, and serializing data. Depending on your application, you may wish to link to the cooking library to process such data at runtime. Alternatively, you may be able to pre-process advance and just load it into memory as required. Initialize the cooking library as follows:

```cpp
mCooking = PxCreateCooking(PX_PHYSICS_VERSION, *mFoundation, PxCookingParams);
if (!mCooking)
    fatalError(" PxCreateCooking failed!");
```

The PxCookingParams struct configures the cooking library to target different platforms, use non-default tolerances or produce optional outputs. It is important to use consistent PxTolerancesScale values everywhere in your application (see Using Different Units for more details).

The cooking library generates data through a streaming interface. Implementations of streams are provided in the PxToolkit library to read from files and memory buffers. Heightfield or Trianglemesh cooked mesh can be directly inserted into PxPhysics without serialization using the PxPhysicsInsertionCallback. The default callback must be used and can be obtained using PxPhysics::getPhysicsInsertionCallback().
Extensions

The extensions library contains many functions that may be useful to many users, but which some users may prefer to omit from their application either for code size reasons or to avoid use of certain subsystems, such as those pertaining to networking.

Initializing the extensions library requires the PxPhysics object:

```cpp
if (!PxInitExtensions(*mPhysics, mPvd))
    fatalError("PxInitExtensions failed!");
```
Optional SDK Components

When linking PhysX as a static library on memory constrained platforms, it is possible to avoid linking the code of some PhysX features that are not always used in order to save memory. Currently the optional features are:

- Articulations
- Height Fields
- Cloth
- Particles

If your application requires a subset of this functionality, it is recommended that you call PxCreateBasePhysics as opposed to PxCreatePhysics and then manually register the components you require. Below is an example that registers some of these features:

```cpp
physx::PxPhysics* customCreatePhysics(physx::PxU32 version,
physx::PxFoundation& foundation,
const physx::PxTolerancesScale& scale,
bool trackOutstandingAllocations
physx::PxPvd* pvd)
{
   physx::PxPhysics* physics = PxCreateBasePhysics(version, foundation,
   trackOutstandingAllocations, pvd);

   if(!physics)
      return NULL;

   PxRegisterArticulations(*physics);
PxRegisterHeightFields(*physics);

   return physics;
}
```

Note that this will only save memory when linking PhysX as a static library, as we rely on the linker to strip out the unused code.
**Delay-Loading DLLs**

The PhysXCommon DLL, PxFoundation DLL and PxPvdSDK DLL are loaded inside of the PhysX, PhysXCooking, PhysXCommon and PxPvd DLLs. It is possible to have delay-loaded PxFoundation, PxPvdSDK, PhysXCommon and PhysXCooking DLLs.

**PhysXCommon DLL and PsFoundation DLL load**

The application links against PhysXCommon DLL, and will usually load PxPvdSDK and PhysXCommon.dll before any other PhysX DLL. The application must be the same one that will be used by the PhysX DLLs. In the PhysX and PhysXCooking DLLs, the choice of PxFoundation and PxPvdSDK is made as follows:

- If delay load hook is specified the PhysXCommon name, PxPvdSDK name provided by user is used
- If delay load hook is not specified, the corresponding Phys PsFoundation DLL or PxPvdSDK DLL is used

**PxDelayLoadHook**

The PxDelayLoadHook class supports loading of different versions DLL, PxFoundation DLL or PxPvdSDK DLL. This can be achieved by DLL names to the PhysX SDK through a custom subclass of PxDelayLoadHook, as the following example:

```cpp
class SampleDelayLoadHook: public PxDelayLoadHook
{
    virtual const char* getPhysXCommonDEBUGDllName() const
    { return "PhysX3CommonDEBUG_x64_Test.dll"; }
    virtual const char* getPhysXCommonCHECKEDDllName() const
    { return "PhysX3CommonCHECKED_x64_Test.dll"; }
    virtual const char* getPhysXCommonPROFILEDllName() const
    { return "PhysX3CommonPROFILE_x64_Test.dll"; }
}```
Now the hook must be set for PhysX, PhysXCooking, PhysXGpu, PxPvdSDK:

```cpp
PxSetPhysXDelayLoadHook(&gDelayLoadHook);
PxSetPhysXCookingDelayLoadHook(&gDelayLoadHook);
PxSetPhysXGpuDelayLoadHook(&gDelayLoadHook);
PxSetPhysXCommonDelayLoadHook(&gDelayLoadHook);
PxPvdSetFoundationDelayLoadHook(&gDelayLoadHook);
```

**PxGpuLoadHook**

The PxGpuLoadHook class supports loading of different versions of PhysX Gpu can be achieved by providing different DLL names to the PhysX SDK subclass of PxGpuLoadHook, see the following example:

```cpp
class SampleGpuLoadHook: public PxGpuLoadHook
{
   virtual const char* getPhysXGpuDEBUGDllName() const
   { return "PhysX3GpuDEBUG_x64_Test.dll"; }
   virtual const char* getPhysXGpuCHECKEDDllName() const
   { return "PhysX3GpuCHECKED_x64_Test.dll"; }
   virtual const char* getPhysXGpuPROFILEDllName() const
   { return "PhysX3GpuPROFILE_x64_Test.dll"; }
};
```
```cpp
virtual const char* getPhysXGpuDllName() const
{
    return "PhysX3GpuPROFILE_x64_Test.dll";
}
gGpuLoadHook;
```

Now the hook must be set for PhysX:

```cpp
PxSetPhysXGpuLoadHook(&gGpuLoadHook);
```

**PhysXCommon Secure Load**

All PhysX DLLs distributed by NVIDIA are signed. The PhysXCommon checked, when it is loaded by PhysX or PhysXCooking. If signature test fails the application is terminated.
Shutting Down

To dispose of any PhysX object, call its release() method. This will destroy all contained objects. The precise behavior depends on the object type, so refer to the reference guide for details. To shut down the extensions library, call the function `PxCloseExtensions()`. To shut down physics, call release() on the `PxPhysics` object, and this will clean up all of the physics objects:

```cpp
mPhysics->release();
```

Do not forget to release the foundation object as well, but only after all other modules have been released:

```cpp
mFoundation->release();
```
Introduction

This chapter explains how to use PhysX in multithreaded applications. The main aspects to using PhysX with multiple threads are:

- how to make read and write calls into the PhysX API from multiple threads without causing race conditions.
- how to use multiple threads to accelerate simulation processing.
- how to perform asynchronous simulation, and read and write while simulation is being processed.
Data Access from Multiple Threads

For efficiency reasons, PhysX does not internally lock access to its data structures by the application, so be careful when calling the API from multiple application threads. The rules are as follows:

- API interface methods marked 'const' are read calls, other API interface methods are write calls.
- API read calls may be made simultaneously from multiple threads.
- Objects in different scenes may be safely accessed by different threads.
- Different objects outside a scene may be safely accessed from different threads.
  Be aware that accessing an object may indirectly cause access to another object via a persistent reference (such as joints and actors referencing one another, or a shape referencing a mesh.)

Access patterns which do not conform to the above rules may result in data corruption, deadlocks, or crashes. Note in particular that it is not legal to perform a write operation on an object in a scene concurrently with a read operation to an object in the same scene.

The checked build contains code which tracks access by application threads to objects within a scene, to try and detect problems at the point when the illegal API call is made.

Scene Locking

Each PxScene object provides a multiple reader, single writer lock to control access to the scene by multiple threads. This is useful for situations where the PhysX scene is shared between more than one system, for example an engine's physics code. The scene lock provides a way for these systems to coordinate with each other.

It is not mandatory to use the lock. If all access to the scene is from a single thread, the lock adds unnecessary overhead. Even if you are accessing the scene from multiple threads, you may be able to synchronize the threads using a simple application-specific mechanism that guarantees your application
conditions. However, using the scene lock has two potential benefits:

- If the `PxSceneFlag::eREQUIRE_RW_LOCK` is set, the checked warning for any API call made without first acquiring the lock, or if a write call is made when the lock has only been acquired for read,
- The APEX SDK uses the scene lock to ensure that it shares the scene safely with your application.

There are four methods for acquiring / releasing the lock:

```cpp
void PxScene::lockRead(const char* file=NULL, PxU32 line=0);
void PxScene::unlockRead();

void PxScene::lockWrite(const char* file=NULL, PxU32 line=0);
void PxScene::unlockWrite();
```

Additionally there is an RAII helper class to manage these locks, see PxSceneLock.h.

**Locking Semantics**

There are precise rules regarding the usage of the scene lock:

- Multiple threads may read at the same time.
- Only one thread may write at a time, no thread may write if any threads are reading.
- If a thread holds a write lock then it may call both read and write APIs.
- Re-entrant read locks are supported, meaning a `lockRead()` on a thread that has already acquired a read lock is permitted. Each `lockRead()` must be paired with an `unlockRead()`.
- Re-entrant write locks are supported, meaning a `lockWrite()` on a thread that has already acquired a write lock is permitted. Each `lockWrite()` must be paired with an `unlockWrite()`.
- Calling `lockRead()` by a thread that has already acquired the write lock and the thread will continue to have read and write access. Each lock must be associated with an `unlock*()` that occurs in reverse order.
• Lock upgrading is not supported - a lockWrite() by a thread that has a read lock is not permitted. Attempting this in checked builds will result in an error, in release builds it will lead to deadlock.
• Writers are favored - if a thread attempts a lockWrite() while the read lock is acquired it will be blocked until all readers leave. If new readers arrive while the lock is blocked they will be put to sleep and the writer will have first chance to access the scene. This prevents writers being starved in the presence of multiple read lock holders.
• If multiple writers are queued then the first writer will receive priority, subsequent writers will be granted access according to OS scheduling.

Note: PxScene::release() automatically attempts to acquire the write lock, it is not necessary to acquire it manually before calling release().

**Locking Best Practices**

It is often useful to arrange your application to acquire the lock a single time to perform multiple operations. This minimizes the overhead of the lock, and in addition can prevent cases such as a sweep test in one thread seeing a rag doll that has only partially been inserted by another thread.

Clustering writes can also help reduce contention for the lock, as acquiring a write lock will stall any other thread trying to perform a read access.
Asynchronous Simulation

PhysX simulation is asynchronous by default. Start simulation by calling

```
scene->simulate(dt);
```

When this call returns, the simulation step has begun in a separate thread. While simulation is running, you can still make calls into the API. Where those calls affect the simulation state, the results will be buffered and reconciled with the previous state when the simulation step completes.

To wait until simulation completes, call:

```
scene->fetchResults(true);
```

The boolean parameter to `fetchResults` denotes whether the call should wait for the simulation to complete, or return immediately with the current completion status. See the API documentation for more detail.

It is important to distinguish two time slots for data access:

1. After the call to `PxScene::fetchResults()` has returned and before the next `PxScene::simulate()` call (see figure below, blue area "1").
2. After the call to `PxScene::simulate()` has returned and before the corresponding `PxScene::fetchResults()` call (see figure below, green area "2").

```
... 1 simulate() 2 fetchResults() 1 ...
```

In the first time slot, the simulation is not running and there are no restrictions for reading or writing object properties. Changes to the position of an object, for example, are applied instantaneously and the next scene query or simulation step will take the new state into account.

In the second time slot the simulation is running and in the process, read
the state of objects. Concurrent access from the user might corrupt the or lead to data races or inconsistent views in the simulation code. Hence code's view of the objects is protected from API writes, and any attribute updates are buffered to allow API reads. The consequences will be discussed in the next section.

Note that simulate() and fetchResults() are write calls on the scene, illegal to access any object in the scene while these functions are running.

Double Buffering

While a simulation is running, PhysX supports read and write accesses to the scene (with some exceptions, see further below). This includes adding/removing objects to/from a scene.

From the user perspective, API changes are reflected immediately. For example, if an object is created while the simulation is running, it can be accessed as soon as it's created. However, these changes are buffered so that the simulator can see the object state as it was when PxScene::simulate() was called. For instance, changes to the filter data of an object while the simulation is running are ignored during collision pair generation of the running step, and will only affect for the next simulation step.

When PxScene::fetchResults() is called, any buffered changes are flushed back to the scene. Any changes made by the simulation are reflected in API view of the objects, and API changes are made visible to the simulation code for the next step. User changes take precedence: for example, a user change to the position of an object while the simulation is running will overwrite the position which resulted from the simulation.

The delayed application of updates does not affect scene queries, which always take into account the latest changes.

Events involving removed objects

Deleting objects or removing them from the scene while the simulation
affect the simulation events sent out at `PxScene::fetchResults()`. This follows:

- `PxSimulationEventCallback::onWake()`, `::onSleep()` events will not get fired if an object is involved which got deleted/removed during the running simulation.
- `PxSimulationEventCallback::onContact()`, `::onTrigger()` events will get fired if an object is involved which got deleted/removed during the running simulation. The deleted/removed object will be marked as `PxContactPairHeaderFlag::eREMOVED_ACTOR_0`, `PxContactPairFlag::eREMOVED_SHAPE_0`, `PxTriggerPairFlag::eREMOVED_SHAPE_TRIGGER`). Furthermore, if `PxPairFlag::eNOTIFY_TOUCH_LOST`, `::eNOTIFY_THRESHOLD_FORCE_LOST` events were requested for the pair containing the deleted/removed object, these events will be created.

**Support**

Not all PhysX objects have full buffering support. Operations which cannot run while the simulation is in process are mentioned in the API documentation and the SDK aborts such operations and reports an error. The most important exceptions are as follows:

- Particles: The particle bulk data can not be read or modified while running, this includes operations like reading/writing particle positions/velocities, creating/deleting particles, adding forces, etc.
- Cloth: The only allowed double buffered operation is to create/add/delete/remove it to/from the scene.

**Memory Considerations**

The buffers to store the object changes while the simulation is running are created on demand. If memory usage concerns outweigh the advantage of reading/writing objects in parallel with simulation, do not write to objects while the simulation is running.
Multithreaded Simulation

PhysX includes a task system for managing CPU and GPU compute resources. Tasks are created with dependencies so that they are resolved in a given order, when ready they are then submitted to a user-implemented dispatcher for execution.

Middleware products typically do not want to create CPU threads for their own use, especially true on consoles where execution threads can have significant overhead. In the task model, the computational work is broken into jobs that are submitted to the thread pool as they become ready to run.

The following classes comprise the CPU task management.

**TaskManager**

A TaskManager manages inter-task dependencies and dispatches ready tasks to their respective dispatcher. There is a dispatcher for CPU tasks and GPU tasks assigned to the TaskManager.

TaskManagers are owned and created by the SDK. Each PxScene will have its own TaskManager instance which users can configure with dispatchers via PxSceneDesc or directly through the TaskManager interface.

**CpuDispatcher**

The CpuDispatcher is an abstract class the SDK uses for interfacing with the thread pool. Typically, there will be one single CpuDispatcher for the entire application, since there is rarely a need for more than one thread pool. A CpuDispatcher instance may be shared by more than one TaskManager, for example if multiple scenes are being used.

PhysX includes a default CpuDispatcher implementation, but we prefer applications to implement this class themselves so PhysX and APEX can efficiently share CPU resources with the application.
Note: The TaskManager will call CpuDispatcher::submitTask() from either API calls (aka: scene::simulate()) or from other running tasks, so the function must be thread-safe.

An implementation of the CpuDispatcher interface must call the following two methods on each submitted task for it to be run correctly:

```cpp
baseTask->run(); // optionally call runProfiled() to wrap with
baseTask->release();
```

The PxExtensions library has default implementations for all dispatchers. The following code snippets are taken from SampleParticles and SampleBase and show how the default dispatchers are created. `mNbThreads` which `PxDefaultCpuDispatcherCreate` defines how many worker threads the CPU dispatcher will have:

```cpp
PxSceneDesc sceneDesc(mPhysics->getTolerancesScale());
[...]
// create CPU dispatcher which mNbThreads worker threads
mCpuDispatcher = PxDefaultCpuDispatcherCreate(mNbThreads);
if(!mCpuDispatcher)
    fatalError("PxDefaultCpuDispatcherCreate failed!");
sceneDesc.cpuDispatcher = mCpuDispatcher;
#endif
// create GPU dispatcher
PxCudaContextManagerDesc cudaContextManagerDesc;
mCudaContextManager = PxCreateCudaContextManager(cudaContextManagerDesc;
sceneDesc.gpuDispatcher = mCudaContextManager->getGpuDispatcher
#endif
[...]
mScene = mPhysics->createScene(sceneDesc);
```

Note: Best performance is usually achieved if the number of threads is equal to the available hardware threads of the platform you are running on. More worker threads than hardware threads will often lead to worse performance. For platforms with a single execution core, the CPU dispatcher can be created with zero worker threads (PxDefaultCpuDispatcherCreate(0)). In this case all work will be executed on the thread that calls PxScene::simulate(), which can be more efficient.
using multiple threads.

**Note:** CudaContextManagerDesc support appGUID now. It only works on release build. If your application employs PhysX modules that use CUDA you need to provide a GUID so that patches for new architectures can be released for your game. To obtain a GUID for your application from NVIDIA. The application should log the failure into a file which can be sent to NVIDIA for support.

**CpuDispatcher Implementation Guidelines**

After the scene's TaskManager has found a ready-to-run task and submitted it to the appropriate dispatcher it is up to the dispatcher implementation to decide how and when the task will be run.

Often in game scenarios the rigid body simulation is time critical and the goal is to reduce the latency from `simulate()` to the completion of `fetchResults()`. The lowest latency will be achieved when the PhysX tasks have exclusive access to CPU resources during the update. In reality, PhysX will have to share compute resources with other game tasks. Below are some guidelines to help ensure a balance between throughput when mixing the PhysX update with other work.

- Avoid interleaving long running tasks with PhysX tasks, this will help reduce latency.
- Avoid assigning worker threads to the same execution core as high priority threads. If a PhysX task is context switched during execution the rest of the program may be stalled, increasing latency.
- PhysX occasionally submits tasks and then immediately waits for them to complete. Because of this, executing tasks in LIFO (stack) order may perform better than FIFO (queue) order.
- PhysX is not a perfectly parallel SDK, so interleaving small to medium granularity tasks will generally result in higher overall throughput.
- If your thread pool has per-thread job-queues then queuing tasks on the thread they were submitted may result in more optimal CPU cache coherence,
required.

For more details see the default CpuDispatcher implementation that comes as part of the PxExtensions package. It uses worker threads that each have their own task queues. It uses worker threads that each have their own queues and steals tasks from the back of other worker's queues (LIFO order) to improve workload distribution.

**BaseTask**

BaseTask is the abstract base class for all task types. All task run() functions will be executed on application threads, so they need to be careful with their stack usage, use as little stack as possible, and they should never block for any reason.

**Task**

The Task class is the standard task type. Tasks must be submitted to each simulation step for them to be executed. Tasks may be named at submission time, this allows them to be discoverable. Tasks will be given a reference count of 1 when they are submitted, and the TaskManager::startSimulation() function decrements the reference count of all tasks and dispatches all Tasks whose reference count reaches zero. Once TaskManager::startSimulation() is called, Tasks can set dependencies to control the order in which they are dispatched. Once simulation has started, it is possible to submit new tasks and add dependencies, but it is up to the programmer to avoid race hazards. You cannot add dependencies to tasks that have already been dispatched, and newly submitted Tasks must have their reference count decremented before that Task will be allowed to execute.

Synchronization points can also be defined using Task names. The program assigns the name a TaskID with no Task implementation. When all of the named Task's dependencies are met, it will decrement the reference count of all Tasks with that name.

APEX uses the Task class almost exclusively to manage CPU resources. The ApexScene defines a number of named Tasks that the modules use to schedule their own Tasks (ex: start after LOD calculations are complete, finish before the PhysX scene...
**LightCpuTask**

LightCpuTask is another subclass of BaseTask that is explicitly programmed. LightCpuTasks have a reference count of 1 when they are initialized, so their reference count must be decremented before they are dispatched. They increment their continuation task reference count when they are initialized, and decrement the reference count when they are released (after completing their run()).

PhysX 3.x uses LightCpuTasks almost exclusively to manage CPU resources. For example, each stage of the simulation update may consist of multiple parallel tasks; each of these tasks has finished execution it will decrement the reference count on the next task in the update chain. This will then be automatically dispatched when its reference count reaches zero.

**Note:** Even when using LightCpuTasks exclusively to manage CPU resources, the TaskManager startSimulation() and stopSimulation() calls must be made each step to keep the GpuDispatcher synchronized.

The following code snippets show how the crabs' A.I. in SampleSubmarine is run as a CPU Task. By doing so the Crab A.I. is run as a background Task in parallel with the PhysX simulation update.

For a CPU task that does not need handling of multiple continuations, it can be subclassed. A *LightCpuTask* subclass requires that the getName and run methods be defined:

```cpp
class Crab: public ClassType, public physx::PxLightCpuTask, public...
{
public:
    Crab(SampleSubmarine& sample, const PxVec3& crabPos, RenderMaterial
~Crab();

    // Implements LightCpuTask
    virtual const char* getName() const { return "Crab AI Task";
    virtual void run();

    [...]
```
After PxScene::simulate() has been called, and the simulation started, the application calls removeReference() on each Crab task, this in turn causes it to be submitted to the CpuDispatcher for update. Note that it is also possible to submit tasks directly (without manipulating reference counts) as follows:

```cpp
PxLightCpuTask& task = &mCrab;
mCpuDispatcher->submitTask(task);
```

Once queued for execution by the CpuDispatcher, one of the thread pool's worker threads will eventually call the task's run method. In this example the Crab task will perform raycasts against the scene and update its internal state machine:

```cpp
void Crab::run()
{
    // run as a separate task/thread
    scanForObstacles();
    updateState();
}
```

It is safe to perform API read calls, such as scene queries, from multiple threads while simulate() is running. However, care must be taken not to overlap API read calls from multiple threads. In this case the SDK will issue an error, see Threading information.

An example for explicit reference count modification and task dependency setup:

```cpp
// assume all tasks have a refcount of 1 and are submitted to the
// 3 task chains a0-a2, b0-b2, c0-c2
// b0 shall start after a1
// the a and c chain have no dependencies and shall run in parallel
//
// a0-a1-a2
// \b0-b1-b2
// c0-c1-c2

// setup the 3 chains
for(PxU32 i = 0; i < 2; i++)
{
    a[i].setContinuation(&a[i+1]);
    b[i].setContinuation(&b[i+1]);
    c[i].setContinuation(&c[i+1]);
}

// b0 shall start after a1
b[0].startAfter(a[1].getTaskID());

// setup is done, now start all task by decrementing their refcount
// tasks with refcount == 0 will be submitted to the dispatcher
for(PxU32 i = 0; i < 3; i++)
{
    a[i].removeReference();
    b[i].removeReference();
    c[i].removeReference();
}
Introduction

This section discusses the PhysX geometry classes. Geometries are used for rigid bodies, as collision triggers, and as volumes in PhysX' scene. PhysX also provides standalone functions for testing intersection between geometries, raycasting against them, and sweeping one geometry against another.

Geometries are value types, and inherit from a common base class, `PxGeometry`. Each geometry class defines a volume or surface with a fixed position and orientation. A transform specifies the frame in which the geometry is interpreted. For plane and capsule geometry types, PhysX provides helper functions to construct these transforms from common alternative representations.

Geometries fall into two classes:

- **primitives** (`PxBoxGeometry`, `PxSphereGeometry`, `PxPlaneGeometry`) where the geometry object contains all of the data.
- **meshes or height fields** (`PxConvexMeshGeometry`, `PxTriangleMeshGeometry`, `PxHeightFieldGeometry`), where the geometry object contains a larger object (`PxConvexMesh`, `PxTriangleMesh`, `PxHeightField` respectively) that use these objects with different scales in each `PxGeometry` type. The larger objects must be created using a *cooking* process, as described below.

When passed into and out of the SDK for use as simulation geometry, it is copied into and out of a `PxShape` class. It can be awkward in this case to retrieve the geometry without knowing its type, so PhysX provides a union-like wrapper class (`PxGeometryHolder`) that can be used to pass any geometry type by value. Each mesh (or height field) has a reference count that tracks the number of `PxShapes` that reference the mesh.
Geometry Types

Spheres

A PxSphereGeometry is specified by one attribute, its radius, and is centered at the origin.

Capsules

A PxCapsuleGeometry is centered at the origin. It is specified by a radius value by which its axis extends along the positive and negative X-axis.

To create a dynamic actor whose geometry is a capsule standing upright, a relative transform that rotates it around the Z-axis by a quarter-circle capsule will extend along the Y-axis of the actor instead of the X-axis: shape and actor is otherwise the same as for the sphere:
The function PxTransformFromSegment() converts from a line segment defining the capsule axis to a transform and halfheight.

**Boxes**

![Box Diagram]

A PxBoxGeometry has three attributes, the three extents halved:

```
PxShape* aBoxShape = PxRigidActorExt::createExclusiveShape(*aBoxActor, PxBoxGeometry(a/2, b/2, c/2), aMaterial);
```

Where a, b and c are the side lengths of the resulting box.

**Planes**
Planes divide space into "above" and "below" them. Everything "below" will collide with it.

The Plane lies on the YZ plane with "above" pointing towards positive X. To convert from a plane equation to an equivalent transform, use PxTransformFromPlaneEquation(). PxPlaneEquationFromTransform() performs the reverse conversion.

A PxPlaneGeometry has no attributes, since the shape's pose entirely defines the collision volume.

Shapes with a PxPlaneGeometry may only be created for static actors.

**Convex Meshes**
A shape is convex if, given any two points within the shape, the shape contains the line between them. A PxConvexMesh is a convex polyhedron represented and polygonal faces. The number of vertices and faces of a convex mesh in PhysX is limited to 255.

Creating a PxConvexMesh requires cooking. It is assumed here that has already been initialized (see *Startup and Shutdown.*) The following to create a simple square pyramid.

First, define the vertices of the convex object:

```cpp
static const PxVec3 convexVerts[] = {PxVec3(0,1,0), PxVec3(1,0,0), PxVec3(0,0,-1)};
```

Then construct a description of the convex data layout:

```cpp
PxConvexMeshDesc convexDesc;
convexDesc.points.count = 5;
convexDesc.points.stride = sizeof(PxVec3);
convexDesc.points.data = convexVerts;
convexDesc.flags = PxConvexFlag::eCOMPUTE_CONVEX;
```

Now use the cooking library to construct a PxConvexMesh:

```cpp
PxDefaultMemoryOutputStream buf;
PxConvexMeshCookingResult::Enum result;
if(!cooking.cookConvexMesh(convexDesc, buf, &result))
```
return NULL;
PxDefaultMemoryInputData input(buf.getData(), buf.getSize());
PxConvexMesh* convexMesh = physics->createConvexMesh(input);

Finally, create a shape using a PxConvexMeshGeometry which instanciates the mesh:

PxShape* aConvexShape = PxRigidActorExt::createExclusiveShape(*aConvexActor, PxConvexMeshGeometry(convexMesh), aMaterial);

Alternatively the PxConvexMesh can be cooked and directly inserted to the physics world without stream serialization. This is useful if real-time cooking is required but it is strongly recommended to use offline cooking and streams. Here is an example to improve cooking speed if needed:

PxConvexMeshDesc convexDesc;
convexDesc.points.count = 5;
convexDesc.points.stride = sizeof(PxVec3);
convexDesc.points.data = convexVerts;
convexDesc.flags = PxConvexFlag::eCOMPUTE_CONVEX | PxConvexFlag::eFAST_INERTIA_COMPUTATION;

#if defined _DEBUG
// mesh should be validated before cooking without the mesh cleaning
bool res = theCooking->validateConvexMesh(convexDesc);
PX_ASSERT(res);
#endif

PxConvexMesh* aConvexMesh = theCooking->createConvexMesh(convexDesc);
thePhysics->getPhysicsInsertionCallback();

Please note that mesh validation is required for debug and checked builds. Creating meshes from unvalidated input descriptors may result in undefined behavior. Providing the PxConvexFlag::eFAST_INERTIA_COMPUTATION flag the volume integration will use SIMD code path which does faster computation but with lesser precision.

The user can optionally provide a per-instance PxMeshScale in the PxConvexMeshGeometry. The scale defaults to identity. Negative scale is not supported for convex meshes.

PxConvexMeshGeometry also contains flags to tweak some aspects of
By default the system computes approximate (loose) bounds around convex objects. Using PxConvexMeshGeometryFlag::eTIGHT_BOUNDS enables smaller/tighter bounds, which are more expensive to compute but could result in improved simulation performance when a lot of convex objects are interacting with each other.

PxConvexMeshGeometry also contains a variable called maxMargin. By default, it is set to 3.4e38f. If the maxMargin is smaller than the margin amount calculated by the contact gen, it will choose the smallest margin for the shrunk shape to perform update using GJK algorithm. In this case, application might notice some vertex collision. If the maxMargin is set to be a small value, this could improve the visibility of these artefacts. If maxMargin is set to zero, PCM will use the original shape for the GJK algorithm. This will result in no artefacts for this approach. However, there is a trade off between performance and accuracy.

**Convex Mesh cooking**

Convex Mesh cooking transforms the mesh data into a form which allows the SDK to perform efficient collision detection. The input to cooking is defined by PxConvexMeshDesc.

There are different ways to fill in this structure, depending on whether you provide a convex mesh starting from just a cloud of vertices, or whether you have the faces of a polyhedron already.

**If Only Vertex Points are Provided**

When providing only vertices, set the PxConvexFlag::eCOMPUTE_CONVEX flag to compute the mesh:

```cpp
PxConvexMeshDesc convexDesc;
convexDesc.points.count = 20;
convexDesc.points.stride = sizeof(PxVec3);
convexDesc.points.data = convexVerts;
convexDesc.flags = PxConvexFlag::eCOMPUTE_CONVEX;
convexDesc.maxVerts = 10;
PxDefaultMemoryOutputStream buf;
```
if(!cooking.cookConvexMesh(convexDesc, buf))
    return NULL;

The algorithm tries to create a convex mesh from the source vertices.
convexDesc.vertexLimit specifies the limit for the maximum number of vertices in the resulting hull.

This routine can sometimes fail when the source data is geometrically challenging, for example if it contains a lot of vertices close to each-other. If cooking failed, an error is reported to the error stream and the routine returns false.

If PxConvexFlag::eCHECK_ZERO_AREA_TRIANGLES is used, the algorithm does not include triangles with an area less than PxCookingParams::areaTestEpsilon. If the algorithm cannot find 4 initial vertices without a small triangle, PxConvexMeshCookingResult::eZERO_AREA_TEST_FAILED is returned indicating that the provided vertices were in a very small area and the cooker could not produce a valid hull. The toolkit helper function PxToolkit::createConvexMeshSafe illustrates the most robust strategy for convex mesh cooking. First it tries to create the hull without inflation, then if that fails it tries inflation, and if that also fails, uses an AABB or OBB.

It is recommended to provide vertices around origin and put transformation in PxShape, otherwise addional PxConvexFlag::eSHIFT_VERTICES flag for the mesh computation.

If huge amount of input vertices are provided, it might be useful to quantize the vertices, in this case use PxConvexFlag::eQUANTIZE_INPUT and PxConvexMeshDesc::quantizedCount.

Convex cooking supports two different algorithms:

**Quickhull Algorithm**

This algorithm does not use inflation. It creates a convex mesh whose vertices are a subset of the original vertices, and the number of vertices is guaranteed to be no more than the specified maximum.

The Quickhull algorithm performs these steps:
- Cleans the vertices - removes duplicates etc.
- Finds a subset of vertices, no more than vertexLimit, that enclose the input set.
- If the vertexLimit is reached, expand the limited hull around the vertices to ensure we encapsulate all the input vertices.
- Compute a vertex map table. (Requires at least 3 neighbor polygons for each vertex.)
- Checks the polygon data - verifies that all vertices are on or inside the hull.
- Computes mass and inertia tensor assuming density is 1.
- Saves data to stream.

When the hull is constructed each new vertex added must be further than PxCookingParams::planeTolerance from the hull, if not that vertex is dropped.

Inflation Based Incremental Algorithm

This algorithm always uses the PxConvexFlag::eINFLATE_CONVEX flag to inflate hull planes by PxCookingParams::skinWidth.

The Inflation Incremental Algorithm performs these steps:

- Cleans the vertices - removes duplicates etc.
- Finds a subset of vertices, no more than vertexLimit, that enclose the input set.
- Creates planes from the produced enclosed hull.
- Inflates planes by defined PxCookingParams::skinWidth.
- Crops the AABB by the inflated planes and produces a new hull.
- Computes vertex map table. (Requires at least 3 neighbor polygons)
- Checks polygon data - verifies all vertices are on or inside the hull.
- Computes mass and inertia tensor assuming density is 1.
- Saves data to stream.

Note that the inflation based algorithm can produce hulls with more input vertices. The algorithm is significantly slower than the quickhull and produces significantly less stable results. It is recommended to use the quickhull algorithm.
Vertex Limit Algorithms

If a vertex limit has been provided, there are two algorithms that handle

The default algorithm computes the full hull, and an OBB around the OBB is then sliced with the hull planes until the vertex limit is reached. This algorithm requires the vertex limit to be set to at least 8, and typically produces results that are much better quality than are produced by plane shifting.

When plane shifting is enabled (PxConvexFlag::ePLANE_SHIFTING), computation stops when vertex limit is reached. The hull planes are all input vertices, and the new plane intersection points are then used to hull with the given vertex limit. Plane shifting may produce sharp edges away from the input cloud, and does not guarantee that all input vertices are inside the resulting hull. However, it can be used with a vertex limit as low as 4, which is better choice for cases such as small pieces of debris with very low vert

Vertex Points, Indices and Polygons are Provided

To create a PxConvexMesh given a set of input vertices (convexVerts) and polygons (hullPolygons):

```cpp
PxConvexMeshDesc convexDesc;
convexDesc.points.count = 12;
convexDesc.points.stride = sizeof(PxVec3);
convexDesc.points.data = convexVerts;
convexDescPolygons.polygons.count = 20;
convexDescPolygons.polygons.stride = sizeof(PxHullPolygon);
convexDescPolygons.polygons.data = hullPolygons;
convexDesc.flags = 0;

PxDefaultMemoryOutputStream buf;
if(!cooking.cookConvexMesh(convexDesc, buf))
    return NULL;
```

When points and polygons are provided, the SDK validates the mesh PxConvexMesh directly. This is the fastest way to create a convex mesh. The SDK requires at least 3 neighbor polygons for each vertex. Othe
structure for PCM is not created and it does result in performance enabled.

(NOTE: the SDK should reject such a mesh as invalid)

Internal steps during convex cooking:

- Compute vertex map table, requires at least 3 neighbor polygons fc
- Check polygons data - check if all vertices are on or inside the hull,
- Compute mass and inertia tensor assuming density 1.
- Save data to stream.

**Triangle Meshes**

Like graphical triangle meshes, a collision triangle mesh consists of a collection of vertices and the triangle indices. Triangle mesh creation requires use of the cooking library assumed here that the cooking library has already been initialized `Shutdown.):

```
PxTriangleMeshDesc meshDesc;
meshDesc.points.count = nbVerts;
meshDesc.points.stride = sizeof(PxVec3);
```
Alternatively \textit{PxTriangleMesh} can be cooked and directly inserted into stream serialization. This is useful if real-time cooking is required to use offline cooking and streams. Example how to speed if needed:

```cpp
PxTolerancesScale scale;
PxCookingParams params(scale);
// disable mesh cleaning - perform mesh validation on development
params.meshPreprocessParams |= PxMeshPreprocessingFlag::eDISABLE;
// disable edge precompute, edges are set for each triangle, slow
params.meshPreprocessParams |= PxMeshPreprocessingFlag::eDISABLE;
// lower hierarchy for internal mesh
params.meshCookingHint = PxMeshCookingHint::eCOOKING_PERFORMANCE;

theCooking->setParams(params);

PxTriangleMeshDesc meshDesc;
meshDesc.points.count = nbVerts;
meshDesc.points.stride = \texttt{sizeof}(PxVec3);
meshDesc.points.data = verts;

meshDesc.triangles.count = triCount;
meshDesc.triangles.stride = 3*\texttt{sizeof}(PxU32);
meshDesc.triangles.data = indices32;

#ifdef _DEBUG
  // mesh should be validated before cooked without the mesh cli
  bool res = theCooking->validateTriangleMesh(meshDesc);
  PX_ASSERT(res);
#endif
```
Indices can be 16 or 32 bit. The strides used here assume that vertex arrays of PxVec3s and 32bit integers respectively with no gaps in the data.

Returned result enum `PxTriangleMeshCookingResult::eLARGE_TRIANGLE` the user if the mesh contains large triangles, which should be tessellated to ensure better simulation and CCT stability.

Like height fields, triangle meshes support per-triangle material indices. To use per-triangle materials for a mesh, provide per-triangle indices to the cooking library in the mesh descriptor. Later, when creating the PxShape, supply a table mapping the index values in the mesh to material instances.

**Triangle Mesh cooking**

Triangle mesh cooking proceeds as follows:

- Check validity of input vertices.
- Weld vertices and check triangle sizes.
- Create acceleration structure for queries.
- Compute edge convexity information and adjacencies.
- Save data to stream.

Note that mesh cleaning may result in the set of triangles produced being a subset different from the original input set. Mesh cleaning removes invalid triangles (containing out-of-range vertex references), duplicate triangles, and zero-area triangles. When this happens, PhysX optionally outputs a mesh remapping table that links each internal triangle to its source triangle in the user's data.

There are multiple parameters to control mesh creation.

In `PxTriangleMeshDesc:`
• *materialIndices* defines per triangle materials. When a triangle collides with another object, a material is required at the collision point. If materialIndices is NULL, then the material of the PxShape instance is used.

In *PxCookingParams*:

• *scale* defines Tolerance scale is used to check if cooked triangles are too huge. This check will help with simulation stability.

• *suppressTriangleMeshRemapTable* specifies whether the face remap table is created. If not, this saves a significant amount of memory, but the SDK will not provide information about which original mesh triangle is hit in collisions, sweeps, or raycasts hits.

• *buildTriangleAdjacencies* specifies if the triangle adjacency information is created. The adjacent triangles can be retrieved for a given triangle using the getTriangleMeshPreprocessParams method.

• *meshPreprocessParams* specifies mesh pre-processing parameters:
  - *PxMeshPreprocessingFlag::eWELD_VERTICES* enables vertex welding during triangle mesh cooking.
  - *PxMeshPreprocessingFlag::eDISABLE_CLEAN_MESH* disables mesh cleaning process. Vertices duplicities are not searched, huge triangles test is not done. Does speed up the cooking.
  - *PxMeshPreprocessingFlag::eDISABLE_ACTIVE_EDGES_PRECOMPUTE* disables vertex edge precomputation. Makes cooking faster but slows contact generation.

• *meshWeldTolerance* - If mesh welding is enabled, this controls the distance at which vertices are welded. If mesh welding is not enabled, this value defines the acceptance distance for mesh validation. Provided no two vertices are within this distance, the mesh is considered to be clean. If not, a warning will be emitted. Having a clean mesh is required to achieve the best possible performance.
- `midphaseDesc` specifies the desired midphase acceleration structure.
  - `PxBVH33MidphaseDesc` - `PxMeshMidPhase::eBVH33` structure. It was the one used in recent PhysX versions up to PhysX 3.3. It has great performance and is supported on all platforms.
  - `PxBVH34MidphaseDesc` - `PxMeshMidPhase::eBVH34` implementation introduced in PhysX 3.4. It can be significantly faster both in terms of cooking performance and runtime performance, only available on platforms supporting the SSE2 instruction.

**`PxBVH33MidphaseDesc` params:**

- `meshCookingHint` specifies mesh hierarchy construction preferences. Enables better cooking performance over collision performance, for applications where cooking performance is more important than best quality mesh creation.
- `meshSizePerformanceTradeOff` specifies the trade-off between mesh size and runtime performance.

**`PxBVH34MidphaseDesc` params:**

- `numTrisPerLeaf` specifies the number of triangles per leaf. Less produces larger meshes with general better runtime performance.

**Height Fields**
Local space axes for the height fields are:
   - Row - X axis
   - Column - Z axis
   - Height - Y axis

As the name suggests, terrains can be described by just the height values on a regular, rectangular sampling grid:

```cpp
PxHeightFieldSample* samples = (PxHeightFieldSample*)alloc(sizeof(PxHeightFieldSample*)
   (numRows*numCols));
```

Each sample consists of a 16 bit integer height value, two materials (for the two triangles in the samples rectangle) and a tessellation flag.

The flag and materials refer to the cell below and to the right of the sample point, and indicate along which diagonal to split it into triangles, and the materials of those triangles. A special predefined material `PxHeightFieldMaterial::eHOLE` specifies a hole in the height field. See the reference documentation for `PxHeightFieldSample` for more details.

<table>
<thead>
<tr>
<th>Tesselation flag set</th>
<th>Tesselation flag not set</th>
</tr>
</thead>
</table>

- [ ]
- [ ]
Examples:

<table>
<thead>
<tr>
<th>Tessellation flags</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,0,0</td>
<td><img src="image1" alt="Result" /></td>
</tr>
<tr>
<td>0,0,0</td>
<td><img src="image2" alt="Result" /></td>
</tr>
<tr>
<td>0,0,0</td>
<td><img src="image3" alt="Result" /></td>
</tr>
<tr>
<td>0,0,0</td>
<td><img src="image4" alt="Result" /></td>
</tr>
<tr>
<td>1,1,1</td>
<td><img src="image5" alt="Result" /></td>
</tr>
<tr>
<td>1,1,1</td>
<td><img src="image6" alt="Result" /></td>
</tr>
<tr>
<td>1,1,1</td>
<td><img src="image7" alt="Result" /></td>
</tr>
<tr>
<td>1,1,1</td>
<td><img src="image8" alt="Result" /></td>
</tr>
</tbody>
</table>
To tell the system the number of sampled heights in each direction, instantiate a PxHeightField object:

```cpp
PxHeightFieldDesc hfDesc;
hfDesc.format = PxHeightFieldFormat::eS16_TM;
hfDesc.nbColumns = numCols;
hfDesc.nbRows = numRows;
hfDesc.samples.data = samples;
hfDesc.samples.stride = sizeof(PxHeightFieldSample);

PxHeightField* aHeightField = theCooking->createHeightField(hfDesc, thePhysics->getPhysicsInsertionCallback());
```

Now create a PxHeightFieldGeometry and a shape:

```cpp
PxHeightFieldGeometry hfGeom(aHeightField, PxMeshGeometryFlags(), colScale);
PxShape* aHeightFieldShape = PxRigidActorExt::createExclusiveShape(hfGeom, aMaterialArray, nbMaterials);
```

The row and column scales tell the system how far apart the sampled points lie in the associated direction. The height scale scales the integer height values to a floating point range.

The variant of `createExclusiveShape()` used here specifies an array of materials for the height field, which will be indexed by the material indices of each cell to resolve collisions with that cell. The single-material variant may be used instead, but the

indices must all be a single value or the special value \texttt{eHOLE}.

Contact generation with triangle edges at the terrain's borders can be \texttt{PxHeightFieldFlag::eNO_BOUNDARY_EDGES} flag, allowing more generation when there are multiple heightfield shapes arranged so that

Heightfield cooking

Heightfield data can be cooked in offline and then used to createHeightField, does precompute and store the edge information. This allows much faster heightfield, since the edges are already precomputed. It is very useful to create heightfields in the runtime, since it does improve the speed of significantly.

Heightfield cooking proceeds as follows:

- Load heightfield samples into internal memory.
- Precompute edge collision information.
- Save data to stream.

Unified Heightfields

PhysX provides two contact generation approaches for heightfields. They are:

- Default unified heightfield contact generation.
- Legacy heightfield contact generation.

The default unified heightfield contact generation approach extracts heightfield and utilizes the same low-level contact generation code that generation against triangle meshes. This approach ensures equivalent and performance if triangle meshes or heightfields are used interchangeably. In this approach, the heightfield surface has no thickness so fast-moving objects may tunnel if CCD is not enabled.

The legacy heightfield collision code, which was default in previous
works differently from triangle mesh contact generation. In addition to generating contacts with shapes touching the surface of the heightfield, it generates contacts with shapes that are beneath the surface. The heightfield's "thickness" is used to control how far beneath the surface contacts are generated. This works by extruding the AABB of the broad phase by the "thickness" along the vertical axis. Contacts are generated for any shape below the surface whose bounds intersect the heightfields extruded bounds.

Unified heightfield contact generation is enabled by calling:

```cpp
PxRegisterHeightFields(PxPhysics& physics);
```

Legacy heightfield contact generation is enabled by calling:

```cpp
PxRegisterLegacyHeightFields(PxPhysics& physics);
```

These calls must be made before and scenes have been created, otherwise warnings will be issued. The heightfield collision setting is a global setting, and it applies to all scenes.

If PxCreatePhysics(...) is called, this will automatically call PxRegisterHeightFields(...) to register the default, unified heightfield collision approach. If PxCreateBasePhysics(...) is called, no heightfield contact generation is registered by default. If heightfields are used, the application must call the appropriate heightfield registration function.
Mesh Scaling

A shared PxTriangleMesh or PxConvexMesh may be stretched or compressed by a geometry. This allows multiple instancing of the same mesh with different scale factors applied. Scaling is specified with the PxMeshScale class, which defines scale factors to be applied along 3 orthogonal axes. A factor greater than 1.0 results in stretching, while a factor less than 1.0 results in compression. The directions are governed by a quaternion, and specified in the local frame of the shape.

Negative mesh scale is supported, with negative values producing a reflection along the corresponding axis. In addition, PhysX will flip the normals for mesh triangles when scale.x*scale.y*scale.z < 0.

The following code creates a shape with a PxTriangleMesh scaled by a factor of x along the x-axis, y along the y-axis, and z along the z-axis:

```cpp
// created earlier
PxRigidActor* myActor;
PxTriangleMesh* myTriMesh;
PxMaterial* myMaterial;

// create a shape instancing a triangle mesh at the given scale
PxMeshScale scale(PxVec3(x, y, z), PxQuat(PxIdentity));
PxTriangleMeshGeometry geom(myTriMesh, scale);
PxShape* myTriMeshShape = PxRigidActorExt::createExclusiveShape(*myActor, geom);
```

Convex meshes are scaled using the PxMeshScale class in a similar manner. The following code creates a shape with a PxConvexMesh scaled by a factor of x along (sqrt(1/2), 1.0, -sqrt(1/2)), by a factor of y along (0,1,0) and a by a factor of z along (sqrt(1/2), 1.0, sqrt(1/2)):

```cpp
PxMeshScale scale(PxVec3(x, y, z), PxQuat(quat(PxPi*0.25f, PxVec3(0, 1, 0)), PxVec3(0.5, 1, 0.5, 1, 1, 1)));
PxConvexMeshGeometry geom(myTriMesh, scale);
PxShape* myConvexMeshShape = PxRigidActorExt::createExclusiveShape(*myActor, geom);
```

Height fields can also be scaled, using scale factors stored in PxHeight
In this example, the coordinates along the x and z axes are scaled by heightScale.
When a geometry is provided for a shape, either on creation with 
`PxShape::setGeometry()`, the geometry is copied into the SDK's internal 
structures. If you know the type of a shape's geometry you may retrieve it directly:

```cpp
PxBoxGeometry boxGeom;
bool status = shape->getBoxGeometry(geometry);
```

The status return code is set to false if the shape's geometry is not of the expected type.

However, it is often convenient to retrieve a geometry object from a shape without 
knowing its type - for example, to call a function which takes a `PxGeometry` 
an argument.

`PxGeometryHolder` is a union-like class that allows the return of a `PxGeometry` value, regardless of type. Its use is illustrated in the `createRenderObjectFromShape()` function in PhysXSample.cpp:

```cpp
PxGeometryHolder geom = shape->getGeometry();
switch(geom.getType())
{
    case PxGeometryType::eSPHERE:
        shapeRenderActor = SAMPLE_NEW(RenderSphereActor)(renderer, geom);
        break;
    case PxGeometryType::eCAPSULE:
        shapeRenderActor = SAMPLE_NEW(RenderCapsuleActor)(renderer, geom.capsule().halfHeight);
        break;
    ...
}
```

The function `PxGeometryHolder::any()` returns a reference to a `PxGeometry` object, for example, to compare two shapes in a scene for overlap:

```cpp
bool testForOverlap(const PxShape& s0, const PxShape& s1)
{
```
return PxGeometryQuery::overlap(s0.getGeometry().any(), PxSha
s1.getGeometry().any(), PxSha}
Vertex and Face Data

Convex meshes, triangle meshes, and height fields can all be queried for vertex and face data. This is particularly useful, for example, when rendering the mesh. The function:

```
RenderBaseActor* PhysXSample::createRenderObjectFromShape(PxShape RenderMaterial* material)
```

in PhysXSample.cpp contains a switch statement with a case for illustrating the steps required to query the vertices and faces.

It is possible to get information about triangle from a triangle mesh or height field using PxMeshQuery::getTriangle function. You can also retrieve adjacent triangle indices for the given triangle (triangle triangleNeighbour[i] shares the edge vertex[i]-v where vertex is in the range from 0 to 'triangleIndex', where vertex is in the range from 0 to 2). To enable this feature the triangle mesh is cooked with buildTriangleAdjacencies parameter.

Convex Meshes

A convex mesh contains an array of vertices, an array of faces, and an index buffer which concatenates the vertex indices for each face. To unpack a convex mesh to extract the shared convex mesh:

```
PxConvexMesh* convexMesh = geom.convexMesh().convexMesh;
```

Then obtain references to the vertex and index buffers:

```
PxU32 nbVerts = convexMesh->getNbVertices();
const PxVec3* convexVerts = convexMesh->getVertices();
const PxU8* indexBuffer = convexMesh->getIndexBuffer();
```

Now iterate over the array of faces to triangulate them:

```
PxU32 offset = 0;
```
for(PxU32 i=0; i<nbPolygons; i++)
{
    PxHullPolygon face;
    bool status = convexMesh->getPolygonData(i, face);
    PX_ASSERT(status);

    const PxU* faceIndices = indexBuffer + face.mIndexBase;
    for(PxU32 j=0; j<face.mNbVerts; j++)
    {
        vertices[offset+j] = convexVerts[faceIndices[j]];
        normals[offset+j] = PxVec3(face.mPlane[0], face.mPlane[1])
    }

    for(PxU32 j=2; j<face.mNbVerts; j++)
    {
        *triangles++ = PxU16(offset);
        *triangles++ = PxU16(offset+j);
        *triangles++ = PxU16(offset+j-1);
    }
    offset += face.mNbVerts;
}

Observe that the vertex indices of the polygon begin at indexBuffer[face.mIndexBase], and the count of vertices is given by face.mNbVerts.

Triangle Meshes

Triangle meshes contain arrays of vertices and index triplets which define triangles by indexing into the vertex buffer. The arrays can be accessed directly from the shared triangle mesh:

PxTriangleMesh* tm = geom.triangleMesh().triangleMesh;
const PxU32 nbVerts = tm->getNbVertices();
const PxVec3* verts = tm->getVertices();
const PxU32 nbTris = tm->getNbTriangles();
const void* tris = tm->getTriangles();

The indices may be stored with either 16-bit or 32-bit values, specified when the mesh was originally cooked. To determine the storage format at runtime, use

API call:
const bool has16bitIndices = tm->has16BitTriangleIndices();

Assuming that the triangle indices are stored in 16-bit format, find the
triangle by:

```
const PxU16* triIndices = (const PxU16*)tris;
const PxU16 index = triIndices[3*i + j];
```

The corresponding vertex is:

```
const PxVec3& vertex = verts[index];
```

**Height Fields**

The storage of height field data is platform-dependent, and therefore
calling for height field samples is not provided. Instead, calls are provided to render
samples to a user-supplied buffer.

Again, the first step is to retrieve the geometry for the height field:

```
const PxHeightFieldGeometry& geometry = geom.heightField();
```

The height field has three scaling parameters:

```
const PxReal rs = geometry.rowScale;
const PxReal hs = geometry.heightScale;
const PxReal cs = geometry.columnScale;
```

And a shared data structure, which stores the row and column count:

```
PxHeightField* hf = geometry.heightField;
const PxU32 nbCols = hf->getNbColumns();
const PxU32 nbRows = hf->getNbRows();
```

To render the height field, first extract the samples to an array:

```
const PxU32 nbVerts = nbRows * nbCols;
```
PxHeightFieldSample* sampleBuffer = new PxHeightFieldSample[nbVer]
hf->saveCells(sampleBuffer, nbVerts * sizeof(PxHeightFieldSample)

The samples are stored in row-major order; that is, row0 is stored first then row2, and so on. Thus the sample corresponding to the ith row and i*nbCols + j.

Evaluate the scaled vertices of the height field as follows:

PxVec3* vertices = new PxVec3[nbVerts];
for(PxU32 i = 0; i < nbRows; i++)
{
    for(PxU32 j = 0; j < nbCols; j++)
    {
        vertices[i * nbCols + j] = PxVec3(PxReal(i) * rs, PxReal((i*nbCols)].height) * hs, PxReal(j) * cs);
    }
}

Then tessellate the field from the samples as required.

**Heightfield Modification**

Heightfield samples can be modified at runtime in rectangular blocks. In snippet we create a HF and modify it's samples:

// create a 5x5 HF with height 100 and materials 2,3
PxHeightFieldSample samples1[25];
for (PxU32 i = 0; i < 25; i ++)
{
    samples1[i].height = 100;
    samples1[i].materialIndex0 = 2;
    samples1[i].materialIndex1 = 3;
}

PxHeightFieldDesc heightFieldDesc;
heightFieldDesc.nbColumns = 5;
heightFieldDesc.nbRows = 5;
heightFieldDesc.thickness = -10;
heightFieldDesc.convexEdgeThreshold = 3;
heightFieldDesc.samples.data = samples1;
heightFieldDesc.samples.stride = sizeof(PxHeightFieldSample);
PxPhysics* physics = getPhysics();
PxHeightField* pHeightField = cooking->createHeightField(heightFieldDesc);

// create modified HF samples, this 10-sample strip will be used
// Source samples that are out of range of target heightfield will
PxHeightFieldSample samplesM[10];
for (PxU32 i = 0; i < 10; i++)
{
    samplesM[i].height = 1000;
    samplesM[i].materialIndex0 = 1;
    samplesM[i].materialIndex1 = 127;
}

PxHeightFieldDesc desc10Rows;
desc10Rows.nbColumns = 1;
desc10Rows.nbRows = 10;
desc10Rows.samples.data = samplesM;
desc10Rows.samples.stride = sizeof(PxHeightFieldSample);

pHeightField->modifySamples(1, 0, desc10Rows); // modify row 1 with new sample data

PhysX does not keep a mapping from the heightfield to heightfield shapes. Call PxShape::setGeometry on each shape which references the heightfield so that internal data structures are updated to reflect the new geometry:

PxShape *hfShape = userGetHfShape(); // the user is responsible for shapes associated with modified heights
hfShape->setGeometry(PxHeightFieldGeometry(pHeightField, ...));

Please also note that PxShape::setGeometry() does not guarantee correct/continuous behavior when objects are resting on top of old or new geometry.

The method PxHeightField::getTimestamp() returns the number of times the heightfield has been modified.
Introduction

This chapter will introduce the fundamentals of simulating rigid body dynamics using the NVIDIA PhysX engine.
Rigid Body Object Model

PhysX uses a hierarchical rigid body object/actor model, which looks like this:

```
Class                  Extends            Functionality
PxBase                 N/A              Reflection/querying object types.
PxActor                PxBase            Actor name, actor flags, dominance, aggregates, query world bounds.
PxRigidActor           PxActor           Shapes and transforms.
PxRigidBody            PxRigidActor      Mass, inertia, velocities, body flags.
PxRigidStatic          PxRigidActor      Interface for static body in the scene body has implicit infinite mass/inertia
PxRigidDynamic         PxRigidBody       Interface for dynamic rigid body in th
PxArticulationLink     N/A              Introduces support for kinematic targ
PxRigidStatic          N/A              Interface for rigid body in the scene
```

<table>
<thead>
<tr>
<th>PxArticulationLink</th>
<th>PxRigidBody</th>
<th>Interface for a dynamic rigid body lin PxArticulation. Introduces support for articulation and adjacent links.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PxArticulation</td>
<td>PxBase</td>
<td>Defines interface for a PxArticulation contained referencing multiple PxArt bodies.</td>
</tr>
</tbody>
</table>

The following diagram shows the relationship between the main types in body pipeline:

![Diagram showing the relationship between main types in body pipeline]
The Simulation Loop

Now use the method PxScene::simulate() to advance the world forward. Here is simplified code from the samples' fixed stepper class:

```cpp
mAccumulator = 0.0f;
mStepSize = 1.0f / 60.0f;

virtual bool advance(PxReal dt) {
    mAccumulator += dt;
    if(mAccumulator < mStepSize)
        return false;

    mAccumulator -= mStepSize;
    mScene->simulate(mStepSize);
    return true;
}
```

This is called from the sample framework whenever the app is done with events and is starting to idle. It accumulates elapsed real time until it is greater than sixtieth of a second, and then calls simulate(), which moves all objects forward by that interval. This is probably the simplest of very many different ways to deal with time when stepping the simulation forward.

To allow the simulation to finish and return the results, simply call:

```cpp
mScene->fetchResults(true);
```

True indicates that the simulation should block until it is finished, so results are guaranteed to be available. When fetchResults completes, event callback functions that you defined will also be called. See the Sequence.

It is possible to read and write from the scene during simulation. The advantage of this to perform rendering work in parallel with physics. However, until fetchResults returns, the results of the current simulation step are not available. So...
parallel with simulation renders the actors as they were when simulate fetchResults() returns, all these functions will return the new, post-simulate state. See chapter Threading for more details about reading and writing while running.

For the human eye to perceive animated motion as smooth, use at least twenty frames per second, with each frame corresponding to a physics time step. For smooth, realistic simulation of more complex physical scenes, use at least fifty frames per second.

**Note:** If you are making a real-time interactive simulation, you may be tempted to take different sized time steps which correspond to the amount of real time that has elapsed since the last simulation frame. Be very careful if you do this, rather than taking constant-sized time steps: The simulation code is sensitive to both very small and large time steps, and also to too much variation between time steps. In these cases it will likely produce jittery simulation.

See *Simulation memory* for details of how memory is used in simulation.
Introduction

This section will introduce the fundamentals of rigid body collision.
Shapes

Shapes describe the spatial extent and collision properties of actors. They are used for three purposes within PhysX: intersection tests that determine the contacting features of rigid objects, scene query tests such as raycasts, and defining trigger volumes that generate notifications when other shapes intersect with them.

Shapes are reference counted, see *Reference Counting*.

Each shape contains a PxGeometry object and a reference to a PxMaterial, both be specified upon creation. The following code creates a shape with a sphere geometry and a specific material:

```cpp
PxShape* shape = physics.createShape(PxSphereGeometry(1.0f), myMaterial);
myActor.attachShape(*shape);
shape->release();
```

The method PxRigidActorExt::createExclusiveShape() is equivalent above.

**Note:** for reference counting behavior of deserialized shapes refer to *Counting of Deserialized Objects*.

The parameter 'true' to createShape() informs the SDK that the shape with other actors. You can use shape sharing to reduce the memory usage when you have many actors with identical geometry, but shape sharing has a very strong restriction: you cannot update the attributes of a shared shape attached to an actor.

Optionally you may configure a shape by specifying shape flags of type PxShapeFlags. By default a shape is configured as

- a simulation shape (enabled for contact generation during simulation)
- a scene query shape (enabled for scene queries)
- being visualized if debug rendering is enabled

When a geometry object is specified for a shape, the geometry object is copied into the shape. There are some restrictions on which geometries may be specified for a shape, depending on the shape flags and the type of the parent actors.

- TriangleMesh, HeightField and Plane geometries are not supported for simulation shapes that are attached to dynamic actors, unless the dynamic actors are configured to be kinematic.
- TriangleMesh and HeightField geometries are not supported for trigger shapes.

See the following sections for more details.

Detach the shape from the actor as follows:

```cpp
myActor.detachShape(*shape);
```

**Note:** in previous versions of PhysX, release() was used to detach a shape from an actor and destroy it. This use of release() is deprecated in PhysX 3.3 and will not be supported in future versions of PhysX.
Simulation Shapes and Scene Query Shapes

Shapes may be independently configured to participate in either or both scene and contact tests. By default, a shape will participate in both.

The following pseudo-code configures a PxShape instance so that it no longer participates in shape pair intersection tests:

```cpp
void disableShapeInContactTests(PxShape* shape)
{
    shape->setFlag(PxShapeFlag::eSIMULATION_SHAPE, false);
}
```

A PxShape instance can be configured to participate in shape pair intersection tests as follows:

```cpp
void enableShapeInContactTests(PxShape* shape)
{
    shape->setFlag(PxShapeFlag::eSIMULATION_SHAPE, true);
}
```

To disable a PxShape instance from scene query tests:

```cpp
void disableShapeInSceneQueryTests(PxShape* shape)
{
    shape->setFlag(PxShapeFlag::eSCENE_QUERY_SHAPE, false);
}
```

Finally, a PxShape instance can be re-enabled in scene query tests:

```cpp
void enableShapeInSceneQueryTests(PxShape* shape)
{
    shape->setFlag(PxShapeFlag::eSCENE_QUERY_SHAPE, true);
}
```

**Note:** If the movement of the shape's actor does not need to be controlled by the simulation at all, i.e., the shape is used for scene queries only and gets moved manually.
if necessary, then memory can be saved by additionally disabling simu
(see the API documentation on PxActorFlag::eDISABLE_SIMULATION).
**Kinematic Triangle Meshes (Planes, Heighfields)**

It is possible to create a kinematic PxRigidDynamic which can have (plane, heighfield) shape. If this shape has a simulation shape flag, the actor must stay kinematic. If you change the flag to not simulated, you can switch even.

To setup kinematic triangle mesh see following code:

```cpp
PxRigidDynamic* meshActor = getPhysics().createRigidDynamic(PxTransform());
PxShape* meshShape;
if (meshActor) {
    meshActor->setRigidDynamicFlag(PxRigidDynamicFlag::eKINEMATIC);
    PxTriangleMeshGeometry triGeom;
    triGeom.triangleMesh = triangleMesh;
    meshShape = PxRigidActorExt::createExclusiveShape(*meshActor, defaultMaterial);
    getScene().addActor(*meshActor);
}
```

To switch a kinematic triangle mesh actor to a dynamic actor:

```cpp
PxRigidDynamic* meshActor = getPhysics().createRigidDynamic(PxTransform());
PxShape* meshShape;
if (meshActor) {
    meshActor->setRigidDynamicFlag(PxRigidDynamicFlag::eKINEMATIC);
    PxTriangleMeshGeometry triGeom;
    triGeom.triangleMesh = triangleMesh;
    meshShape = PxRigidActorExt::createExclusiveShape(*meshActor, defaultMaterial);
    getScene().addActor(*meshActor);

    PxConvexMeshGeometry convexGeom = PxConvexMeshGeometry(convexBox);
    convexShape = PxRigidActorExt::createExclusiveShape(*meshActor, defaultMaterial);
```
Broad-phase Algorithms

PhysX supports several broad-phase algorithms:

- **sweep-and-prune (SAP)**
- **multi box pruning (MBP)**

`PxBroadPhaseType::eSAP` was the default algorithm used until PhysX 3.2. A good generic choice with great performance when many objects are sleeping. Performance can degrade significantly though, when all objects are moving, or when objects are added to or removed from the broad-phase. This algorithm does not need world bounds to be defined in order to work.

`PxBroadPhaseType::eMBP` is a new algorithm introduced in PhysX 3.3. This broad-phase algorithm that does not suffer from the same performance issues when all objects are moving or when inserting large numbers of objects. However, its generic performance when many objects are sleeping might be inferior to `eSAP`, and it requires users to define world bounds in order to work.

The desired broad-phase algorithm is controlled by the `PxBroadPhaseType` in the `PxSceneDesc` structure.
Regions of Interest

A region of interest is a world-space AABB around a volume of space for the broad-phase. Objects contained inside those regions are properly handled by the broad-phase. Objects falling outside of those regions lose all collision detection. Ideally, those regions should cover the whole game space, while limiting the amount of empty space.

Regions can overlap, although for maximum efficiency it is recommended to minimize the amount of overlap between regions as much as possible. Note that AABBs just touch are not considered overlapping. For example, the ` PxBroadPhaseExt::createRegionsFromWorldBounds ` helper function creates non-overlapping region bounds by simply subdividing a given world AABB into a regular 2D grid.

Regions can be defined by the ` PxBroadPhaseRegion ` structure, along with user data assigned to them. They can be defined at scene creation time or at runtime using the ` PxScene::addBroadPhaseRegion ` function. The SDK returns handles assigned to the newly created regions, that can be used later to remove regions using the ` PxScene::removeBroadPhaseRegion ` function.

A newly added region may overlap already existing objects. The SDK would then add those objects to the new region, if the ` populateRegion ` parameter of the ` PxScene::addBroadPhaseRegion ` call is set. However, this operation might have a high impact on performance, especially when several regions are added in the same frame. Thus, it is recommended to disable it whenever possible. The region would then be created empty, and it would only be populated either with new objects added to the scene after the region has been created, or with previously existing objects when they are updated (i.e. when they move).

Note that only ` PxBroadPhaseType::eMBP ` requires regions to be defined, while the ` PxBroadPhaseType::eSAP ` algorithm does not. This information is captured within the ` PxBroadPhaseCaps ` structure, which lists information and capabilities of each broad-phase algorithm. This structure can be retrieved by the ` PxScene::getBroadPhaseCaps ` function.
function.

Runtime information about current regions can be retrieved using `PxScene::getNbBroadPhaseRegions` and `PxScene::getBroadPhaseRegions`.

The maximum number of regions is currently limited to 256.
Broad-phase Callback

A callback for broad-phase-related events can be defined within structure. This *PxBroadPhaseCallback* object will be called when objects are found out of the specified regions of interest, i.e. "out of bounds". The SDK disables collision detection for those objects. It is re-enabled automatically as soon as the objects re-enter a valid region.

It is up to users to decide what to do with out-of-bounds objects. Typical options are:

- delete the objects
- let them continue their motion without collisions until they re-enter a valid place
- artificially teleport them back to a valid place
Collision Filtering

In almost all applications beyond the trivial, the need arises to exempt objects from interacting, or to configure the SDK collision detection behavior for an interacting pair. In the submarine sample, like indicated above, we need to be notified when the submarine touched a mine, or the chain of a mine, so that they blow up. The crab's AI also needs to know when crabs touch the heightfield.

Before we can understand what the sample does to achieve this, we need to understand the possibilities of the SDK filtering system. Because filtering potentially interacting pairs happens in the deepest parts of the simulation engine, and needs to be applied to all pairs of objects that come near each other, it is particularly performance sensitive. The way to implement it would be to always call a callback function for each potentially interacting pair, where the application, based on the two object pointers using some custom logic -- like consulting its game data base -- whether to interact. Unfortunately this quickly becomes too slow if done for a very large game world, especially if the collision detection processing happens on a remote GPU or an other kind of vector processor with local memory, which would have to suspend its parallel computations, interrupt the main processor that runs game code, and have it execute the callback before it can continue. Even if it were to be executed simultaneously on multiple cores or hyperthreads, the code would have to be put in place to make sure that concurrent access to shared data is safe. Far better is to use some kind of fixed function logic that can execute on the remote processor. This is what we did in PhysX 2.x -- unfortunately the simplifying filtering rules we provided were not flexible enough to cover all applications. We introduce both a shader system, which lets the developer implement an arbitrary system of rules using code that runs on the vector processor (and is therefore not bound to access any eventual game data base in main memory), which is more flexible than filtering, but just as efficient, and a totally flexible callback mechanism where the filter shader calls a CPU callback function that is able to access any application data -- see PxSimulationFilterCallback for details. The application can decide on a per-pair basis to make this speed vs. flexibility trade-off.

Let us look at the shader system first: Here is the filter shade
SampleSubmarineFilterShader is a simple shader function that is an implementation of the PxSimulationFilterShader prototype declared in PxFiltering.h. The shader (called SampleSubmarineFilterShader above) may not reference any non-local arguments of the function and its own local stack variables -- because the function may be compiled and executed on a remote processor.

SampleSubmarineFilterShader() will be called for all pairs of shapes that come near each other -- more precisely: for all pairs of shapes whose axis aligned bounding boxes in world space are found to intersect for the first time. All behavior beyond that is determined by what SampleSubmarineFilterShader() returns.

The arguments of SampleSubmarineFilterShader() include PxFilterObjectAttributes and PxFilterData for the two objects, and a constant block of memory. Note that the two objects are NOT passed, because those pointers refer to the computer's main memory, and that may, as we said, not be available to the shader, so not be very useful, as dereferencing them would likely
PxFilterObjectAttributes and PxFilterData are intended to contain all the information that one could quickly glean from the pointers. PxFilterObjectAttributes encode the type of object: For example PxFilterObjectType::eRIGID_DYNAMIC, or even ::ePARTICLE_SYSTEM. Additionally, it tells whether the object is kinematic, or a trigger.

Each PxShape and PxParticleBase object in PhysX has a member variable PxFilterData. This is 128 bits of user defined data that can be used to store specific information related to collision filtering. This is the other variable passed to SampleSubmarineFilterShader() for each object.

There is also the constant block. This is a chunk of per-scene global information that the application can give to the shader to operate on. You will want to use this to encode rules about what to filter and what not.

Finally, SampleSubmarineFilterShader() also has a PxPairFlags parameter. This tells the SDK if it should ignore the pair for good (eKILL), ignore the pair while it is overlapping, but ask again, when filtering related data changes for one of the objects (eSUPPRESS), or call the low performance but more flexible CPU callback if the shader cannot decide (eCALLBACK).

PxPairFlags specifies additional flags that stand for actions that the simulation should take in the future for this pair. For example, eNOTIFY_TOUCH_FOUND means notify the user when the pair really starts to touch, not just potentially.

Let us look at what the above shader does:

```cpp
// let triggers through
if(PxFilterObjectIsTrigger(attributes0) || PxFilterObjectIsTrigger(attributes1)) {
    pairFlags = PxPairFlag::eTRIGGER_DEFAULT;
    return PxFilterFlag::eDEFAULT;
}
```

This means that if either object is a trigger, then perform default trigger behavior (notify the application about start and end of touch), and otherwise perform...
detection between them.

```cpp
// generate contacts for all that were not filtered above
pairFlags = PxPairFlag::eCONTACT_DEFAULT;

// trigger the contact callback for pairs (A,B) where
// the filtermask of A contains the ID of B and vice versa.
if((filterData0.word0 & filterData1.word1) && (filterData1.word0 & pairFlags |= PxPairFlag::eNOTIFY_TOUCH_FOUND;

return PxFilterFlag::eDEFAULT;
```

This says that for all other objects, perform 'default' collision handling. There is a rule based on the filterDatas that determines particular pairs where we ask for touch notifications. To understand what this means, we need to know the specific meaning that the sample gives to the filterDatas.

The needs of the sample are very basic, so we will use a very simple structure for it. The sample first gives named codes to the different object types using a custom enumeration:

```cpp
struct FilterGroup
{
    enum Enum
    {
        eSUBMARINE = (1 << 0),
        eMINE_HEAD = (1 << 1),
        eMINE_LINK = (1 << 2),
        eCRAB = (1 << 3),
        eHEIGHTFIELD = (1 << 4),
    }
};
```

The sample identifies each shape's type by assigning its PxFilterData::word0 to this FilterGroup type. Then, it puts a bit mask that specifies each type of object that should generate a report when touched by an object of type word0 into word1. In the samples whenever a shape is created, but because shape creation is encapsulated in SampleBase, it is done after the fact, using this function:
void setupFiltering(PxRigidActor* actor, PxU32 filterGroup, PxU32
{
    PxFilterData filterData;
    filterData.word0 = filterGroup;  // word0 = own ID
    filterData.word1 = filterMask;   // word1 = ID mask to filter
    // contact callback

    const PxU32 numShapes = actor->getNbShapes();
    PxShape** shapes = (PxShape**)SAMPLE_ALLOC(sizeof(PxShape*)*numShapes)
actor->getShapes(shapes, numShapes);
for(PxU32 i = 0; i < numShapes; i++)
{
    PxShape* shape = shapes[i];
    shape->setSimulationFilterData(filterData);
}
SAMPLE_FREE(shapes);
}

This sets up the PxFilterDatas of each shape belonging to the passed actor, some examples how this is used in SampleSubmarine:

setupFiltering(mSubmarineActor, FilterGroup::eSUBMARINE, FilterGroup::eMINE_LINK);
setupFiltering(link, FilterGroup::eMINE_LINK, FilterGroup::eSUBMARINE);
setupFiltering(mineHead, FilterGroup::eMINE_HEAD, FilterGroup::eSUBMARINE);
setupFiltering(heightField, FilterGroup::eHEIGHTFIELD, FilterGroup::eSUBMARINE);
setupFiltering(mCrabBody, FilterGroup::eCRAB, FilterGroup::eHEIGHTFIELD);

This scheme is probably too simplistic to use in a real game, but it shows the basic usage of the filter shader, and it will ensure that SampleSubmarine::onContact() is called for all interesting pairs.

An alternative group based filtering mechanism is provided with source function PxDefaultSimulationFilterShader. And, again, if this shader base too inflexible, consider using the callback approach provided with PxSimulationFilterCallback.
Aggregates

An aggregate is a collection of actors. Aggregates do not provide extra features, but allow you to tell the SDK that a set of actors will be clustered in turn allows the SDK to optimize its spatial data operations. A typical use case is a ragdoll, made of multiple different actors. Without aggregates, this gives rise to as many broad-phase entries as there are shapes in the ragdoll. It is typically more efficient to represent the ragdoll in the broad-phase as a single entity, and perform internal overlap tests in a second pass if necessary. Another potential use case is an actor with a large number of attached shapes.
Creating an Aggregate

Create an aggregate from the *PxPhysics* object:

```cpp
PxPhysics* physics; // The physics SDK object
PxU32 nbActors;    // Max number of actors expected in the aggregate
bool selfCollisions = true;

PxAggregate* aggregate = physics->createAggregate(nbActors, selfCollisions);
```

The maximum number of actors is currently limited to 128, and for efficiency, should be set as low as possible.

If you will never need collisions between the actors of the aggregate, disable them at creation time. This is much more efficient than using the scene filtering mechanism, as it bypasses all internal filtering logic. A typical use case would be an aggregate of static or kinematic actors.

Note that both the maximum number of actors and the self-collision attribute are immutable.
Populating an Aggregate

Adds an actor to an aggregate as follows:

```cpp
PxActor& actor;  // Some actor, previously created
aggregate->addActor(actor);
```

Note that if the actor already belongs to a scene, the call is ignored. Either add the actors to an aggregate and then add the aggregate to the scene, or add the aggregate to the scene and then the actors to the aggregate.

To add the aggregate to a scene (before or after populating it):

```cpp
scene->addAggregate(*aggregate);
```

Similarly, to remove the aggregate from the scene:

```cpp
scene->removeAggregate(*aggregate);
```
Releasing an Aggregate

To release an aggregate:

```c
PxAggregate* aggregate; // The aggregate we previously created
aggregate->release();
```

Releasing the PxAggregate does not release the aggregated actors. If the PxAggregate belongs to a scene, the actors are automatically re-inserted in that scene. If you intend to delete both the PxAggregate and its actors, it is most efficient to release the actors first, then release the PxAggregate when it is empty.
Amortizing Insertion

Adding many objects to a scene in one frame can be a costly operation. One case for a ragdoll, which as discussed is a good candidate for PxAggregate, is localized debris, for which self-collisions are often disabled. To amortize the cost of object insertion into the broad-phase structure over several frames, spawn the debris in a PxAggregate, then remove each actor from the aggregate and re-insert it into the scene over those frames.
**Trigger Shapes**

Trigger shapes play no part in the simulation of the scene (though they can be configured to participate in scene queries). Instead, their role is to report that there has been an overlap with another shape. Contacts are not generated for the intersection, and as a result contact reports are not available for trigger shapes. Further, because they play no part in the simulation, the SDK will not allow the the eSIMULATION_SHAPE and eTRIGGER_SHAPE flags to be raised simultaneously; that is, if one attempts to raise the other will be rejected, and an error will be passed to the error stream.

Trigger shapes have been used in SampleSubmarine to determine if the submarine has reached the treasure. In the following code the PxActor representing the submarine has its solitary shape configured as a trigger shapes:

```cpp
PxShape* treasureShape;
gTreasureActor->getShapes(&treasureShape, 1);
treasureShape->setFlag(PxShapeFlag::eSIMULATION_SHAPE, false);
treasureShape->setFlag(PxShapeFlag::eTRIGGER_SHAPE, true);
```

The overlaps with trigger shapes are reported in SampleSubmarine of the implementation of PxSimulationEventCallback::onTrigger in the PxSampleSubmarine class, a sub-class of PxSimulationEventCallback:

```cpp
void SampleSubmarine::onTrigger(PxTriggerPair* pairs, PxU32 count)
{
    for(PxU32 i=0; i < count; i++)
    {
        // ignore pairs when shapes have been deleted
        if (pairs[i].flags & (PxTriggerPairFlag::eREMOVED_SHAPE_TRIGGER |
                              PxTriggerPairFlag::eREMOVED_SHAPE_OTHER))
            continue;

        if ((&pairs[i].otherShape->getActor() == mSubmarineActor) &&
            (&pairs[i].triggerShape->getActor() == gTreasureActor))
            gTreasureFound = true;
    }
}
```
The code above iterates through all pairs of overlapping shapes that are of the same shape. If it is found that the treasure has been touched by the submarine, then the flag `gTreasureFound` is set true.
Interactions

The SDK internally creates an interaction object for each overlapping pair reported by the broad-phase. These objects are not only created for pairs of colliding rigid bodies, but also for pairs of overlapping triggers. Generally speaking users should assume that objects are created regardless of the involved objects' types (rigid body, cloth, etc) and regardless of involved PxFilterFlag flags.

There is currently a limit of 65535 such interaction objects for each actor. If more than 65535 interactions involve the same actor, then the SDK outputs an error message and the extra interactions are ignored.
In this chapter we cover a number of topics that are also important to your understanding once you are comfortable with setting up a basic rigid body simulation world.
Velocity

A rigid body's motion is separated into linear and angular velocity components. During simulation, PhysX will modify the velocity of an object in accordance with applied forces and torques and as a result of various constraints, such as collisions or joints.

A body's linear and angular velocities can be read using the following methods:

```cpp
PxVec3 PxRigidBody::getLinearVelocity();
PxVec3 PxRigidBody::getAngularVelocity();
```

A body's linear and angular velocities can be set using the following methods:

```cpp
void PxRigidBody::setLinearVelocity(const PxVec3& linVel, bool autowake);
void PxRigidBody::setAngularVelocity(const PxVec3& angVel, bool autowake);
```
A dynamic actor needs mass properties: the mass, moment of inertia, and mass frame which specifies the position of the actor's center of mass and inertia axes. The easiest way to calculate mass properties is to use the PxRigidBodyExt::updateMassAndInertia() helper function, which will set all three properties based on the actor's shapes and a uniform density value. Variants of this function allow combinations of per-shape densities and manual specification of some mass properties. See the reference for PxRigidBodyExt for more details.

The Wobbly Snowmen in the North Pole Sample illustrate the use of mass properties. The snowmen act like roly-poly toys, which are usually just an empty shell with the bottom filled with some heavy material. The low centers of mass cause them to move back to an upright position after they have been tilted. They come in different flavors, depending on how the mass properties are set:

The first is basically massless. There is just a little sphere with a relatively high mass at the bottom of the Actor. This results in a quite rapid movement due to the small resulting moments of inertia. The snowman feels light.

The second uses the mass of the bottom snowball only, resulting in a bigger inertia. Later on, the center of mass is moved to the bottom of the actor. This approximation is by no means physically correct, but the resulting snowman feels a bit more filled.

The third and fourth snowman use shapes to calculate the mass. The one calculates the moments of inertia first (from the real center of mass) and then the center of mass is moved to the bottom. The other calculates the moments of inertia about the low center of mass that we pass to the calculation routine. Note how wobbling is for the second case although both have the same mass. The head accounts for much more in the moment of inertia (the distance squared).

The last snowman's mass properties are set up manually. The sample uses rough values for the moment of inertia to create a specific desired behavior. The dia
low value in X, and high values in Y and Z, producing a low resistance to rotation around the X-axis and high resistance around Y and Z. As a consequence, wobble back and forth only around the X axis.

If you have a 3x3 inertia matrix (for example, you have real-life inert objects) use the PxDiagonalize() function to obtain principal axes and tensors to initialize PxRigidDynamic actors.

When manually setting the mass/inertia tensor of bodies, PhysX requires positive values for the mass and each principal axis of inertia. However, it is legal to provide 0s in these values. When provided with a 0 mass or inertia value, PhysX interprets this to mean infinite mass or inertia around that principal axis. This can be used to create bodies that resist all linear motion or that resist all or some angular motion. Examples of the effects that could be achieved using this approach are:

- Bodies that behave as if they were kinematic.
- Bodies whose translation behaves kinematically but whose rotation is dynamic.
- Bodies whose translation is dynamic but whose rotation is kinematic.
- Bodies which can only rotate around a specific axis.

Some examples of what could be achieved are detailed below. First, let's assume that we are creating a common structure - a windmill. The code to construct the windmill and its parts is provided below:

```cpp
PxRigidDynamic* dyn = physics.createRigidDynamic(PxTransform(PxVec3(0.f, 0.f, 15.f)), PxRigidActorExt::createExclusiveShape(*dyn, PxBoxGeometry(2.f, 0.2f, 2.f));
dyn->setActorFlag(PxActorFlag::eDISABLE_GRAVITY, true);
dyn->setAngularDamping(0.f);
dyn->setAngularVelocity(PxVec3(0.f, 0.f, 5.f));

PxRigidStatic* st = mPhysics.createRigidStatic(PxTransform(PxVec3(0.f, 0.f, 1.f));
scene.addActor(dyn);
scene.addActor(st);
```

The above code creates a static box frame for the windmill and a cross that represents the blades of the turbine. We turn off gravity and angular damping on the
give it an initial angular velocity. As a result, this turbine blade will rotate at a constant angular velocity indefinitely. However, if another object collided with the turbine, the windmill would cease to function correctly because the turbine blade would be knocked out of place. There are several options to make the turbine blade stay in place when other bodies interact with it. One such approach might be to make the turbine have infinite mass and inertia. In this case, any interactions with other bodies would not affect the turbine at all:

```cpp
dyn->setMass(0.f);
dyn->setMassSpaceInertiaTensor(PxVec3(0.f));
```

This example retains the previous behavior of the turbine spinning at a constant angular velocity indefinitely. However, now the body's velocities cannot be affected by constraints because the body has infinite mass and inertia. If a body collided with the turbine blade, the collision would behave as if the turbine blade was a kinematic body.

Another alternative would be to make the turbine have infinite mass and limit its rotation to just around the body's local z-axis. This would provide the same effect as applying a revolute joint between the turbine and the static windmill frame:

```cpp
dyn->setMass(0.f);
dyn->setMassSpaceInertiaTensor(PxVec3(0.f, 0.f, 10.f));
```

In both examples, the body's mass was set to 0, indicating that the body has infinite mass, so its linear velocity cannot be changed by any constraints. However, in the second example, the body's inertia is configured to permit the body's angular velocity to be affected by constraints around one principal axis or inertia. This provides a similar effect as a revolute joint. The value of the inertia around the z-axis can be increased or decreased to make the turbines more/less resistant to motion.
Applying Forces and Torques

The most physics-friendly way to interact with a body is to apply a force. In classical mechanics, most interactions between bodies are typically solved by using forces. Because of the law:

\[ f = m \cdot a \] (force = mass \times acceleration)

Forces directly control a body's acceleration, but its velocity and position have an indirect influence. For this reason control by force may be inconvenient if you need immediate response. The advantage of forces is that regardless of what forces you apply to the bodies in the scene, the simulation will be able to keep all the defined constraints (joints and contacts) satisfied. For example gravity works by applying a force to bodies.

Unfortunately applying large forces to articulated bodies at the resonant frequency of a system may lead to ever increasing velocities, and eventually to the failure of the simulation solver. This is not unlike a real world system, where the joints would ultimately break.

The forces acting on a body are accumulated before each simulation frame, applied to the simulation, and then reset to zero in preparation for the next frame. The relevant methods of PxRigidBody and PxRigidBodyExt are listed below. Please refer to the API reference for more detail:

```cpp
void PxRigidBody::addForce(const PxVec3& force, PxForceMode::Enum mode);
void PxRigidBody::addTorque(const PxVec3& torque, PxForceMode::Enum mode);
void PxRigidBodyExt::addForceAtPos(PxRigidBody& body, const PxVec3& pos, PxForceMode::Enum mode, bool wakeup);
void PxRigidBodyExt::addTorqueAtLocalPos(PxRigidBody& body, const PxVec3& pos, PxForceMode::Enum mode, bool wakeup);
void PxRigidBodyExt::addLocalForceAtPos(PxRigidBody& body, const PxVec3& pos, PxForceMode::Enum mode, bool wakeup);
void PxRigidBodyExt::addLocalForceAtLocalPos(PxRigidBody& body, const PxVec3& pos, PxForceMode::Enum mode, bool wakeup);
```
The PxForceMode member defaults to PxForceMode::eFORCE to apply simple forces. There are other possibilities. For example PxForceMode::eIMPULSE will apply an impulsive force. PxForceMode::eVELOCITY_CHANGE will do the same as the mass of the body, effectively leading to an instantaneous velocity change. See the API documentation of PxForceMode for the other possibilities.

**Note:** The methods in PxRigidBodyExt support only the force modes eFORCE and eIMPULSE.

There are further extension functions that compute the linear and angular velocity that would arise in the next simulation frame if an impulsive force or impulsive torque were to be applied:

```cpp
void PxRigidBodyExt::computeVelocityDeltaFromImpulse(const PxRigidBody& body, const PxVec3& impulsiveForce, const PxVec3& impulsiveTorque, PxVec3& deltaLinearVelocity, PxVec3& deltaAngularVelocity);
```

A use case for this function might be to predict an updated velocity for a game object so that asset loading may be initiated in advance of the simulation frame when the velocity is likely to exceed a threshold velocity at the end of the frame. The impulsive force and torque are simply the force and torque that are to be applied to the body multiplied by the timestep of the simulation frame. Neglecting the effect of constraint and contact forces, the change in linear and angular velocity that are expected to arise in the next simulation frame are returned in deltaLinearVelocity and deltaAngularVelocity. The predicted linear velocity can then be computed with body.getLinearVelocity() + deltaLinearVelocity, while the predicted angular velocity can be computed with body.getAngularVelocity() + deltaAngularVelocity. If required, it is possible to immediately update the velocity of the rigid body without recalculating:

```cpp
body.setLinearVelocity(body.getLinearVelocity() + deltaLinearVelocity);
body.setAngularVelocity(body.getAngularVelocity() + deltaAngularVelocity);
```
Gravity

Gravity is such a common force in simulations that PhysX makes it particularly simple to apply. For a scene-wide gravity effect, or any other uniform force field, set the PxScene class’ gravity vector using PxScene::setGravity().

The parameter is the acceleration due to gravity. In meters and seconds, have a magnitude of about 9.8 on earth, and should point downwards. The force that will be applied at the center of mass of each body in the scene is this acceleration times the actor’s mass.

Certain special effects can require that some dynamic actors are not in a gravitational field. To specify this set the flag:

```c++
PxActor::setActorFlag(PxActorFlag::eDISABLE_GRAVITY, true);
```

**Note:** Be careful when changing gravity (or enabling/disabling it) during the simulation. For performance reasons the change will not wake up sleeping actors automatically. Thus it may be necessary to iterate through all actors and call PxRigidDynamic::wakeUp() manually.

An alternative to PxActorFlag::eDISABLE_GRAVITY is to use a zero gravity vector for the whole scene, then apply your own gravity force to rigid bodies, each frame. This can be used to create radial gravity fields, as demonstrated in SampleCustomGravity.
Friction and Restitution

All physical objects have at least one material, which defines the friction and restitution properties used to resolve a collision with the objects.

To create a material, call PxPhysics::createMaterial():

```cpp
PxMaterial* mMaterial;
mMaterial = mPhysics->createMaterial(0.5f, 0.5f, 0.1f); // static friction, dynamic friction,
// restitution
if(!mMaterial)
    fatalError("createMaterial failed");
```

Materials are owned by the PxPhysics object, and can be shared among multiple scenes. The material properties of two objects involved in a collision can be combined in various ways. See the reference documentation for PxMaterial for more details.

PhysX objects whose collision geometry is a triangle mesh or a heightfield can have a material per triangle.

Friction uses the coulomb friction model, which is based around two coefficients: the static friction coefficient and the dynamic friction coefficient (sometimes called kinetic friction). Friction resists relative lateral motion of two surfaces in contact. These two coefficients define a relationship between the normal force on each surface on the other and the amount of friction force that is applied to resist motion. Static friction defines the amount of friction that is applied between surfaces that are not moving relative to each other. Dynamic friction defines the amount of friction that is applied between surfaces that are moving relative to each other.

The coefficient of restitution of two colliding objects is a fractional value representing the ratio of speeds after and before an impact, taken along the line of impact. A coefficient of restitution of 1 is said to collide elastically, while a coefficient of restitution < 1 is said to be inelastic.
Sleeping

When an actor does not move for a period of time, it is assumed that it will not move in the future either until some external force acts on it that throws it out of equilibrium. Until then, it is no longer simulated in order to save resources. This state is called sleeping. You can query an actor's sleep state with the following method:

```cpp
bool PxRigidDynamic::isSleeping() const;
```

It is however often more convenient to listen for events that the SDK sends when actors fall asleep or wake up. To receive the following events, `PxActorFlag::eSEND_SLEEP_NOTIFIES` must be set for the actor:

```cpp
void PxSimulationEventCallback::onWake(PxActor** actors, PxU32 count);
void PxSimulationEventCallback::onSleep(PxActor** actors, PxU32 count);
```

See the section *Callback Sequence* and the subsection *Sleep state* for more information.

An actor goes to sleep when its kinetic energy is below a given threshold for a certain time. Basically, every dynamic rigid actor has a wake counter which gets decremented by the simulation time step when the kinetic energy of the actor is below the threshold. However, if the energy is above the threshold after a simulation step, the wake counter gets reset to a minimum default value and the whole process starts anew. Once the wake counter reaches zero, it does not get decremented any further and the actor is ready to go to sleep. Please note that a zero wake counter does not mean that the actor has to be asleep, it only indicates that it is ready to go to sleep. There are other factors that might keep an actor awake for a while longer.

The energy threshold as well as the minimum amount of time an actor will stay awake can be manipulated using the following methods:

```cpp
void PxRigidDynamic::setSleepThreshold(PxReal threshold);
PxReal PxRigidDynamic::getSleepThreshold() const;
```
void PxRigidDynamic::setWakeCounter(PxReal wakeCounterValue);
PxReal PxRigidDynamic::getWakeCounter() const;

**Note:** For kinematic actors, special sleep rules apply. A kinematic actor is asleep unless a target pose has been set (in which case it will stay awake until the next simulation step where no target pose has been set anymore). As a consequence, it is not allowed to use `setWakeCounter()` for kinematic actors. The wake counter of a kinematic actor is solely defined based on whether a target pose has been set.

If a dynamic rigid actor is sleeping, the following state is guaranteed:

- The wake counter is zero.
- The linear and angular velocity is zero.
- There is no force update pending.

When an actor gets inserted into a scene, it will be considered asleep if all the points above hold, else it will be treated as awake.

In general, a dynamic rigid actor is guaranteed to be awake if at least one of the following holds:

- The wake counter is positive.
- The linear or angular velocity is non-zero.
- A non-zero force or torque has been applied.

As a consequence, the following calls will wake the actor up automatically:

- `PxRigidDynamic::setWakeCounter()`, if the wake counter value is larger than zero.
- `PxRigidBody::setLinearVelocity()`, `::setAngularVelocity()`, if the velocity is non-zero.
- `PxRigidBody::addForce()`, `::addTorque()`, if the torque is non-zero.

In addition, the following calls and events wake an actor up:

- `PxRigidDynamic::setKinematicTarget()` in the case of a kinematic actor (this also sets the wake counter to a positive value).
• PxRigidActor::setGlobalPose(), if the autowake parameter is set to true.
• Simulation gets disabled for a PxRigidActor by raising PxActorFlag::eDISABLE_SIMULATION.
• PxScene::resetFiltering().
• PxShape::setSimulationFilterData(), if the subsequent re-filtering causes the shape pair to transition between suppressed, trigger and contact.
• Touch with an actor that is awake.
• A touching rigid actor gets removed from the scene (this is the default behavior but can be specified by the user, see note further below).
• Contact with a static rigid actor is lost.
• Contact with a dynamic rigid actor is lost and this actor is awake in the next simulation step.
• The actor gets hit by a two-way interaction particle.

**Note:** When removing a rigid actor from the scene or a shape from an actor, it is possible to specify whether to wake up the objects that were touching the removed object in the previous simulation step. See the API comments in PxScene::removeActor() and PxRigidActor::detachShape() for details.

To explicitly wake up a sleeping object, or force an object to sleep, use:

```cpp
void PxRigidDynamic::wakeUp();
void PxRigidDynamic::putToSleep();
```

**Note:** It is not allowed to use these methods for kinematic actors. The sleep state of a kinematic actor is solely defined based on whether a target pose has been set.

The API reference documents exactly which methods cause an actor to sleep.

**Sleep state change events**

As mentioned above, PhysX provides an event system that reports changes in the sleep state of actors.
state of dynamic rigid bodies during `PxScene::fetchResults()`:

```c++
void PxSimulationEventCallback::onWake(PxActor** actors, PxU32 count)
void PxSimulationEventCallback::onSleep(PxActor** actors, PxU32 count)
```

It is important to understand the correct usage of these events, and their limitations:

- A body added since the previous `fetchResults()` or `flushSimulation()` generates an event, even if no sleep state transition occurred.
- If there have been multiple changes in a body's sleep state since the previous `fetchResults()` or `flushSimulation()`, PhysX will report only the most recent.

Sometimes it is desirable to detect transitions between awake and asleep states, for example, keeping track of the number of awake bodies. Suppose a sleeping body `B` is added since the previous `fetchResults()`, and so an `onWake()` event will be generated for it. Even though `B`'s sleep state did not change during simulation, it has changed since the previous `fetchResults()`, and so an `onWake()` event will be generated for it. If the counter is incremented again in response to this event, its value will be incorrect.

To use sleep state events to detect transitions, a record of the sleep state for objects of interest has to be kept, for example in a hash. When processing an event, this record can be used to check whether there has been a transition.
## Kinematic Actors

Sometimes controlling an actor using forces or constraints is not precise or flexible. For example moving platforms or character controls need to manipulate an actor’s position or have it exactly follow a specific path. Such a control scheme is provided by kinematic actors.

A kinematic actor is controlled using the `PxRigidDynamic::setKinematicTarget()` function. Each simulation step PhysX moves the actor to its target position, regardless of external forces, gravity, collision, etc. Thus one must continually call `setKinematicTarget()` at every time step, for each kinematic actor, to make them move along their desired paths. The movement of a kinematic actor affects dynamic actors with which it collides or is constrained with a joint. The actor will appear to have infinite mass and push regular dynamic actors out of the way.

To create a kinematic actor, simply create a regular dynamic actor then set its kinematic flag:

```cpp
PxRigidBody::setRigidBodyFlag(PxRigidBodyFlag::eKINEMATIC, true);
```

Use the same function to transform a kinematic actor back to a regular dynamic actor.

While you do need to provide a mass for the kinematic actor as for all dynamic actors, this mass will not actually be used for anything while the actor is in kinematic mode.

### Caveats:

- It is important to understand the difference between `PxRigidDynamic::setKinematicTarget()` and `PxRigidActor::setGlobalPose()`. While `setGlobalPose()` would also move the actor to the desired position, it would not make that actor properly interact with other objects. In particular, when the kinematic actor would not push away other dynamic actors in its path; instead it would go right through them. The `setGlobalPose()` function can still be used if one simply wants to teleport a kinematic actor to a new position.
A kinematic actor can push away dynamic objects, but nothing pushes it back. As a result, a kinematic can easily squish a dynamic actor against a static actor or another kinematic actor. As a result, the squished dynamic object can deeply penetrate the geometry it has been pushed into.

There is no interaction or collision between kinematic actors. However, it is possible to request contact information for these cases if PxSceneFlag::eENABLE_KINEMATIC_PAIRS or ::eENABLE_KINEMATIC_STATIC_PAIRS gets set.
Active Transforms

**Note:** the active transforms are currently deprecated. See next paragraph for its replacement.

The active transforms API provides an efficient way to reflect actor transform changes in a PhysX scene to an associated external object such as a render mesh.

When a scene's fetchResults() method is called an array of `PxActiveTransform` generated, each entry in the array contains a pointer to the actor that moved and its new transform. Because only actors that have moved will be included in the list, this approach is potentially much more efficient than, for example, analyzing every actor in the scene individually.

The example below shows how to use active transforms to update a render object:

```cpp
// update scene
scene.simulate(dt);
scene.fetchResults();

// retrieve array of actors that moved
PxU32 nbActiveTransforms;
PxActiveTransform* activeTransforms = scene.getActiveTransforms(nbActiveTransforms);

// update each render object with the new transform
for (PxU32 i=0; i < nbActiveTransforms; ++i)
{
    MyRenderObject* renderObject = static_cast<MyRenderObject*>(activeTransforms[i].actor2World);
    renderObject->setTransform(activeTransforms[i].actor2World);
}
```

**Note:** `PxSceneFlag::eENABLE_ACTIVETRANSFORMS` must be set on the scene for the active transforms array to be generated.

**Note:** Since the target transform for kinematic rigid bodies is set by the user, kinematics can be excluded from the list by setting the flag `PxSceneFlag::eEXCLUDE_KINEMATICS_FROM_ACTIVE_ACTORS`. 
Active Actors

The active actors API provides an efficient way to reflect actor transforms in a PhysX scene to an associated external object such as a render mesh.

When a scene's `fetchResults()` method is called an array of active `PxActor` objects is returned. Because only actors that have moved will be included in the list this approach is much more efficient than, for example, analyzing each actor in the scene individually.

The example below shows how to use active actors to update a render object:

```cpp
// update scene
scene.simulate(dt);
scene.fetchResults();

// retrieve array of actors that moved
PxU32 nbActiveActors;
PxActor** activeActors = scene.getActiveActors(nbActiveActors);

// update each render object with the new transform
for (PxU32 i=0; i < nbActiveActors; ++i)
{
    MyRenderObject* renderObject = static_cast<MyRenderObject*>(activeActors[i]);
    renderObject->setTransform(activeActors[i]->getGlobalPose());
}
```

**Note:** `PxSceneFlag::eENABLE_ACTIVE_ACTORS` must be set on the scene for the active actors array to be generated.

**Note:** Since the target transform for kinematic rigid bodies is set by the user, kinematics can be excluded from the list by setting the flag `PxSceneFlag::eEXCLUDE_KINEMATICS_FROM_ACTIVE_ACTORS`. 
Dominance

Dominance is a mechanism to enable dynamic bodies to dominate each other effectively imbibes the dominant body in a pair with infinite mass. This mass modification within the constraint solver and, as such, can override the bodies in a pair. Similar effects can be achieved through local mass contact modification but dominance has the advantage of being handled automatically within the SDK so does not incur the additional memory and performance overhead of contact modification.

Each actor must be assigned a dominance group ID. This is a 5-bit value in the range [0, 31]. As such, you are restricted to at-most 32 dominance groups. By default, all bodies are placed in dominance group 0. An actor can be assigned to a dominance group using the following method on PxActor:

```cpp
class PxActor {
public:
    virtual void setDominanceGroup(PxDominanceGroup dominanceGroup) = 0;
}
```

Dominance is defined by 2 real numbers in the following struct:

```cpp
struct PxDominanceGroupPair {
    PxDominanceGroupPair(PxReal a, PxReal b) : dominance0(a), dominance1(b) {}
    PxReal dominance0;
    PxReal dominance1;
};
```

And dominance between two dominance groups can be configured using the following method on PxScene:

```cpp
class PxScene {
public:
    virtual void setDominanceGroupPair(PxDominanceGroup group1, PxDominanceGroup group2, const PxDominanceGroupPair& dominance) = 0;
};
```

The user can define 3 different states for a given PxDominanceGroupPair, each indicating that both bodies have equal dominance. This is the default behavior.

---

1: 1. This indicates that both bodies have equal dominance. This is the default behavior.
1: 0. This
indicates that body B dominates body A. * 0 : 1. This indicates that body B.

Any values other than 0 and 1 are not valid in a PxDominanceGroupPair. Both sides of the PxDominanceGroupPair is also invalid. These values to be scales applied to the bodies' respective inverse mass and dominance value of 0 would therefore equate to an infinite mass body.

The following example sets two actors, actorA and actorB, into different dominace and configures the dominance group to make actorA dominate actorB:

```cpp
PxRigidDynamic* actorA = mPhysics->createRigidDynamic(PxTransform);
PxRigidDynamic* actorB = mPhysics->createRigidDynamic(PxTransform);
actorA->setDominanceGroup(1);
actorB->setDominanceGroup(2);
mScene->setDominanceGroupPair(1, 2, PxDominanceGroupPair(0.f, 1.f));
```

Dominance values will not affect joints. Local mass modification can be performed using the following methods on PxJoint:

```cpp
virtual void setInvMassScale0(PxReal invMassScale) = 0;
virtual void setInvMassScale1(PxReal invMassScale) = 0;
virtual void setInvInertiaScale0(PxReal invInertiaScale) = 0;
virtual void setInvInertiaScale1(PxReal invInertiaScale) = 0;
```

As previously mentioned, dominance does not permit values other than 0 and 1. Dominance values are applied uniformly to both the inverse mass and inverse inertia scales, which accept any values within the range [0, PX_MAX_REAL] so can be used to achieve a wider range of effects than dominance can.

Dominance can produce some very peculiar results if misused. For example, A, B and C configured in the following way:

- Body A dominates body B
- Body B dominance body C
Body C dominates body A

In this situation, body A cannot push body C directly. However, it can pushes body B into body C.
Solver Iterations

When the motion of a rigid body is constrained either by contacts or joints, the constraint solver comes into play. The solver satisfies the constraints on the bodies by iterating over all the constraints restricting the motion of the body a certain number of times. The more iterations, the more accurate the results become. The solver iteration count defaults to 4 position iterations and 1 velocity iteration. Those counts may be set individually for each body using the following function:

```cpp
void PxRigidDynamic::setSolverIterationCounts(PxU32 minPositionIters,
                                               PxU32 minVelocityIters); // positions, velocities
```

Typically it is only necessary to significantly increase these values for objects with lots of joints and a small tolerance for joint error. If you find a need to use a setting higher than 30, you may wish to reconsider the configuration of your simulation.

The solver groups contacts into friction patches; friction patches are groups of contacts which share the same materials and have similar contact normals. However, the solver permits a maximum of 32 friction patches per contact manager (pair of shapes). If more than 32 friction patches are produced, which may be due to very complex collision geometry or very large contact offsets, the solver will ignore the remaining patches. A warning will be issued in checked/debug builds when this happens.
Immediate Mode

In addition to simulation using a PxScene, PhysX offers a low-level simulation mode called "immediate mode". This provides an API to access the low-level contact generation and constraint solver. This approach currently supports only CPU rigid bodies and does not support articulations, clothing or particles.

The immediate mode API is defined in PxImmediateMode.h and there is a Snippet demonstrating its usage in "SnippetImmediateMode".

The API provides a function to perform contact generation:

```c
PX_C_EXPORT PX_PHYSX_CORE_API bool PxGenerateContacts(const PxGeometry* geometries, const PxReal contactDistance, const PxReal meshContactMargin);
```

This function takes a set of pairs of PxGeometry objects located at specific poses and performs collision detection between the pairs. If the pair of geometries collide, contacts are generated, which are reported to contactRecorder. In addition, information may be cached in contactCache to accelerate future queries between these pairs. Any memory required for this cached information will be allocated using "allocator".

In addition, the immediate mode provides APIs for the constraint solver. These include functions to create bodies used by the solver:

```c
PX_C_EXPORT PX_PHYSX_CORE_API voidPxConstructSolverBodies(const PxRigidBodyData* bodies);  
PX_C_EXPORT PX_PHYSX_CORE_API void PxConstructStaticSolverBody(const PxStaticBodyData* bodyData);  
```

In addition to constructing the bodies, PxConstraintSolverBodies also integrates the provided gravitational acceleration into the bodies velocities.

The following function is optional and is used to batch constraints:

```c
PX_C_EXPORT PX_PHYSX_CORE_API PxU32 PxBatchConstraints(PxSolverConstraintDesc* outOrderedConstraintDescs);
```
Batching constraints reorders the provided constraints and produces batchHeaders, which can be used by the solver to accelerate constraint solving by grouping together independent constraints and solving them in parallel using multiple lanes in SIMD registers. This process is entirely optional and can be bypassed if not desired. Note that this will change the order in which constraints are processed, which can change the outcome of the solver.

The following methods are provided to create contact constraints:

```cpp
PX_C_EXPORT PX_PHYSX_CORE_API bool PxCreateContactConstraints(PxConstraintBatchHeader allocator, PxReal invDt, PxReal bounceThreshold)
```

This method can be provided with the contacts produced by PxGenerateContacts or by application-specific contact generation approaches.

The following methods are provided to create joint constraints:

```cpp
PX_C_EXPORT PX_PHYSX_CORE_API bool PxCreateJointConstraints(PxConstraintBatchHeader)
PX_C_EXPORT PX_PHYSX_CORE_API bool PxCreateJointConstraintsWithShaders(PxConstraintBatchHeader)
```

The methods provide a mechanism for the application to define joint rows or for the application to make use of PhysX PxConstraint objects, which create the constraint rows.

The following method solves the constraints:

```cpp
PX_C_EXPORT PX_PHYSX_CORE_API void PxSolveConstraints(PxConstraintBatchHeader linearMotionVelocity, PxVec3* angularMotionVelocity)
```

This method performs all required position and velocity iterations and updates the objects' delta velocities and motion velocities, which are stored in F linear/angularMotionVelocity respectively.

The following method is provided to integrate the bodies' final poses...
bodies' velocities to reflect the motion produced by the constraint solver.

An example of how the immediate mode can be used: SnippetImmediateMode.
Enhanced Determinism

PhysX provides limited deterministic simulation. Specifically, the results will be identical between runs if simulating the exact same scene (same actors in the same order) using the same time-stepping scheme and same PhysX release running on the same platform. The simulation behavior is not influenced by the number of worker threads that are used.

However, the results of the simulation can change if actors are inserted in a different order. In addition, the overall behavior of the simulation can change if additional actors are added or if some actors are removed from the scene. This means that the particular collection of actors can change depending on whether other actors are present in the scene or not, irrespective of whether these actors actually interact with other actors. This behavioral property is usually tolerable but there are circumstances in which it is not acceptable.

To overcome this issue, PhysX provides PxSceneFlag::eENABLE_ENHANCED_DETERMINISM, which provides additional levels of determinism. Specifically, provided the application inserts the actors in a deterministic order, with this flag raised, the simulation of an island will be identical regardless of any other islands in the scene. However, this mode sacrifices some performance to ensure this additional determinism.
Axis locking

It is possible to restrict motion along or around specific world-space axes using PxRigidDynamicLockFlag. For example, the below code snippet demonstrates how to restrict a PxRigidDynamic to a two-dimensional simulation. In this case, we permit the PxRigidDynamic to rotate only around the Z-axis and to translate only along the X- and Y-axes:

```cpp
PxRigidDynamic* dyn = physics.createRigidDynamic(PxTransform(PxVec3...

//Lock the motion
dyn->setRigidDynamicLockFlags(PxRigidDynamicLockFlag::eLOCK_LINEAR_Z)
```

It is legal to restrict movement or rotation around any combination of degrees of freedom.
Callback Sequence

The simplest type of simulation callbacks are the events. Using callbacks, an application can simply listen for events and react as required, provided the callback obeys the rule that SDK state changes are forbidden. This restriction may be a bit surprising given that the SDK permits writes to an inactive back-buffer while the simulation is running. The callbacks, however, are not called from within the simulation thread, but rather from inside fetchResults(). The key point here is that fetchResults() processes the buffered writes, meaning that writing to the SDK from an event callback can be a particularly fragile affair. To avoid this fragility it is necessary to impose the rule that SDK state changes are not permitted from an event callback.

Inside fetchResults(), among other things, the buffers are swapped. More specifically, this means that properties of each object's internal simulation state are copied to the API-visible state. Some event callbacks happen before this swap, and some happen after. Those that happen before are:

- onTrigger
- onContact
- onConstraintBreak

When these events are received in the callback, the shapes, actors, etc. will still be in the state they were in immediately before the simulation started. This is preferable because these events were detected early on during the simulation, before objects were integrated (moved) forward. For example, a pair of shapes that get an onContact() to report that they are in contact will still be in contact when the call is made, even though they bounced apart again after fetchResults() returns.

On the other hand, these events are sent after the swap:

- onSleep
- onWake

Sleep information is updated after objects have been integrated, so
send these events after the swap.

To 'listen' to any of these events it is necessary to subclass PxSimulationEventCallback so that the various virtual functions may be implemented as desired. An instance of this subclass can then be registered per scene with PxScene::setSimulationEventCallback or PxSceneDesc::simulationEventCallback. Following these steps alone will ensure that constraint break events are reported. One further step is required to report sleep and wake events: to avoid the expense of reporting all sleep and wake events, actors identified as worthy of notification require the flag PxActorFlag::eSEND_SLEEP_NOTIFIES to be raised. To receive onContact and onTrigger events it is necessary to set a flag in the filter shader callback for all pairs of interacting objects for which events are required. The filter shader callback can be found in Section Collision Filtering.
Simulation memory

PhysX relies on the application for all memory allocation. The primary PxAllocatorCallback interface required to initialize the SDK:

```cpp
class PxAllocatorCallback
{
public:
    virtual ~PxAllocatorCallback() {};
    virtual void* allocate(size_t size, const char* typeName, const int line) = 0;
    virtual void deallocate(void* ptr) = 0;
};
```

After the self-explanatory function argument describing the size of the allocation, the next three function arguments are an identifier name, which identifies the type of allocation, and the __FILE__ and __LINE__ location inside the SDK code where the allocation was made. More details on these function arguments can be found in the PhysXAPI documentation.

**Note:** An important change since 2.x: The SDK now requires that the memory returned be 16-byte aligned. On many platforms malloc() returns memory that is 16-byte aligned, but on Windows the system function _aligned_malloc() provides this capability.

**Note:** On some platforms PhysX uses system library calls to determine the type name, and the system function that returns the type name may call the memory allocator. If you are instrumenting system memory allocations, you may observe this behavior. To prevent PhysX requesting type names, disable allocation names using the method PxFoundation::setReportAllocationNames().

Minimizing dynamic allocation is an important aspect of performance tuning. PhysX provides several mechanisms to control and analyze memory usage, as discussed in turn.

**Scene Limits**
The number of allocations for tracking objects can be minimized by resizing the capacities of scene data structures, using either PxSceneDesc::limits or the function PxScene::setLimits(). It is useful to note that these limits do not represent hard limits, meaning that PhysX will automatically perform further allocations if the number of objects exceeds the scene limits.

### 16K Data Blocks

Much of the memory PhysX uses for simulation is held in a pool of blocks, each 16K in size. The initial number of blocks allocated to the pool can be controlled by setting PxSceneDesc::nbContactDataBlocks, while the maximum number of blocks that can be in the pool is governed by PxSceneDesc::maxNbContactDataBlocks. If PhysX internally needs more blocks than nbContactDataBlocks then it will allocate further blocks to the pool until the number of blocks reaches maxNbContactDataBlocks. If PhysX subsequently needs more blocks than the maximum number on the pool, it will simply start dropping contacts and joint constraints. When this happens, warnings are passed to the error stream in the PX_CHECKED configuration.

To help tune nbContactDataBlocks and maxNbContactDataBlocks it can be useful to query the number of blocks currently allocated to the pool using PxScene::getNbContactDataBlocksUsed(). It can also be useful to query the maximum number of blocks that can ever be allocated to the pool using PxScene::getMaxNbContactDataBlocksUsed.

Unused blocks can be reclaimed using PxScene::flushSimulation(). When this function is called any allocated blocks not required by the current scene state will be deleted so they may be reused by the application. Additionally, a number of other memory resources are freed by shrinking them to the minimum size required by the scene configuration.

### Scratch Buffer

A scratch memory block may be passed as a function argument to PxScene::simulate. As far as possible, PhysX will internally allocate temporary buffers from the scratch memory block, thereby reducing the need to perform temporary allocations from PxAllocatorCallback. The block may be reused by the application.
PxScene::fetchResults() call, which marks the end of simulation. One restriction on the scratch memory block is that it must be a multiple of 16K, and it must be 16-byte aligned.

**In-place Serialization**

PhysX objects can be stored in memory owned by the application using its deserialization mechanism. See [Serialization](#) for details.

**PVD Integration**

Detailed information about memory allocation can be recorded and displayed in the Visual Debugger. This memory profiling feature can be configured by setting the `trackOutstandingAllocations` flag when calling `PxCreatePhysics()`, and raising the `PxVisualDebuggerConnectionFlag::eMEMORY` when connecting to the debugger using `PxVisualDebuggerExt::createConnection()`.
Completion Tasks

A completion task is a task that executes immediately after PxScene::simulate. If PhysX has been configured to use worker threads then PxScene::simulate will start simulation tasks on the worker threads and will likely exit before the worker threads have completed the work necessary to complete the scene update. As a consequence, a typical completion task would first need to call PxScene::fetchResults(true) to ensure fetchResults blocks until all worker threads started during simulate() have completed their work. After calling fetchResults(true), the completion task can perform physics work deemed necessary by the application:

    scene.fetchResults(true); game.updateA(); game.updateB(); ... game.

The completion task is specified as a function argument in PxScene::simulate. More details can be found in the PhysAPI documentation.
Synchronizing with Other Threads

An important consideration for substepping is that simulate() and fetchResults() are classed as write calls on the scene, and it is therefore illegal to read from a scene while those functions are running. For the simulate() function it is illegal to read from a scene before simulate() exits. It is perfectly legal, however, to read from a scene after simulate() has exited but before the worker threads that started during the simulate() call have completed their work.

**Note:** PhysX does not lock its scene graph, but it will report an error if it detects that multiple threads make concurrent calls to the same scene, unless they are all read calls.
Substepping

For reasons of fidelity simulation or better stability it is often desired that the simulation frequency of PhysX be higher than the update rate of the application. To do this is just to call simulate() and fetchResults() multiple times:

```cpp
for(PxU32 i=0; i<substepCount; i++)
{
    ... pre-simulation work (update controllers, etc) ...
    scene->simulate(substepSize);
    scene->fetchResults(true);
    ... post simulation work (process physics events, etc) ...
}
```

Sub-stepping can also be integrated with the completion task feature of the simulate() function. To illustrate this, consider the situation where the scene is simulated until the graphics component signals that it has completed updating the render state. Here, the completion task will naturally run after simulate() has exited. It will block with fetchResults(true) to ensure that it waits until both simulate() and fetchResults() have completed their sequential work. When the completion task is required to proceed its next work item will be to query the graphics component to check if another simulate() is required or if it can exit. In the case that another simulate() step is required, it will need to pass a completion task to simulate(). A tricky point here is that a completion task cannot submit itself as the next completion task because it would cause recursion. A solution to this problem might be to have two completion tasks where each stores a reference to the other. Each completion task can then pass its partner to simulate():

```cpp
scene.fetchResults(true);
if(!graphics.isComplete())
{
    scene.simulate(otherCompletionTask);
}
```
Split sim

As an alternative to simulate(), you can split the simulation into two phases, collide() and advance(). For some properties, called write-through properties, modifications during the collide() phase will be seen immediately by the advance() phase. This allows collide() to begin before the data required by advance() is available and to run in parallel with game logic that generates inputs to advance(), particularly useful for animation logic generating kinematic targets, and for controllers applying forces to bodies. The write-through properties are listed below:

- addForce()
- addTorque()
- clearForce()
- clearTorque()
- setAngularVelocity()
- setLinearVelocity()
- setKinematicTarget()
- wakeUp()
- setWakeCounter()

When using the split sim, a physics simulation loop would look like this:

```java
scene.collide(dt)
scene.fetchCollision()
scene.advance()
scene.fetchResults()
```

Any other sequence of API calls is illegal. The SDK will issue error messages. For example, you can interleave the physics-dependent game logic between collide() and fetchCollision() as follows:

```java
scene.collide(dt)
physics-dependent game logic(animation, rendering)
scene.fetchCollision()
```

fetchCollision() will wait until collide() has finished before it updates the write-through properties in the SDK. Once fetchCollision() has completed, any state modifications on the objects in the executing scene will be buffered and will not be reflected until the simulation and a call to fetchResults() has completed. The solver will take the write-through properties into account when computing the new sets of velocities and poses for the actors being simulated.
Split fetchResults

The fetchResults() method is available in both a standard and split form. The split format offers some advantages over the standard fetchResult() method because it permits the user to parallelize processing of contact reports, which can be expensive when simulating complex scenes.

A simplistic way to use split fetchResults would look something like this:

```cpp
// Call fetchResultsStart. Get the set of pair headers
const PxContactPairHeader* pairHeader;
PxU32 nbContactPairs;
gScene->fetchResultsStart(pairHeader, nbContactPairs, true);

// Set up continuation task to be run after callbacks have been processed
callbackFinishTask.setContinuation(*gScene->getTaskManager(), NULL);
callbackFinishTask.reset();

// Process the callbacks
callbackFinishTask.removeReference();
callbackFinishTask.wait();
gScene->fetchResultsFinish();
```

The user is free to use their own task/threading system to process the callbacks. The PhysX scene provides a utility function that processes the callbacks using multiple threads, which is used in this code snippet. This method takes a continuation task that will be run when the tasks processing callbacks have completed. In this example, the completion task raises an event that can be waited upon to notify the main thread that callback processing has completed.

This feature is demonstrated in SnippetSplitFetchResults. In order to
approach, contact notification callbacks must be thread-safe. For this approach to be beneficial, contact notification callbacks need to be doing a significant amount of work to benefit from multi-threading them.
Advanced Collision Detection
Tuning Shape Collision Behavior

Shapes used for contact generation influence the motion of the dynamo are attached to through contact points. The constraint solver generates the contact points to keep the shapes resting or moving without passing. Shapes have two important parameters that control how generates contact points between them, which in turn are central for collisions or stacking: contactOffset and restOffset. They are set using PxShape::setContactOffset() and PxShape::setRestOffset() respectively. values is used directly. Collision detection always operates on a pair of shapes, and it always considers the sum of the offsets of the two shapes, the contactDistance and restDistance respectively.

Collision detection is able to generate contact points between two shapes still a distance apart, when they are exactly touching, or when they are not. To make the discussion simpler, we treat interpenetration as a negative distance between two shapes can be positive, zero, or negative. Separation distance at which collision detection will start to generate contacts. It is than zero, meaning that PhysX will always generate contacts when penetrating (unless collision detection between the two shapes is somehow disabled, such as with filtering). By default, when using metric units and PxTolerancesScale, contactOffset is 0.02, which means contactDistance in centimeters. So when two shapes approach each other within 4 centimeters, be generated until they are again moved further apart than 4 centimeters.

The generation of contact points does not however mean that an immediately be applied at these locations to separate the shapes, or further motion in the direction of penetration. This would make the simulation time step is selected to be tiny, which is not desirable for performance. Instead, we want the force at the contact to smoothly increase as penetration increases until it reaches a value sufficiently high to stop penetrating motion. The distance at which this maximum force is reached is the restDistance, because at this distance two shapes stacked on each other will reach static equilibrium and come to rest. When the shapes are for some reason p...
much that they have a distance below restDistance, an even greater force is applied to push them apart until they are at restDistance again. The variation of force as the distance changes is not necessarily linear, but it is smooth and continues a pleasing simulation even at large time steps.

There are a few different things to consider when choosing contactOffset and restOffset for shapes. Typically the same values can be used for all shapes in a simulation. The goal is typically to have the shapes appear to stack such that they are exactly touching, like bodies do in real life. Collision shapes are sized to be the exact same size as the graphics shape, so a restOffset of zero is needed. If the collision shapes are an epsilon bigger than the graphics shapes, a restOffset of negative epsilon is correct. This will let the larger collision shapes sink into each other until the smaller graphics shapes touch too. restOffsets that are larger than zero are practical for example if there are problems with sliding on triangle geometry where the penetration based contact generation has more trouble generating contact points than a separation one, resulting in a smoother slide.

Once the restOffset is determined, the contactOffset should be chosen to be slightly larger. The rule of thumb is to make the difference between the two as small as possible that still effectively avoids jitter at the time step size the simulation uses. The drawback of setting it too large is that contacts will be generated sooner as two shapes approach, which increases the number of contacts that the simulation has to worry about. This affects performance. Also, the simulation code often makes the assumption that contact points are close to the convex shapes' surface. If the contact offset is very large, this assumption breaks down which could lead to behavior artefacts.
**Contact Modification**

Under certain circumstances, it may be necessary to specialize contact behavior to implement sticky contacts, give objects the appearance of swimming inside each other, or making objects go through apparent holes in walls. A simple approach to achieve such effects is to let the user change contact behavior after they have been generated by collision detection, but before the contact solver. Because both of these steps occur within the scene simulate() function, a callback must be used.

The callback occurs for all pairs of colliding shapes for which the user has specified the pair flag PxCollideFlag::eMODIFY_CONTACTS in the filter shader.

To listen to these modify callbacks, derive from the class PxContactModifyCallback:

```cpp
class MyContactModification : public PxContactModifyCallback
{
    ...
    void onContactModify(PxContactModifyPair* const pairs, PxU32 count);
};
```

And then implement the function onContactModify of PxContactModifyCallback:

```cpp
void MyContactModification::onContactModify(PxContactModifyPair* const pairs, PxU32 count)
{
    for(PxU32 i=0; i<count; i++)
    {
        ...
    }
}
```

Every pair of shapes comes with an array of contact points, that properties that can be modified, such as position, contact normal, and time being, restitution and friction properties of the contacts cannot be modified. See PxModifiableContact and PxContactSet for properties that can be modified.
In addition to modifying contact properties, it is possible to:

- Set target velocities for each contact
- Limit the maximum impulse applied at each contact
- Adjust inverse mass and inverse inertia scales separately for each body

Conveyor belt-like effects can be achieved by setting target velocities achieved by having target velocities running in tangential directions to the contact normal, but the solver does also support target velocities in the direction of the contact normal.

The user can limit the impulse applied at each contact by limiting the maximum impulse applied at each contact. This can be useful to produce "soft" contact effects like the impression of energy dissipation due to compression or to limit the impulse applied on a dynamic body due to a kinematic collision. Note that limiting the max impulse potentially lead to additional penetration and bodies passing through each other.

Adjusting mass and inertia scales can be used to tune how contacts between bodies affect the bodies' linear and angular velocities respectively. Each contact pair has a separate inverse mass and inverse inertia scale. These scales are initialized to 1 and can be adjusted as part of the callback. Note that these scales perform local mass modification within the contact pair and affect all contacts within the pair.

Uniformly scaling a body's inverse mass and inverse inertia by the same value results in the body behaving like a body that is either heavier or lighter depending on the value used. Providing inverse mass/inertia scales < 1 results in the body appearing to be heavier; providing scales > 1 result in the body appearing lighter. For example, inverse mass/inertia scales of 0.5 result in the body appearing to have double the original mass. Providing inverse mass/inertia scales of 4 would result in the body appearing to have a quarter of its original mass. Providing inverse mass/inertia scale of 0 results in the body behaving as if it has infinite mass.

However, it is also possible to non-uniform scale a body's inverse mass and inertia by providing different values to a body's inverse mass and inverse inertia. For example, it is possible to reduce or increase the amount of angular velocity result of contacts by adjusting just the inverse inertia scale. The use-cases for this kind of modification are extremely game-dependent but may involve, for example,
interactions between a player's vehicle and traffic vehicles in an arcade-style game, where the player's car is expected to be bumped by traffic vehicles. It would be extremely frustrating to the player if the car was to spin-out as a result of the collision. This could also be achieved by making the traffic vehicles much lighter than the player's vehicle but this may make the traffic vehicles appear “too light” and thus damage the player's immersion.

When performing local mass modification, the impulse reported in PxSimulationEventCallback::onContact() will be relative to the locally scaled bodies involved in that contact. Therefore, this reported impulse may not accurately reflect the change in momentum caused by a given contact. To address this issue, we have provided the following methods in the rigid body extensions to extract the linear and angular impulse and velocity change caused by a contact using local mass modification:

```cpp
static void computeLinearAngularImpulse(const PxRigidBody& body, const PxVec3& point, const PxVec3& impulse, const PxReal invMassScale, const PxReal invInertiaScale, PxVec3& linearImpulse, PxVec3& angularImpulse);
static void computeVelocityDeltaFromImpulse(const PxRigidBody& body, const PxTransform& globalPose, const PxVec3& point, const PxVec3& impulse, const PxReal invMassScale, const PxReal invInertiaScale, PxVec3& deltaLinearVelocity, PxVec3& deltaAngularVelocity);
```

These methods return separate linear and angular impulse and velocity values to reflect the fact that the mass and inertia may have been non-uniformly scaled. When local mass modification has been used, it may be necessary to extract separate linear and angular impulses for each contact point, for each body in the pair. Please note that these helper functions are provided to provide users with accurate impulse values and are by no means mandatory. For simple use-cases, e.g. triggering effects or decision-making based on impulse thresholds, the single impulse value reported by the contact report is perfectly acceptable even when local mass modification has been used. However, when mass modification has been used and the impulse values are being used for more complex behaviors, e.g. balance control for a ragdoll, then these helper functions most-likely be required to achieve correct behavior. Please note that for articulations, computeLinearAngularImpulse will return the correct impulse
respective articulation link. However, computeVelocityDeltaFromImpulse does not return the correct velocity changes for an articulation link because it does not take into account the effect of other links of the articulation into account.

In addition, the following considerations must be made when using local mass modification:

- Force thresholding for callbacks will be based on the scalar impulse value in contact reports. This was calculated using the scaled mass/inertias of the bodies so using mass scaling may require these thresholds to be re-tuned.
- Maximum impulse clamping occurs in the solver on an impulse value of the scaled masses/inertias. As a result, the magnitude of impulses calculated from computeLinearAngularImpulse(...) may exceed the maxImpulse. In situations where mass scaling was used, the magnitude of the magnitude of linear impulse will not exceed massScale * maxImpulse and angular impulse will not exceed inertiaScale * maxImpulse.

There are a couple of special requirements for the callback due to the fact that it is coming from deep inside the SDK. In particular, the callback should be thread-safe and re-entrant. In other words, the SDK may call onContactModify() from any thread and concurrently (i.e., asked to process sets of contact modification pairs simultaneously).

The contact modification callback can be set using the contactModifyCallback member of PxSceneDesc or the setContactModifyCallback() method of PxScene.
Contact reporting

Here is an example for a contact event function from SampleSubmarine:

```cpp
template

```void SampleSubmarine::onContact(const PxContactPairHeader& pairHeader, const PxContactPair* pairs, PxU32 nbPairs)
{
    for(PxU32 i=0; i < nbPairs; i++)
    {
        const PxContactPair& cp = pairs[i];

        if(cp.events & PxPairFlag::eNOTIFY_TOUCH_FOUND)
        {
            if((pairHeader.actors[0] == mSubmarineActor) ||
                (pairHeader.actors[1] == mSubmarineActor))
            {
                PxActor* otherActor = (mSubmarineActor == pairHeader.actors[0] ? pairHeader.actors[1] : pairHeader.actors[0]);
                Seamine* mine = reinterpret_cast<Seamine*>(otherActor);
                // insert only once
                if(std::find(mMinesToExplode.begin(), mMinesToExplode.end()) == mMinesToExplode.end())
                {
                    mMinesToExplode.push_back(mine);
                    break;
                }
            }
        }
    }
}
```

SampleSubmarine is a subclass of PxSimulationEventCallback. `onContact` receives the pair for which the requested contact events have been triggered. The function is only interested in eNOTIFY_TOUCH_FOUND events, which are raised whenever two shapes start to touch. In fact it is only interested in touch events of the submarine -- which is checked in the second if-statement. It then goes on to assume that the second actor is a mine (which works in this example because the sample is configured such that contact reports will get sent when a submarine actor is involved). After that it adds the mine to a set of mines that should explode during the next update.
**Note:** By default collisions between kinematic rigid bodies and kinematic rigid bodies will not get reported. To enable these reports raise the PxSceneFlag::eENABLE_KINEMATIC_PAIRS or ::eENABLE_KINEMATIC_STATIC_PAIRS flag respectively by calling PxScene::setFlag().

Frequently, users are only interested in contact reports, if the force of impact is larger than a certain threshold. This allows to reduce the amount of reported pairs which need to get processed. To take advantage of this option the following additional configurations are necessary:

- Use PxPairFlag::eNOTIFY_THRESHOLD_FORCE_FOUND, ::eNOTIFY_THRESHOLD_FORCE_PERSISTS, ::eNOTIFY_THRESHOLD_FORCE_LOST instead of eNOTIFY_TOUCH_FOUND etc.
- Specify the threshold force for a dynamic rigid object through PxRigidDynamic::setContactReportThreshold(). If the body collides with an object and the contact force is above the threshold, a report will get sent (if enabled according to the PxPairFlag setting of the pair). If two colliding dynamic bodies both have a force threshold specified then the lower threshold will be used.

**Note:** If a dynamic rigid body collides with multiple static objects, then the impact force of all those contacts will get summed up and used to compare against the threshold. In other words, even if the impact force against each individual object is below the threshold, the contact reports will still get sent for each pair if the sum of those forces exceeds the threshold.

**Contact Reports and CCD**

If continuous collision detection (CCD) with multiple passes is enabled, a fast moving object might bounce on and off the same object multiple times during
step. By default, only the first impact will get reported as an `eNOTIFY` event in this case. To get events for the other impacts too, `eNOTIFY_TOUCH_CCD` has to be raised for the collision pair. `eNOTIFY_TOUCH_CCD` events for the non-primary impacts. For performance reasons, the system cannot always tell whether the contact pair lost touch in a CCD pass and thus cannot always tell whether the contact persisted. `eNOTIFY_TOUCH_CCD` just reports when the two collision objects were detected as being in contact during a CCD pass.
Extracting Contact information

The onContact simulation event permits read-only access to all contact PxContactPair. In previous releases, these were available as a PxContactPoint objects. However, PhysX 3.3 introduces a new format, compressed contact stream. The contact information is now compressed into an appropriate format for a given PxContactPair depending on certain properties, e.g. depending on the shapes involved, the properties of the contacts, materials and whether the contacts are modifiable.

As there are a large number of combinations of different formats, the user is provided with two built-in mechanisms to access the contact data. The first approach provides a mechanism to extract contacts from a user buffer and can be used as below:

```cpp
void MySimulationCallback::onContact(const PxContactPairHeader& pairHeader, const PxContactPair* pairs, PxU32 nbPairs)
{
    const PxU32 bufferSize = 64;
    PxContactPairPoint contacts[bufferSize];
    for(PxU32 i=0; i < nbPairs; i++)
    {
        const PxContactPair& cp = pairs[i];

        PxU32 nbContacts = cp.extractContacts(contacts, bufferSize);
        for(PxU32 j=0; j < nbContacts; j++)
        {
            PxVec3 point = contacts[j].position;
            PxVec3 impulse = contacts[j].impulse;
            PxU32 internalFaceIndex0 = contacts[j].internalFaceIndex0;
            PxU32 internalFaceIndex1 = contacts[j].internalFaceIndex1;
            //...
        }
    }
}
```

This approach requires copying data to a temporary buffer in order to access it. The second approach allows the user to iterate over the contact information without extracting their own copy:
```cpp
void MySimulationCallback::onContact(const PxContactPairHeader& pairHeader, const PxContactPair* pairs, PxU32 nbPairs)
{
    for(PxU32 i=0; i < nbPairs; i++)
    {
        const PxContactPair& cp = pairs[i];

        PxContactStreamIterator iter(cp.contactPatchقدرة

        const PxReal* impulses = cp.contactImpulses;

        PxU32 flippedContacts = (cp.flags & PxContactPairFlag::eINTERNAL_CONTACTS_ARE_FLIPPED);
        PxU32 hasImpulses = (cp.flags & PxContactPairFlag::eINTERNAL_HAS_IMPULSES);
        PxU32 nbContacts = 0;

        while(iter.hasNextPatch())
        {
            iter.nextPatch();
            while(iter.hasNextContact())
            {
                iter.nextContact();
                PxVec3 point = iter.getContactPoint();
                PxVec3 impulse = hasImpulses ? dst.normal * impulse : 0;

                PxU32 internalFaceIndex0 = flippedContacts ? iter.getFaceIndex1() : iter.getFaceIndex0();
                PxU32 internalFaceIndex1 = flippedContacts ? iter.getFaceIndex0() : iter.getFaceIndex1();

                //...
                nbContacts++;
            }
        }
    }
}
```

This approach is slightly more involved because it requires the user to not only iterate over all of the data but also consider conditions like whether the pair has been flipped or whether impulses have been reported with the pair. However, this approach of iterating over the data in-place may be more efficient because it doesn't require copy.

Extra Contact Data
Since pointers to the actors of a contact pair are provided in contact properties can be read directly within the callback. However, the pose of an actor usually refer to the time of impact. If for some reasons the velocity response is of interest, then the actor can not provide that information possible to get the actor velocity or the pose at impact if those properties the user while the simulation was running (in such a case the newly set will be returned). Last but not least, if CCD with multiple passes is enabled, moving object might bounce on and off the same object multiple times and velocities for each such impact can not get extracted from the actor callback. For these scenarios, the PhysX SDK provides an additional stream can hold all sorts of extra information related to the contact pair. This can be requested per pair through the pair flags PXPairFlags (see the API PXPairFlag::ePRE_SOLVER_VELOCITY, PXPairFlag::ePOST_SOLVER_VELOCITY, PXPairFlag::eCONTACT_EVENT_POSE for details). If requested, the extra data available as a member of the PXPxContactPairHeader structure. The stream can then be parsed by using the predefined iterator PxpContactPairExtraDataIterator custom parsing code (see the implementation of PxpContactPairExtraDataIterator details about the format of the stream).

Example code:

```cpp
void MySimulationCallback::onContact(const PxpContactPairHeader& pairHeader, const PxpContactPair* pairs, PxU32 nbPairs)
{
    PxpContactPairExtraDataIterator iter(pairHeader.extraDataStream, pairHeader.extraDataStreamSize);
    while(iter.nextItemSet())
    {
        if (iter.postSolverVelocity)
        {
            PxVec3 linearVelocityActor0 = iter.postSolverVelocity
            PxVec3 linearVelocityActor1 = iter.postSolverVelocity
            ...
        }
    }
}
```
Continuous Collision Detection

When continuous collision detection (or CCD) is turned on, the affected rigid bodies will not go through other objects at high velocities (a problem also known as tunnelling). To enable CCD, three things need to be happen:

1. CCD needs to be turned on at scene level:

   ```
   PxPhysics* physx;
   ...
   PxSceneDesc desc;
   desc.flags |= PxSceneFlag::eENABLE_CCD;
   ...
   ```

2. Pairwise CCD needs to be enabled in the pair filter:

   ```
   static PxFilterFlags filterShader(
   PxFilterObjectAttributes attributes0,
   PxFilterData filterData0,
   PxFilterObjectAttributes attributes1,
   PxFilterData filterData1,
   PxPairFlags& pairFlags,
   const void* constantBlock,
   PxU32 constantBlockSize)
   {
   pairFlags = PxPairFlag::eSOLVE_CONTACT;
   pairFlags |= PxPairFlag::eDETECT_DISCRETE_CONTACT;
   pairFlags |= PxPairFlag::eDETECT_CCD_CONTACT;
   return PxFilterFlags();
   }
   ...
   desc.filterShader = testCCDFilterShader;
   physx->createScene(desc);
   ```

3. CCD need to be enabled for each PxRigidBody that requires CCD:

   ```
   PxRigidBody* body;
   ...
Once enabled, CCD only activates between shapes whose relative speeds exceed the sum of their respective CCD velocity thresholds. These velocity thresholds are automatically calculated based on the shape's properties and support non-uniform scales.

**Contact Notification and Modification**

CCD supports the full set of contact notification events that are supported by discrete collision detection. For details on contact notification, see the documentation for Callbacks.

CCD supports contact modification. To listen to these modify callbacks, derive from the class `PxCCDContactModifyCallback`:

```cpp
class MyCCDContactModification : public PxCCDContactModifyCallback
{
    ...
    void onCCDContactModify(PxContactModifyPair* const pairs, PxU32 count);
};
```

And then implement the function `onContactModify` of `PxContactModifyCallback`:

```cpp
void MyContactModification::onContactModify(PxContactModifyPair* const pairs, PxU32 count)
{
    for(PxU32 i=0; i<count; i++)
    {
        ...
    }
}
```

This `onContactModify` callback operates using the same semantic collision detection contact modification callbacks. For further details, see the documentation on Callbacks.

As with discrete collision detection, CCD will only emit contact modification events for a given pair if the user has specified the pair flag `PxPairFlag::eMODIFY_
Triggers

Currently, shapes flagged with PxShapeFlag::eTRIGGER_SHAPE will not be included in CCD. However, it is possible to get trigger events from CCD by not flagging as PxShapeFlag::eTRIGGER_SHAPE and instead configuring the filter shader. For pairs involving trigger shapes:

```cpp
pairFlags = PxPairFlag::eTRIGGER_DEFAULT | PxPairFlag::eDETECT_CCD_CONTACT; return PxFilterFlag::eDEFAULT;
```

It should be noted that not flagging shapes as PxShapeFlag::eTRIGGER_SHAPE can result in the triggers being more expensive. Therefore, this workaround should be reserved for use only in situations where important trigger events will be missed without CCD.

Tuning CCD

The CCD should generally work without any tuning. However, there are 4 properties that can be adjusted:

1. PxSceneDesc.ccdMaxPasses: This variable controls the number of CCD passes to perform. This is defaulted to 1, meaning that all objects are attempted to be updated to the TOI of their first contact. Any remaining time after the TOI of their first contact will be dropped. Increasing this value permits the CCD to run multiple passes, reducing the likelihood of time being dropped but can increase the cost of the CCD.

2. PxRigidBody::setMinCCDAccelCoefficient(PxReal advanceCoefficient): This method allows you to adjust the amount by which the CCD advances objects in a given pass. By default, this value is 0.15, meaning that CCD will advance the object by the 0.15 * ccdThreshold, where ccdThreshold is a value computed per-shape that acts as a lower-bound of the maximum amount of time that could have passed before there is a chance that the object could have tunnelled. The
0.15 improves the fluidity of motion without risking missed collisions. This value can negatively impact fluidity but will reduce the likelihood of objects clipping at the end of a frame. Increasing this value may increase the likelihood of objects tunnelling. This value should only be set in the range [0,1].

3. Enabling the flag `PxSceneFlag::eDISABLE_CCD_RESWEEP` in `PxSceneDesc.flags`: Enabling this flag disables CCD resweeps. This can result in missed collisions as the result of ricochets but has the potential to reduce overhead of the CCD. In general, enabling this advancement mode ensures that objects will not pass through the static environment but no longer guarantees that dynamic objects with CCD enabled will not pass through each other.

4. `PxRigidBody::setRigidBodyFlag(PxRigidBodyFlag::eENABLE_CCD_FRICTION, true)`: Enabling this flag enables the application of friction forces in the CCD. This is disabled by default. As the CCD operates using only linear motion, enabling friction inside CCD can cause visual artefacts.

**Performance Implications**

Enabling CCD on a scene/all bodies in a scene should be relatively efficient, but some performance impact even when all the objects in the scene are moving slowly. A great deal of effort has been put into optimizing the CCD and additional overhead should only constitute a very small portion of the total time when the objects are moving slowly. As the objects' velocities increase, overhead will increase, especially if there are a lot of high-speed objects in close proximity. Increasing the number of CCD passes can make the CCD more expensive, but the CCD will terminate early if the additional passes aren't required.

**Limitations**

The CCD system is a best-effort conservative advancement scheme. The number of CCD substeps (defaulted to 1) and drops any remaining time only dropped on high-speed objects at the moment of impact so it is not noticeable. However, this artefact can become noticeable if you simulate an object...
small/thin relative to the simulation time-step that the object could be accelerated by gravity from rest for 1 frame, i.e. a paper-thin rigid body would always be moving at above its CCD velocity threshold and could cause a proportion of simulation time being dropped for that object and any other objects within the same island as it (any objects whose bounds overlap the bounds of that object). This could cause a noticeable slow-down/stuttering effect caused by the object becoming noticeably out-of-sync with the rest of the simulation. It is therefore recommended that paper-thin/tiny objects should be avoided if possible.

It is also recommended that you filter away CCD interactions between objects that are constrained together, e.g. limbs in the same ragdoll. Allowing CCD interactions between limbs of the same ragdoll could increase the cost of CCD and also potentially cause time to be dropped unnecessarily. CCD interactions are automatically disabled between links in an articulation.
Raycast CCD

The PhysX SDK supports an alternative CCD implementation based on raycasts. This "raycast CCD" algorithm is available in PhysX Extensions, and it is demonstrated in a snippet ("SnippetRaycastCCD"). Contrary to the built-in CCD algorithm implemented within the PhysX SDK, this cheaper and simpler alternative version is fully implemented outside of the SDK itself.

After the traditional simulate/fetchResults calls, the system performs raycasts from the shapes' center positions to double-check that they did not tunnel. If tunneling is detected for an object, it is moved back to a previous position along the ray, in an overlap position. Then next frame, the SDK's contact generation takes over and generates a convincing motion. There are some subtle details not described here, but this is how it works in a nutshell.

Since it is raycast-based, the solution is not perfect. In particular, small dynamic objects can still go through the static world if the ray goes through a crack between edges or a small hole in the world (like the keyhole from a door). Also, dynamic-vs-dynamic CCD is very approximate. It only works well for fast-moving dynamic objects colliding against slow-moving dynamic objects. Other known limitations are that it is currently implemented for PxRigidDynamic objects (not for PxArticulationLink) and for simple actors with one shape (not for "compounds").

However, the implementation should be able to prevent important objects from leaving the game world, provided the world is watertight. The code is very small and easy to follow or modify, and its performance is often better overall than for the built-in CCD. It can be a valuable alternative if the default CCD becomes too expensive.
Speculative CCD

In addition to sweep-based CCD, PhysX also provides a cheaper but less robust approach called speculative CCD. This approach functions differently to the sweep-based CCD in that it operates entirely as part of the discrete simulation by inflating contact offsets based on object motion and depending on the constraint solver to ensure that objects do not tunnel through each other.

This approach generally works well and, unlike the sweep-based CCD, speculative CCD on kinematic actors. However, there are cases where objects do not pass through each other. As an example, if the constraint solver accelerates an actor (as a result of a collision or joint) such that the actor passes through objects during that time-step, speculative CCD can result in tunneling.

To enable this feature, raise PxRigidBodyFlag::eENABLE_SPECULATIVE_CCD

```
PxRigidBody* body;
...
body->setRigidBodyFlag(PxRigidBodyFlag::eENABLE_SPECULATIVE_CCD,
```

Unlike the sweep-based CCD, this form of CCD does not require settings to be raised on either the scene or on the pair in the filter shader.

Note that this approach works best with PCM collision detection. It may not work as well if the legacy SAT-based collision detection approach is used.

This feature can work in conjunction with the sweep-based CCD, e.g., a fast-moving kinematic has speculative CCD enabled but dynamic rigid bodies use sweep-based CCD. However, if speculative CCD is used on kinematics in conjunction with sweep-based CCD, it is important to ensure that interactions between the kinematic actor's speculative contacts and the CCD-enabled dynamic actors do not also enable sweep-based CCD interactions otherwise the sweep-based CCD may overrule the speculative CCD leading to poor behavior.
Persistent Contact Manifold (PCM)

The PhysX SDK provides two types of collision detection:

1. Default collision detection

The default collision detection system uses a mixture of SAT (Separating Axis Theorem) and distance-based collision detection to generate full contact manifolds. The potential contacts in one frame, so it lends itself better to stable stacking. This approach is stable for small contact offsets and rest offsets but may not generate the correct contact points when large offsets are used because it approximates the contact points in these situations by plane shifting.

2. Persistent Contact Manifold (PCM)

PCM is a fully distance-based collision detection system. PCM generates contacts when two shapes first come into contact. It recycles and updates contacts from the previous frame in the manifold and then it generates the subsequent frame if the shapes move relative to each other more than a threshold amount or if a contact was dropped from the manifold. If too many contacts are dropped from the manifold due to a large amount of relative motion in a frame, full manifold generation is re-run. This approach is quite efficient in terms of performance. However, because PCM potentially generates fewer contacts than the default detection, it might reduce stacking stability when simulating tall stacks with insufficient solver iterations. As this approach is distance-based, it will generate correct contact points for arbitrary contact offsets/rest offsets.

To enable PCM, set the flag in the PxSceneDesc::flags:

```cpp
PxSceneDesc sceneDesc;
sceneDesc.flags |= PxSceneFlag::eENABLE_PCM;
```
Joint Basics

A joint constrains the way two actors move relative to one another. A typical use would be to model a door hinge or the shoulder of a character. Joints are implemented in the PhysX extensions library and cover many common scenarios, but if you have cases that are not met by the joints packaged with PhysX, you can implement your own. Since joints are implemented as extensions, the pattern for creating them is slightly different from other PhysX objects.

Creation of simple joints and limits is demonstrated in the SnippetJoint snippet.

To create a joint, call the joint's creation function:

```
PxRevoluteJointCreate(PxPhysics& physics, 
    PxRigidActor* actor0, const PxTransform& localFrame0, 
    PxRigidActor* actor1, const PxTransform& localFrame1)
```

This has the same pattern for all joints: two actors, and for each actor a constraint frame.

One of the actors must be movable, either a `PxRigidDynamic` or a `PxArticulationLink`, other may be of one of those types, or a `PxRigidStatic`. Use a NULL pointer there to indicate an implicit actor representing the immovable global reference frame.

Each localFrame argument specifies a constraint frame relative to the actor. Each joint defines a relationship between the global positions and origins of the constraint frames that will be enforced by the PhysX constraint solver. In this example, the revolute joint constrains the origin points of the two frames to be coincident and their x-axes to coincide, but allows the two actors to rotate freely relative to one another around this common axis.

PhysX supports six different joint types:

- a **fixed** joint locks the orientations and origins rigidly together
- a **distance** joint keeps the origins within a certain distance range
- a **spherical** joint (also called a *ball-and-socket*) keeps the origins together
the orientations to vary freely.

- A **revolute** joint (also called a *hinge*) keeps the origins and x-axes together, and allows free rotation around this common axis.
- A **prismatic** joint (also called a *slider*) keeps the orientations identical, but allows the origin of each frame to slide freely along the common x-axis.
- A **D6** joint is a highly configurable joint that allows specification of freedom either to move freely or be locked together. It can be used for a wide variety of mechanical and anatomical joints, but is somewhat more configurable than the other joint types. This joint is covered in detail below.

All joints are implemented as plugins to the SDK through the PxConstraint class. A number of the properties for each joint are configured using the PxConstraintFlag enumeration.

**Note:** As in the rest of the PhysX API, all joint angles for limits and drive targets are specified in radians.

### Visualization

All standard PhysX joints support debug visualization. You can visualize each actor, and also any limits the joint may have.

By default, joints are not visualized. To visualize a joint, set its visualization and the appropriate scene-level visualization parameters:

```cpp
scene->setVisualizationParameter(PxVisualizationParameter::eJOINT_FRAMES
scene->setVisualizationParameter(PxVisualizationParameter::eJOINT_LIMITS
...  
joint->setConstraintFlag(PxConstraintFlag::eVISUALIZATION)
```

### Force Reporting
The force applied at a joint may be retrieved after simulation with a call:

```cpp
scene->fetchResults(...)
joint->getConstraint().getForce(force, torque);
```

The force is resolved at the origin of actor1's joint frame.

Note that this force is only updated while the joint's actors are awake.

### Breakage

All of the standard PhysX joints can be made *breakable*. A maximum torque may be specified, and if the force or torque required to maintain the joint exceeds this threshold, the joint will break. Breaking a joint generates a simulation event (see `PxSimulationEventCallback::onJointBreak`), and the joint no longer participates in the simulation, although it remains attached to its actors until it is deleted.

By default the threshold force and torque are set to FLT_MAX, making joints effectively unbreakable. To make a joint breakable, specify the force and torque thresholds:

```cpp
joint->setBreakForce(100.0f, 100.0f);
```

A constraint flag records whether a joint is currently broken:

```cpp
bool broken = (joint->getConstraintFlags() & PxConstraintFlag::eBROKEN) != 0;
```

Breaking a joint causes a callback via `PxSimulationEventCallback::onConstraintBreak`. In this callback, a pointer to the joint and its type are specified in the externalReference and type fields of the `PxConstraintInfo` struct. If you have implemented your own joint types, use the `PxConstraintInfo::type` field to determine the dynamic type of the broken constraint. Otherwise, simply cast the externalReference to a `PxJoint`:

```cpp
class MySimulationEventCallback
{
    void onConstraintBreak(PxConstraintInfo* constraints, PxU32 count)
    {
        for(PxU32 i=0; i<count; i++)
        {
```
Projection

Under stressful conditions, PhysX’ dynamics solver may not be able to enforce the constraints specified by the joint. PhysX provides kinematic projection to bring violated constraints back into alignment even when the solver fails. It is a physical process and does not preserve momentum or respect collision geometry. It is best avoided if practical, but can be useful in improving simulation separation results in unacceptable artifacts.

By default projection is disabled. To enable projection, set the linear and angular tolerance values beyond which a joint will be projected, and set the constraint projection flag:

```cpp
joint->setProjectionLinearTolerance(0.1f);
joint->setConstraintFlag(PxConstraintFlag::ePROJECTION, true);
```

Very small tolerance values for projection may result in jittering around the joint.

A constraint with projection enabled can be part of a graph of rigid bodies connected by constraints. If this graph is acyclic, the algorithm will choose a root connected rigid bodies, traverse the graph, and project the bodies towards the root. If the constraint graph has cycles, the algorithm will split the graph into multiple subgraphs, dropping edges that create cycles, and do the projection separately for each. Please note that having more than one constraint attached to a fixed anchor (world or static/kinematic rigid body) in a graph does count as a cycle (for example, bodies connected with constraints and both ends attached to world anchors). Constraints fighting over the same body or conflicting projection directions will be chosen based on the following priorities (highest priority first):

- world attachment or a rigid static actor with a projecting constraint
- kinematic actor with a projecting constraint
• all dominant dynamic actor (has projecting constraints and all of projecting towards this dynamic)
• dominant dynamic actor (same as above but there is at least one constraint as well)
• partially dominant dynamic actor (has at least one one-way projecting constraint towards this dynamic and at least one one-way projecting constraint)
• world attachment or a rigid static actor without any projecting constraints
• kinematic actor without any projecting constraints
• dynamic actor with or without two-way projecting constraints (among these, the one with the highest constraint count wins)

Limits

Some PhysX joints constrain not just relative rotation or translation, but limits on the range of that motion. For example, in its initial configuration, allows free rotation around its axis, but by specifying and enabling a limit, bounds may be placed upon the angle of rotation.

Limits are a form of collision, and like collision of rigid body shapes, so requires a contactDistance tolerance specifying how far from the configuration may be before the solver tries to enforce it. Note that enforcement starts before the limit is violated, so the role played by contactDistance is analogous to the role a positive contactDistance value plays in collision. contact makes the limit less likely to be violated even at high relative velocity because the limit is active more of the time, the joint is more expensive.

Limit configuration is specific to each type of joint. To set a limit, geometry and set the joint-specific flag indicating that the limit is enabled:

```cpp
revolute->setLimit(PxJointAngularLimitPair(-PxPi/4, PxPi/4, 0.1f))
revolute->setRevoluteJointFlag(PxRevoluteJointFlag::eLIMIT_ENABLE)
```
Limits may be either *hard* or *soft*. When a hard limit is reached, relative motion will stop dead if the limit is configured with zero restitution, or bounce if the restitution is non-zero. When a soft limit is violated, the solver will pull the joint back towards the limit using a spring specified by the limit's spring and damping parameters. By default, limits are hard and without restitution, so when the joint reaches a limit motion will simply stop. To specify softness for a limit, declare the limit structure and set the spring and damping directly:

```cpp
PxJointAngularLimitPair limitPair(-PxPi/4, PxPi/4, 0.1f));
limitPair.spring = 100.0f;
limitPair.damping = 20.0f;
revolute->setRevoluteJointLimit(limitPair);
revolute->setRevoluteJointFlag(PxRevoluteJointFlag::eLIMIT_ENABLED);
```

**Note:** Limits are not projected.

When using spring limits, the eACCELERATION flag is strongly recommended. This flag will automatically scale the strength of the spring according to the masses and inertias of objects that the limit is acting upon, and can substantially reduce the amount of tuning required for good, stable behavior.

### Actuation

Some PhysX joints may be actuated by a motor or a spring implicitly integrated by the PhysX solver. While driving simulations with actuated joints is more expensive than simply applying forces, it can provide much more stable control of simulation motion. See *Prismatic Joint*, and *Revolute Joint* for details.

**Note:** The force generated by actuation is not included in the force reported by the solver, nor does it contribute towards exceeding the joint's breakage force.

**Note:** Changing the drive parameters for a joint, or activating or deactivating the drive, does not wake sleeping bodies attached to the joint. If required, wake them manually.
When using spring drives (in particular, drives on the D6 joint), the eACCELERATION flag is strongly recommended. This flag will automatically scale the strength according to the masses and inertias of objects that the limit is acting upon, substantially reduce the amount of tuning required for good, stable behavior.

**Mass Scaling**

PhysX joints may apply scale to the mass and moment of inertia of bodies for the purposes of resolving a joint. For example, if you have a ragdoll of masses 1 and 10, PhysX will typically resolve the joint by changing the velocity of the lighter body much more than the heavier one. You can apply a mass scale to the first body to make PhysX change the velocity of both bodies by an equal amount. To ensure the same property holds for both linear and angular velocity, you should adjust the inertia scales in accordance with the bodies' inertias as well. Applying mass scales such that the joint sees similar effective masses and inertias makes the solver converge faster, which can make individual joints seem less rubbery or separated, and sets of jointed bodies appear less twitchy.

Many applications that prioritize visual behavior over adherence to physical laws can benefit from tuning these scale values. But if you use this feature, bear in mind that mass and inertia scaling is fundamentally nonphysical. In general momentum will not be conserved, the energy of the system may increase, the force reported for the joint may be incorrect, and non-physical tuning of breakage thresholds and force limits may be required.
Fixed Joint

The fixed joint constrains two objects so that the positions and orientations of their constraint frames are the same.

**Note:** All joints are enforced by the dynamics solver, so although under ideal conditions the objects will maintain their spatial relationship, there may be some drift. A common alternative, which is cheaper to simulate and does not suffer from drift, is to construct a single actor with multiple shapes. However fixed joints are useful, for example, when a joint must be breakable or report its constraint force.
Spherical Joint

A spherical joint constrains the origins of the actor's constraint frames to be coincident.

The spherical joint supports a cone limit, which constrains the angle between the origins of the two constraint frames. Actor1's X-axis is constrained by a limit cone around the x-axis of actor0's constraint frame. The allowed limit values are the maximum rotation around the y- and z- axes of that frame. Different values for the y- and z- axes may be specified, in which case the limit takes the form of an elliptical angular cone:

```cpp
joint->setLimitCone(PxJointLimitCone(PxPi/2, PxPi/6, 0.01f);
joint->setSphericalJointFlag(PxSphericalJointFlag::eLIMIT_ENABLED);
```

Note that very small or highly elliptical limit cones may result in solver jitter.

**Note:** Visualization of the limit surface can help considerably in understanding its shape.
Revolute Joint

A revolute joint removes all but a single rotational degree of freedom from two objects. The axis along which the two bodies may rotate is specified by the common frames and their common x-axis. In theory, all origin points along the axis of rotation are equivalent, but simulation stability is best in practice when the point bodies are closest.

The joint supports a rotational limit with upper and lower extents. The angle between the y- and z- axes of the joint frames are coincident, and increases moving towards the z-axis:

```cpp
joint->setLimit(PxJointLimitPair(-PxPi/4, PxPi/4, 0.01f));
joint->setRevoluteJointFlag(PxRevoluteJointFlag::eLIMIT_ENABLED,
```

The joint also supports a motor which drives the relative angular velocity towards a user-specified target velocity. The magnitude of the force applied may be limited to a specified maximum:

```cpp
joint->setDriveVelocity(10.0f);
joint->setRevoluteJointFlag(PxRevoluteJointFlag::eDRIVE_ENABLED,
```
By default, when the angular velocity at the joint exceeds the target velocity, the motor acts as a brake; a freespin flag disables this braking behavior.

The drive force limit for a revolute joint may be interpreted either as a force or an impulse, depending on the value of PxConstraintFlag::eDRIVE_LIMITS_ARE_FORCES.
A prismatic joint prevents all rotational motion, but allows the origin of frame to move freely along the x-axis of actor0's constraint frame. It supports a single limit with upper and lower bounds on the distance constraint frames' origin points:

```
joint->setLimit(PxJointLimitPair(-10.0f, 20.0f, 0.01f));
joint->setPrismaticJointFlag(PxPrismaticJointFlag::eLIMIT_ENABLED);
```
The distance joint keeps the origins of the constraint frames within distance. The range may have both upper and lower bounds, \( m \) separately by flags:

```cpp
joint->setMaxDistance(10.0f);
joint->setDistanceJointFlag(eMAX_DISTANCE_ENABLED, true);
```

In addition, when the joint reaches the limits of its range motion beyond either be entirely prevented by the solver, or pushed back towards implicit spring, for which spring and damping parameters may be specifi
D6 Joint

The D6 joint is by far the most complex of the standard PhysX joints. In its default state it behaves like a fixed joint - that is, it rigidly fixes the constraint frames of its two actors. However, individual degrees of freedom may be unlocked to permit a rotation around the x-, y- and z-axes, and translation along these axes.

Locking and Unlocking Axes

To unlock and lock degrees of freedom, use the joint's setMotion function:

```cpp
d6joint->setMotion(PxD6Axis::eX, PxD6Motion::eFREE);
```

Unlocking translational degrees of freedom allows the origin point of the frame to move along a subset of the axes defined by actor0's constraint frame. For example, unlocking just the X-axis creates the equivalent of a prismatic joint.

Rotational degrees of freedom are partitioned as twist (around the X-axis of actor0's constraint frame) and swing (around the Y- and Z-axes). Different effects are achieved by unlocking various combinations of twist and swing.

- if just a single degree of angular freedom is unlocked, the result is equivalent to a revolute joint. It is recommended that if just one angular freedom is unlocked it should be the twist degree, because the joint has various configurations and optimizations that are designed for this case.

- if both swing degrees of freedom are unlocked but the twist degree remains locked, the result is a zero-twist joint. The x-axis of actor1 swings freely away from the x-axis of actor0 but twists to minimize the rotation required to align the frames. This creates a kind of isotropic universal joint which avoids the problem of the 'engineering style' universal joint (see below) that is sometimes used as a twist constraint. There is a nasty singularity at π radians (180 degrees).
limit should be used to avoid the singularity.

- if one swing and one twist degree of freedom are unlocked but the kept locked, a zero-swing joint results (often also called a uni example the SWING1 (y-axis rotation) is unlocked, the x-axis of ac to remain orthogonal to the z-axis of actor0. In character application used to model an elbow swing joint incorporating the twist freedom or a knee swing joint incorporating the twist freedom of the low applications, these joints can be used as 'steered wheel' joints in w is the wheel, free to rotate about its twist axis, while the free swing acts as the steering axis. Care must be taken with this combi anisotropic behavior and singularities (beware the dreaded gimba π/2 radians (90 degrees), making the zero-twist joint a better beh most use cases.

- if all three angular degrees are unlocked, the result is equivalent to

Three of the joints from PhysX 2 that have been removed from implemented as follows:

- The cylindrical joint (with axis along the common x-axis of the two is given by the combination:

```cpp
d6joint->setMotion(PxD6Axis::eX, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eTWIST, PxD6Motion::eFREE);
```

- the point-on-plane joint (with plane axis along the x-axis of actor0' is given by the combination:

```cpp
d6joint->setMotion(PxD6Axis::eY, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eZ, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eTWIST, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eSWING1, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eSWING2, PxD6Motion::eFREE);
```
• the point-on-line joint (with axis along the x-axis of actor0's constraint frame) can be specified by the combination:

```cpp
d6joint->setMotion(PxD6Axis::eX, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eTWIST, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eSWING1, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eSWING2, PxD6Motion::eFREE);
```

**Note:** Angular projection is implemented only for the cases when two or three angular degrees of freedom are locked.

**Limits**

Instead of specifying that an axis is free or locked, it may also be specified as limited. D6 supports three different limits which may be used in any combination.

A single linear limit with only an upper bound is used to constrain any of the translational degrees of freedom. The limit constrains the distance between the origins of the constraint frames when projected onto these axes. For example, the combination:

```cpp
d6joint->setMotion(PxD6Axis::eX, PxD6Motion::eFREE);
d6joint->setMotion(PxD6Axis::eY, PxD6Motion::eLIMITED);
d6joint->setMotion(PxD6Axis::eZ, PxD6Motion::eLIMITED);
d6joint->setLinearLimit(PxJointLinearLimit(1.0f, 0.1f));
```

constrains the y- and z- coordinates of actor1's constraint frame to lie within a cylinder of radius 0.1.

Since the x-axis is unconstrained, the effect is to constrain the origin of actor1's constraint frame to lie within a cylinder of radius 1 extending along the x-axis of actor0's constraint frame.

The twist degree of freedom is limited by a pair limit with upper and lower bounds identical to the limit of the revolute joint.

If both swing degrees of freedom are limited, a limit cone is generated, identical to the limit of the spherical joint. As with the spherical joint, very small or highly elliptical limit cones may result in solver jitter.
If only one swing degree of freedom is limited, the corresponding angle is used to limit rotation. If the other swing degree is locked, the maximum is $\pi$ radians (180 degrees). If the other swing degree is free, the maximum limit is $\pi/2$ radians (90 degrees).

**Drives**

The D6 has a linear drive model, and two possible angular drive models:

*proportional derivative* drive, which applies a force as follows:

$$force = spring \times (targetPosition - position) + damping \times (targetVelocity - velocity)$$

The drive model may also be configured to generate a proportional acceleration drive instead of a force, factoring in the masses of the actors to which the joint is attached. Acceleration drive is often easier to tune than force drive.

The linear drive model for the D6 has the following parameters:

- target position, specified in actor0's constraint frame
- target velocity, specified in actor0's constraint frame
- spring
- damping
- forceLimit - the maximum force the drive can apply (note that this can be an impulse, depending on PxConstraintFlag::eDRIVE_LIMITS_ARE_FORCES)
- acceleration drive flag

The drive attempts to follow the desired position input with the configured stiffness and damping properties. A physical lag due to the inertia of the driven body and the drive spring will occur; therefore, sudden step changes will result over a number of time steps. Physical lag can be reduced by stiffening the spring or supplying a velocity target.

With a fixed position input and a zero target velocity, a position drive will spring the drive position with the specified springing/damping characteristics:

```cpp
// set all translational degrees free
```
Angular drive differs from linear drive in a fundamental way: it does not have an intuitive representation free from singularities. For this reason, the D6 joint provides two angular drive models - twist and swing and SLERP (Spherical Linear Interpolation).

The two models differ in the way they estimate the path in quaternion space between the current orientation and the target orientation. In a SLERP drive, the quaternion is used directly. In a twist and swing drive, it is decomposed into separate twist and swing components and each component is interpolated separately. Twist and swing is intuitive in many situations; however, there is a singularity when driven to 180 degrees swing. In addition, the drive will not follow the shortest arc between two orientations. On the other hand, SLERP drive will follow the shortest arc between a pair of angular configurations, but may cause unintuitive changes in the joint's twist and swing.

The angular drive model has the following parameters:

- An angular velocity target specified relative to actor0's constraint frame
- An orientation target specified relative to actor0's constraint frame
- Drive specifications for SLERP (slerpDrive), swing (swingDrive) and twist (twistDrive):
- Spring - amount of torque needed to move the joint to its target
• damping - applied to the drive spring (used to smooth out oscillations about the drive target).
• forceLimit - the maximum torque the drive can apply (note that impulsive torque, depending on PxConstraintFlag::eDRIVE_LIMITS_ARE_FORCES)
• acceleration drive flag. If this flag is set the acceleration (rather than the force) applied by the drive is proportional to the angle from the target.

Best results will be achieved when the drive target inputs are consistent with joint freedom and limit constraints.

**Note:** if any angular degrees of freedom are locked, the SLERP drive parameters are ignored. If all angular degrees of freedom are unlocked, and parameters are set for multiple angular drives, the SLERP parameters will be used.

### Configuring Joints for Best Behavior

The behavior quality of joints in PhysX is largely determined by the ability of the iterative solver to converge. Better convergence can be achieved simply by increasing the attributes of the PxRigidDynamic which controls the solver iteration count. However, joints can also be configured to produce better convergence.

• the solver can have difficulty converging well when a light object is constrained between two heavy objects. Mass ratios of higher than 10 are best avoided in such scenarios.
• when one body is significantly heavier than the other, make the heavier body the second actor in the joint. Similarly, when one of the objects is static or kinematic (the actor pointer is NULL) make the dynamic body the second actor.

A common use for joints is to move objects around in the world. Best results are achieved when the solver has access to the velocity of motion as well as the change in position.
• if you want a very stiff controller that moves the object to specific p
  consider jointing the object to a kinematic actor and use the i
  function to move the actor.
• if you want a more springy controller, use a D6 joint with a driv
  desired position and orientation, and control the spring paran
  stiffness and damping. In general, acceleration drive is much easie
  drive.

When using mass scaling or when constraining bodies with infinite i
axes, the reduction in degrees of freedom of the rigid bodies cont
inaccuracies in floating point calculation can produce arbitrarily stiff
trying to correct unnoticeably small errors. This can appear, for exampl
perform 2D-simulation using infinite inertia to suppress velocity ou
simulation. In these cases, set the flag PxConstraintFlag::eDISABLE_P
and set the minResponseThreshold on the constraint to a small value,
result in such stiff constraint rows being ignored when encountered, an
improve simulation quality.
Custom Constraints

It is also possible to add new joint types to PhysX. Use the existing PhysXExtensions library as a reference, and also the source for SnippetCustomJoint, which shows how to implement a Pulley Joint. Serialized custom objects are discussed in the chapter *Serialization*, so the discussion here is limited to how to define behavior in simulation. This is an advanced topic, and assumes familiarity with the mathematics underlying rigid body simulation. The presentation here assumes that joint constrains two bodies; the case for a static body is equivalent to a body of infinite mass whose transform is the identity.

The functions which implement dynamic behavior of joints are PhysX nature to the PxFilterShader (see *Collision Filtering*). In particular, execute in parallel and asynchronously, and should not access any state except that passed in as parameters.

To create a custom joint class, define the following:

- the functions which implement the behavior of the constraint. The stateless, because they may be called simultaneously from multiple threads, each function is called, PhysX passes a constant block which contains the joint configuration parameters (offsets, axes, limits etc).
- a static instance of PxConstraintShaderTable containing pointers to the functions.
- a class implementing the PxConstraintConnector interface, that connects the joint to PhysX.

**Defining Constraint Behavior**

There are two functions that define the joint behavior: the *solver pr* function, which generates inputs to PhysX' velocity-based constraint solver, and a function, which allows direct correction of position error.

The processing sequence during simulation is as follows:
in the simulate() function, before starting simulation the scene updates a copy of the joint's constant block (so that the joint's copy may be modified during simulation without causing races).

• collision detection runs, and may wake bodies. If the joint connects two bodies, the simulation will ensure that either both bodies are awake, or neither.

• for every joint connected to an awake body, the simulation calls the function.

• the solver updates body velocities and positions.

• if the constraint's ePROJECTION flag is set, the simulation calls the function.

The Solver Preparation Function

The solver preparation function for a joint has the following signature:

```cpp
PxU32 prepare(Px1DConstraint* constraints,
              PxVec3& bodyAWorldOffset,
              PxU32 maxConstraints,
              PxConstraintInvMassScale &invMassScale,
              const void* constantBlock,
              const PxTransform& bA2w,
              const PxTransform& bB2w);
```

The parameters are as follows:

• `constraints` is the output buffer of constraint rows.

• `bodyAWorldOffset` is the point, specified in world space as an offset from bodyA, at which the constraint forces act to enforce the joint. The solver ignores this value as the information is already encoded in the constraint array, but when reporting forces it is necessary to choose a point at which the forces are considered to act. For PhysX joints, the attachment point of the joint is used.

• `maxConstraints` is the size of the buffer, which limits the number
that may be generated.

- **invMassScale** is the inverse mass scales which should be applied to the purpose of resolving the joint. In the standard joints, these are just a scaling parameters (see *Mass Scaling*).
- **constantBlock** is the simulation's copy of the joint constant block.
- **bA2w** is the transform of the first body. It is the identity transform if the actor is static, or a NULL pointer was supplied in constraint creation.
- **bB2w** is the transform of the second body. It is the identity transform if the actor is static, or a NULL pointer was supplied in constraint creation.

The role of the solver preparation function is to populate the buffer or provide the point of application for force reporting, and provide mass scaling properties. The return value is the number of Px1DConstraints generated buffer.

Notice that although the joint parameters (relative pose etc) are typically relative to an actor, the solver preparation function works with the transforms of rigid bodies. The constraint infrastructure (see *Data Management*), maintaining consistency when, for example, the application modifies the center of mass of an actor.

Each Px1D constraint constrains one degree of freedom between the bodies. The structure looks like this:

```c
struct Px1DConstraint
{
    PxVec3 linear0;
    PxReal geometricError;
    PxVec3 angular0;
    PxReal velocityTarget;

    PxVec3 linear1;
    PxReal minImpulse;
    PxVec3 angular1;
    PxReal maxImpulse;

union
```
Each Px1DConstraint is either a hard constraint (for example, one axis of a fixed joint) or a soft constraint (for example, a spring). A joint may have a mixture of constraint rows - for example, the actuated joint at a rag doll shoulder often has:

- 3 hard 1D-constraints which prevent the shoulder from separating.
- 3 hard 1D-constraints constraining the angular degrees of freedom within some limits.
- 3 soft constraints simulating resistance to angular motion from muscles.

The constraint is treated as hard unless the Px1DConstraintFlag::eSPRING flag is set.

For both soft and hard constraints, the solver velocity for each row is the:

\[
v = \text{body0vel}.\text{dot}(\text{lin0, ang0}) - \text{body1vel}.\text{dot}(\text{lin1, ang1})
\]

**Hard Constraints**

For a hard constraint, the solver attempts to generate:

- a set of motion solver velocities \(v\text{Motion}\) for objects which, when integrated, respect the constraint errors, represented by the equation:
\[ vMotion + (\text{geometricError} / \text{timestep}) = \text{velocityTarget} \]

- a set of post-simulation solver velocities \( v\text{Next} \) for the objects constraints:

\[ v\text{Next} = \text{velocityTarget} \]

The motion velocities are used for integration and then discarded. The velocities are the values that \text{getLinearVelocity()} and \text{getAngularVelocity()}

There are two special options for hard constraints, both most often used to implement limits: restitution and velocity biasing. They are set by the constraint flags \text{eRESTITUTION} and \text{eKEEPBIAS}, are mutually exclusive, and restitution takes priority (in the sense that if restitution is set, biasing is ignored).

Restitution simulates bouncing (off a limit, for example). If the impact \( v\text{Current} \) at the start of simulation exceeds the restitution velocity threshold, the target velocity of the constraint will be set to:

\[ \text{restitution} * -v\text{Current} \]

and the input velocityTarget field will be ignored. To use restitution, set \text{Px1DConstraintFlag::eRESTITUTION}.

Velocity biasing generates post-simulation velocities to satisfy the same constraints as the motion velocities:

\[ v\text{Next} + (\text{geometricError} / \text{timestep}) = \text{velocityTarget} \]

This can be useful if, for example, the joint is approaching a limit but hasn't hit it. If the target velocity is 0 and the geometric error is the distance remaining to the limit, the solver will constrain the velocity below that required to violate the limit. The joint should then converge smoothly to the limit.

\textbf{Soft Constraints}
Alternatively, the solver can attempt to resolve the velocity constraint as an implicit spring. In this case, the motion velocity $v_{Motion}$ and post-simulation velocity $v_{Next}$ are the same. The solver solves the equation:

$$F = \text{stiffness} \times -\text{geometricError} + \text{damping} \times (\text{velocityTarget} - v)$$

where $F$ is the constraint force.

Springs are fully implicit: that is, the force or acceleration is a function of the position and velocity after the solve. There is one special option that applies only to acceleration springs (PxConstraintFlag::eACCELERATION). With this option, the solver will scale the magnitude of the force in accordance with the response of the two bodies; effectively it implicitly solves the equation:

$$\text{acceleration} = \text{stiffness} \times -\text{geometricError} + \text{damping} \times (\text{velocityTarget} - v)$$

### Force Limits and Reporting

All constraints support limits on the minimum or maximum impulse applied. There is a special flag for force limits: eHAS_DRIVE_FORCE_LIMIT. If this flag is set, the force limits will be scaled by the timestep. PxConstraintFlag::eLIMITS_ARE_FORCES is set for the constraint.

The flag eOUTPUT_FORCE flag on a 1D constraint determines whether the force for this row should be included in the constraint force output. The reporting force is also used internally to determine joint breakage. For example, if creating a spherical joint with angular drive that breaks when the stress on the linear part exceeds a threshold, set the flag for the linear equality rows but not the angular drive rows.

### Solver Preprocessing

The joint solver attempts to preprocess hard constraints to improve convergence. The solveHint value controls preprocessing for each row:

- if the constraint is a hard equality constraint with unbounded impulse
impulse limits are -PX_MAXFLT and PX_MAXFLT). PxConstraintSolveHint::eEQUALITY.

- If one of the force limits is zero and the other unbounded, set this to PxConstraintSolveHint::eINEQUALITY.
- For all soft constraints, and hard constraints with impulse limits other than the above, set it to PxConstraintSolveHint::eNONE.

The solver does not check that the hint value is consistent with Px1DConstraint. Using inconsistent values may result in undefined behavior.

The Projection Function

The other behavior that joints may specify for simulation is projection: positional correction designed to act when the velocity-based solver fails. The projection function has the following signature:

```cpp
typedef void (*PxConstraintProject)(const void* constantBlock,
                                            PxTransform& bodyAToWorld,
                                            PxTransform& bodyBToWorld,
                                            bool projectToA);
```

It receives the constant block and the two body transforms. It updates the bodyBToWorld transform if the projectToA flag is set, and otherwise the bodyBToWorld transform. See the implementations in the extensions library for examples of how to define projection functions.

The Constraint Shader Table

After coding the behavior functions, define a structure of type PxConstraintShaderTable, which holds the pointers to the constraint functions. This structure will be passed as an argument to PxPhysics::createConstraint, and is shared by all instances.

```cpp
struct PxConstraintShaderTable
{
    PxConstraintSolverPrep solverPrep;
    PxConstraintProject project;
}
```
The constraint visualizer allows the joint to generate visualization information using the PxConstraintVisualizer interface. The functionality of this interface is somewhat biased towards the standard joints; examples of its use can be found in the extensions library.

### Data Management

Next, define the class which lets PhysX manage the joint. This class should inherit from the PxConstraintConnector interface.

To create a joint, call PxPhysics::createConstraint. The arguments to this function are the constrained actors, the connector object, the shader table, and the size of the joint's constant block. The return value is a pointer to PxConstraint object.

PxConstraintConnector has a number of data management callbacks:

```cpp
virtual void* prepareData();
virtual void onConstraintRelease();
virtual void onComShift(PxU32 actor);
virtual void onOriginShift(const PxVec3& shift);
virtual void* getExternalReference(PxU32& typeID);
```

These functions are usually boilerplate; sample implementations can be found in the extensions library:

- The prepareData() function requests a pointer to the joint constant block, allowing the joint to update any state caches etc. When the function returns, the scene makes an internal copy of this data, so that the joint may be modified during simulation without race conditions. The function is called at the start of the simulation step after the joint is inserted into the scene, and on a subsequent simulation step if PhysX is informed that the joint's state has changed. To inform PhysX that the joint's state has changed, call PxConstraint::markDirty().
- onConstraintRelease() is associated with joint deletion. To delete a joint, call

```cpp
PxPhysics::destroyConstraint(PxConstraint* constraint);
```
PxConstraint::release() on the constraint. When it is safe to destroy no internal references are being held by currently executing simulation code, the constraint code will call PxConstraint::onConstraintRelease(). This function can safely run the destructor and release the joint's memory etc.

- onComShift() is called when the application calls setCMassLocalPose() on one of the actors connected by the joint. This is provided because the solver projection functions are defined using the frame of the underlying rigid body, but the joint configuration is typically defined in terms of the actors.

- onOriginShift() is called when the application shifts the origin of the scene. This is necessary because some joints may have a NULL actor, signifying that they are attached to the world frame.

- getExternalReference() is used by PhysX to report simulation constraints, particularly breakage. The returned pointer is passed to the application in the event callback, along with the typeID which the application can use in order to cast the pointer to the appropriate type. The typeID should be distinct for each custom joint type, and different from any of the values in PxJointConcreteType. If the joint also implements the PxBase interface, use the concrete type ID, PxBase for the typeID.
An articulation is a single actor comprising a set of links (each of which is a rigid body) connected together with special joints. Every articulation has a tree-like structure - so there can be no loops or breaks. Their primary use is modelling physically actuated characters. They support higher mass ratios, more accurate drive models, better dynamic stability and a more robust recovery from joint separation than standard PhysX joints. However, they are considerably more expensive to simulate.

Although articulations do not directly build on joints, they use very similar configuration mechanisms. In this section we assume familiarity with PhysX joints.
Creating an Articulation

To create an articulation, first create the articulation actor without links:

```cpp
PxArticulation* articulation = physics.createArticulation();
```

Then add links one by one, each time specifying a parent link (NULL for the initial link), and the pose of the new link:

```cpp
PxArticulationLink* link = articulation->createLink(parent, linkPose);
PxRigidActorExt::createExclusiveShape(*link, linkGeometry, material);
PxRigidBodyExt::updateMassAndInertia(*link, 1.0f);
```

Articulation links have a restricted subset of the functionality of rigid bodies: they cannot be kinematic, and they do not support damping, velocity clamping, or contact force thresholds. Sleep state and solver iteration counts are properties of the entire articulation rather than the individual links.

Each time a link is created beyond the first, a `PxArticulationJoint` is created between it and its parent. Specify the joint frames for each joint, in exactly the same way as for a `PxJoint`:

```cpp
PxArticulationJoint* joint = link->getInboundJoint();
joint->setParentPose(parentAttachment);
joint->setChildPose(childAttachment);
```

Finally, add the articulation to the scene:

```cpp
scene.addArticulation(articulation);
```
Articulation Joints

The only form of articulation joint currently supported is an anatomical joint, whose properties are similar to D6 joint configured for a typical rag doll. Specifically, the joint is a spherical joint, with angular drive, a twist limit around the child joint frame's x-axis, and an elliptical swing cone limit around the parent joint frame's x-axis. The configuration of these properties is very similar to a D6 or spherical joint, but the options provided are slightly different.

The swing limit is a hard elliptical cone limit which does not support spring or restitution from movement perpendicular to the limit surface. You can set the limit as follows:

```cpp
joint->setSwingLimit(yAngle, zAngle);
```

for the limit angles around y and z. Unlike the PxJoint cone limit the limit provides a tangential spring to limit movement of the axis along the limit surface. Once configured, enable the swing limit:

```cpp
joint->setSwingLimitEnabled(true);
```

The twist limit allows configuration of upper and lower angles:

```cpp
joint->setTwistLimit(lower, upper);
```

and again you must explicitly enable it:

```cpp
joint->setTwistLimitEnabled(true);
```

As usual with joint limits, it is good practice to use a sufficient limit or contactDistance value that the solver will start to enforce the limit before the limit threshold is exceeded.

Articulation joints are not breakable, and it is not possible to retrieve the constraint force applied at the joint.
Driving an Articulation

Articulations are driven through joint acceleration springs. You can set a target, an angular velocity target, and spring and damping parameters to control how strongly the joint drives towards the target. You can also set compliance values to indicate how strongly a joint resists acceleration. A compliance near zero indicates very strong resistance, and a compliance of 1 indicates no resistance.

Articulations are driven in two phases. First the joint spring forces are applied (we use the term *internal* forces for these) and then any *external* forces such as gravity and contact forces. You may supply different compliance values at each joint for each phase.

Note that with joint acceleration springs, the required strength of the spring is estimated using just the mass of the two bodies connected by the joint. By contrast, articulation drive springs account for the masses of all the bodies in the articulation, and any actuation at other joints. This estimation is an iterative process, controlled using the `externalDriveIterations` and `internalDriveIterations` properties of the PxArticulation class.

Instead of setting the target quaternion for the joint drive, it is possible to set the orientation error term directly as a rotation vector. The value is set as the imaginary part of the target quaternion, with the real part set to 0.

```cpp
joint->setDriveType(PxArticulationJointDriveType::eERROR);
joint->setTargetOrientation(PxQuat(error.x, error.y, error.z, 0));
```

This allows the spring to be driven with a larger positional error than can be set by the difference between 2 quaternions. Obtain the same behavior with quaternions by computing the error from the target quaternion, link frames as follows:

```cpp
PxTransform cA2w = parentPose.transform(joint.parentPose);
PxTransform cB2w = childPose.transform(joint.childPose);
transforms.cB2cA = transforms.cA2w.transformInv(transforms.cB2w);
if(transforms.cB2cA.q.w<0)
    transforms.cB2cA.q = -transforms.cB2cA.q;
```
// rotation vector from relative transform to drive pose
PxVec3 error = log(j.targetPosition * cB2cA.q.getConjugate());
Articulation Projection

When any of the joints in an articulation separate beyond a specified threshold, the articulation is projected back together automatically. Projection is an iterative process, and the PxArticulation functions `PxArticulation::setSeparationTolerance()` and `PxArticulation::setMaxProjectionIterations()` control when projection occurs for robustness.
Articulations and Sleeping

Like rigid dynamic objects, articulations are also put into a sleep state below a certain threshold for a period of time. In general, all the pc Sleeping apply to articulations as well. The main difference is that articulations can only go to sleep if each individual articulation link fulfills the sleep criteria.
The further away objects move from the origin, the larger the chance to point precision issues. This can cause troubles especially in scenar worlds. To avoid these problems, a straightforward solution seems to towards the origin in certain intervals. However, this is not only cumber be pretty expensive due to the invalidation of cached data and persister some of these issues, PhysX offers an API to shift the origin of a scene.
Shifting The Scene Origin

The following method will shift the origin of a scene by a translation vector:

```cpp
PxScene::shiftOrigin(const PxVec3& shift)
```

The positions of all objects in the scene and the corresponding data structures will get adjusted to reflect the new origin location (basically, the shift vector will get subtracted from all object positions). The intended use pattern for this API is to shift the origin such that object positions move closer towards zero. Please note that it is the user's responsibility to keep track of the summed total origin shift and adjust input/output to/from PhysX accordingly. Even though this method preserves some internally cached data, it is still an expensive operation and we recommend to use it only in the case where distance related precision issues may arise in areas far from the origin. If extension modules of PhysX are used like the character controller or vehicle library, it may be necessary to propagate the scene shift to those modules as well. Please refer to the documentation of these modules for details.
Introduction

GPU Rigid Bodies is a new feature introduced in PhysX 3.4. It supports the entire rigid body pipeline feature-set but currently does not support articulations. Accelerated rigid bodies can be modified and queried using the exact same API as used to modify and query CPU rigid bodies. GPU rigid bodies can interact with clothing and particles in the same way that CPU rigid bodies can and can easily be integrated with character controllers (CCTs) and vehicles.
Using GPU Rigid Bodies

GPU rigid bodies are no more difficult to use than CPU rigid bodies. GPUs use the exact same API and same classes as CPU rigid bodies. GPU rigid body acceleration is enabled on a per-scene basis. If enabled, all rigid bodies occupying the scene will be processed by the GPU. This feature is implemented in CUDA and requires a Kepler or later compatible GPU. If no compatible device is found, simulation will fall back onto the CPU and corresponding error messages will be provided.

This feature is split into two components: rigid body dynamics and broad phase. It is enabled using PxSceneFlag::eENABLE_GPU_DYNAMICS and PxSceneDesc::broadphaseType to PxBroadPhaseType::eGPU respectively. Properties are immutable properties of the scene. In addition, you must create a context manager and set the GPU dispatcher on the PxSceneDesc. The snippet below demonstrates how to enable GPU rigid body simulation is provided in SnippetHelloGRB.

The code example below serves as a brief reference:

```cpp
PxCudaContextManagerDesc cudaContextManagerDesc;
gCudaContextManager = PxCreateCudaContextManager(*gFoundation, cudaContextManagerDesc);

PxSceneDesc sceneDesc(gPhysics->getTolerancesScale());
sceneDesc.gravity = PxVec3(0.0f, -9.81f, 0.0f);
gDispatcher = PxDefaultCpuDispatcherCreate(4);
sceneDesc.cpuDispatcher = gDispatcher;
sceneDesc.filterShader = PxDefaultSimulationFilterShader;
sceneDesc.gpuDispatcher = gCudaContextManager->getGpuDispatcher();

sceneDesc.flags |= PxSceneFlag::eENABLE_GPU_DYNAMICS;
sceneDesc.broadPhaseType = PxBroadPhaseType::eGPU;

gScene = gPhysics->createScene(sceneDesc);
```

Enabling GPU rigid body dynamics turns on GPU-accelerated contact generation, shape/body management and the GPU-accelerated constraint solver. This accelerates the majority of the discrete rigid body pipeline.
Turning on GPU broad phase replaces the CPU broad phase with a GPU-accelerated broad phase.

Each can be enabled independently so, for example, you may enable GPU broad phase with CPU rigid body dynamics, CPU broad phase (either SAP or MBP) with GPU rigid body dynamics or combine GPU broad phase with GPU rigid body dynamics.
What is GPU accelerated?

The GPU rigid body feature provides GPU-accelerated implementations of:

- Broad Phase
- Contact generation
- Shape and body management
- Constraint solver

All other features are performed on the CPU.

There are several caveats to GPU contact generation. These are as follows:

- GPU contact generation supports only boxes, convex hulls, triangle meshes, and heightfields. Any spheres, capsules or planes will have contact generation involving those shapes processed on the CPU, rather than GPU.
- Convex hulls require PxCookingParam::buildGRBData to be set to true to be required to perform contact generation on the GPU. If a hull with more than 64 vertices or more than 32 vertices per-face is used, it will be processed on the CPU. If the PxConvexFlag::eGPU_COMPATIBLE flag is used when the convex hull is created, the limits are applied to ensure the resulting hull can be used on GPU.
- Triangle meshes require PxCookingParam::buildGRBData to be set to true to build data required to process the mesh on the GPU. If this flag is not set during cooking, the GPU data for the mesh will be absent and any contact generation involving this mesh will be processed on CPU.
- Any pairs requesting contact modification will be processed on the CPU.
- PxSceneFlag::eENABLE_PCM must be enabled for GPU contact generation to be performed. This is the only form of contact generation implemented on the GPU. If eENABLE_PCM is not raised, contact generation will be performed for all pairs using the non distance-based legacy contact generation.
Irrespective of whether contact generation for a given pair is processed on CPU or GPU, the GPU solver will process all pairs with contacts that request collision response in their filter shader.

As mentioned above, GPU rigid bodies currently do not support articulations. If eENABLE_GPU_DYNAMICS is enabled on the scene, any attempts to add an articulation to the scene will result in an error message being displayed and the articulation will not be added to the scene.

The GPU rigid body solver provides full support for joints and contacts. Best performance is achieved using D6 joints because D6 joints are natively supported on the GPU, i.e. the full solver pipeline from prep to solve is implemented on the GPU. Other joint types are supported by the GPU solver but their joint shaders are run on the CPU, which will incur some additional host-side performance overhead compared to D6 joints.
Tuning

Unlike CPU PhysX, the GPU rigid bodies feature is not able to dy buffers. Therefore, it is necessary to provide some fixed buffer sizes body feature. If insufficient memory is available, the system will is discard contacts/constraints/pairs, which means that behavior may be adverse. The following buffers are adjustable in PxSceneDesc::gpuDynamicsCor

```c
struct PxnDynamicsMemoryConfig
{
    PxU32 constraintBufferCapacity; ///< Capacity of constraint buffer allocated in GPU global memory
    PxU32 contactBufferCapacity;   ///< Capacity of contact buffer allocated in GPU global memory
    PxU32 tempBufferCapacity;      ///< Capacity of temp buffer allocated in pinned host memory.
    PxU32 contactStreamCapacity;   ///< Capacity of contact stream buffer allocated in pinned host memory.
    PxU32 patchStreamCapacity;     ///< Capacity of the contact patch stream buffer allocated in pinned host memory.
    PxU32 forceStreamCapacity;     ///< Capacity of force buffer allocated in pinned host memory.
    PxU32 heapCapacity;            ///< Initial capacity of the GPU and pinned host memory heap.
    PxU32 foundLostPairsCapacity;  ///< Capacity of found and lost buffers allocated in GPU global memory.

    PxnDynamicsMemoryConfig() :
        constraintBufferCapacity(32 * 1024 * 1024),
        contactBufferCapacity(24 * 1024 * 1024),
        tempBufferCapacity(16 * 1024 * 1024),
        contactStreamCapacity(6 * 1024 * 1024),
        patchStreamCapacity(5 * 1024 * 1024),
        forceStreamCapacity(1 * 1024 * 1024),
        heapCapacity(64 * 1024 * 1024),
        foundLostPairsCapacity(256 * 1024)
    {
    }
};
```

The default values are generally sufficient for scenes simulating approximately 10,000 rigid bodies.

- `constraintBufferCapacity` defines the total amount of memory that can be occupied by constraints in the solver. If more memory is required, a warning is issued and no further constraints will be created.
- **contactBufferCapacity** defines the size of a temporary contact constraint solver. If more memory is required, a warning is issued and dropped.
- **tempBufferCapacity** defines the size of a buffer used for miscellaneous transient memory allocations used in the constraint solver.
- **contactStreamCapacity** defines the size of a buffer used to store contact stream. This data is allocated in pinned host memory and if insufficient memory is allocated, a warning will be issued and dropped.
- **patchStreamCapacity** defines the size of a buffer used to store contact patches in the contact stream. This data is allocated in pinned host memory and if insufficient memory is allocated, a warning will be issued and dropped.
- **forceStreamCapacity** defines the size of a buffer used to report applied contact forces to the user. This data is allocated in pinned host memory. If insufficient memory is allocated, a warning will be issued and contacts will be dropped.
- **heapCapacity** defines the initial size of the GPU and pinned host memory. Additional memory will be allocated if more memory is required. The cost of physically allocating memory can be relatively high so a custom heap allocator is used to reduce these costs.
- **foundLostPairsCapacity** defines the maximum number of found or lost pairs that the GPU broad phase can produce in a single frame. This does not limit the number of pairs but only limits the number of new or lost pairs that can be detected in a frame. If more pairs are detected or lost in a frame, an error is emitted and pairs will be dropped by the broad phase.
Performance Considerations

GPU rigid bodies can provide extremely large performance advantages over CPU rigid bodies in scenes with several thousand active rigid bodies. However, there are some performance considerations to be taken into account.

GPU rigid bodies currently only accelerate contact generation involving boxes (against convex hulls, boxes, triangle meshes and heighfields). If you make heavy use of other shapes, e.g. capsules or spheres, contact generation involving these shapes will only be processed on CPU.

D6 joints will provide best performance when used with GPU rigid bodies. Other joint types will be partially GPU-accelerated but the performance advantages will be less than the performance advantage exhibited by D6 joints.

Convex hulls with more than 64 vertices or with more than 32 vertices per-face will have their contacts processed by the CPU rather than the GPU, so, if possible, keep vertex counts within these limits. Vertex limits can be defined in cooking to ensure that cooked convex hulls do not exceed these limits.

If your application makes heavy use of contact modification, this may limit the number of pairs that have contact generation performed on the GPU.

Modifying the state of actors forces data to be re-synced to the GPU; actors must be updated if the application adjusts global pose, velocities etc. The associated cost to the GPU is relatively low but it should be taken into consideration.

Features such as joint projection, CCD and triggers are not GPU accelerated and are still processed on the CPU.
Introduction

This chapter describes how to use PhysX' collision functionality with individual geometry objects. There are four main kinds of geometry queries:

- raycasts ("raycast queries") test a ray against a geometry object.
- sweeps ("sweep queries") move one geometry object along a line to find the first point of intersection with another geometry object.
- overlaps ("overlap queries") determine whether two geometry objects intersect.
- penetration depth computations ("minimal translational distance queries", abbreviated here to "MTD") test two overlapping geometry objects to find the direction along which they can be separated by the minimum distance.

In addition, PhysX provides helpers to compute the AABB of a geometry object and to compute the distance between a point and a geometry object.

In all of the following functions, a geometry object is defined by its shape (a structure) and its pose (a PxTransform structure). All transforms are interpreted as being in the same space, and the results are also returned in that space.
Raycasts

A raycast query traces a point along a line segment until it hits a geometry object. PhysX supports raycasts for all geometry types.

The following code illustrates how to use a raycast query:

```cpp
PxRaycastHit hitInfo;
PxU32 maxHits = 1;
PxHitFlags hitFlags = PxHitFlag::ePOSITION | PxHitFlag::eNORMAL | PxHitFlag::eALL;
PxU32 hitCount = PxGeometryQuery::raycast(origin, unitDir, geom, pose, maxDist, hitFlags, maxHits, &hitInfo);
```

The arguments are interpreted as follows:

- `origin` is the start point of the ray.
- `unitDir` is a unit vector defining the direction of the ray.
- `maxDist` is the maximum distance to search along the ray. It must be in the `[0, inf)` range. If the maximum distance is 0, a hit will only be returned if the ray starts inside a shape, as detailed below for each geometry.
- **geom** is the geometry to test against.
- **pose** is the pose of the geometry.
- **hitFlags** specifies the values that should be returned by the query processing the query.
- **maxHits** is the maximum number of hits to return.
- **hitInfo** specifies the **PxRaycastHit** structure(s) into which the raycast results will be stored.
- The **anyHit** parameter is deprecated. It is equivalent to **PxHitFlag::eMESH_ANY** which should be used instead.

The returned result is the number of intersections found. For each **PxRaycastHit** is populated. The fields of this structure are as follows:

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PxRigidActor*</td>
<td>actor;</td>
</tr>
<tr>
<td>PxShape*</td>
<td>shape;</td>
</tr>
<tr>
<td>PxVec3</td>
<td>position;</td>
</tr>
<tr>
<td>PxVec3</td>
<td>normal;</td>
</tr>
<tr>
<td>PxF32</td>
<td>distance;</td>
</tr>
<tr>
<td>PxHitFlags</td>
<td>flags;</td>
</tr>
<tr>
<td>PxU32</td>
<td>faceIndex;</td>
</tr>
<tr>
<td>PxF32</td>
<td>u, v;</td>
</tr>
</tbody>
</table>

Some fields are optional, and the flags field indicates which members have result values. The query will fill fields in the output structure if the corresponding flag is set in the input - for example, if the **PxHitFlag::ePOSITION** is set in the input, the query will fill in the **PxRaycastHit::position** field, and set the **PxHitFlag::PxRaycastHit::flags**. If the input flag is not set for a specific member, the corresponding field in the output structure may or may not contain valid data for that member. Omitting the **ePOSITION** flags in the input can sometimes result in faster queries.

For a raycast which is not initially intersecting the geometry object, the fields are filled as follows (optional fields are listed together with the flag that controls their filling):

- **actor** and **shape** are not filled (these fields are used only in scene-level raycasts).
• position (PxHitFlag::ePOSITION) is the position of the intersection.
• normal (PxHitFlag::eNORMAL) is the surface normal at the point of
• distance (PxHitFlag::eDISTANCE) is the distance along the
interception was found.
• flags specifies which fields of the structure are valid.
• faceIndex is the index of the face which the ray hit. For triangle m e
interceptions, it is a triangle index. For convex mesh intersections,
index. For other shapes it is always set to 0xffffffff.
• u and v (PxHitFlag::eUV) are the barycentric coordinates of the i
fields (and the flag) are supported only for meshes and heightfields

The position field is related to the barycentric coordinates via the follow
v0, v1 and v2 are the vertices from the hit triangle:

position = (1 - u - v)*v0 + u*v1 + v*v2;

This mapping is implemented in PxTriangle::pointFromUV().

See Geometry for details of how to retrieve face and vertex data from
convex meshes and height fields using face and vertex indices.

Exceptions to the above behavior may apply if a ray starts inside an object:
PhysX may not be able to compute meaningful output values for some
cases the field will remain unmodified and the corresponding flag will not
be set. Specific details vary by geometry type, and are described below.

The exact conditions for raycast intersections are as follows:

Raycasts against Spheres, Capsules, Boxes and Convex

For solid objects (sphere, capsule, box, convex) at most 1 result is
origin is inside a solid object:

• the reported hit distance is set to zero, and the PxHitFlag::eDIST
the output.

- the hit normal is set to be the opposite of the ray's
  
  `PxHitFlag::eNORMAL` flag is set in the output.

- the hit impact position is set to the ray's origin and the `PxHitFlag::ePOSITION`
  set in the output.

If the start or end point of a ray is very close to the surface of the object, it may be treated as being on either side of the surface.

### Raycasts against Planes

For raycasts, a plane is treated as an infinite single-sided quad that includes its boundary (note that this is not the same as for overlaps). At most one result is returned: if the ray origin is behind the plane's surface, no hit will be reported even if the ray intersects the plane.

If the start or end point of a ray is very close to the plane, it may be treated as being on either side of the plane.

### Raycasts against Triangle Meshes

Triangle meshes are treated as thin triangle surfaces rather than solid objects. They may be configured to return either an arbitrary hit, the closest hit, or multiple hits:

- if maxHits is 1 and `PxHitFlag::eMESH_ANY` is not set, the query will return the closest intersection.
- if maxHits is 1 and `PxHitFlag::eMESH_ANY` is set, the query will return an arbitrary intersection. Use this when it is sufficient to know whether or not the ray hits the mesh, e.g. for line-of-sight queries or shadow rays.
- if maxHits is greater than 1, the query will return multiple intersections. If more than maxHits intersection points exist, there is no guarantee that the results will include the closest. Use this for e.g. wall-piercing bullets that hit multiple triangles, or where special filtering is required. Note that `PxHitFlag::eMESH_MULTIPLE`
be used in this case.

In general "any hit" queries are faster than "closest hit" queries, and "closest hit" queries are faster than "multiple hits" queries.

By default, back face hits (where the triangle's outward-facing normal product with the ray direction) are culled, and so for any triangle hit the reported normal will have a negative dot product with the ray direction. This behavior is controlled by the mesh instance's `PxMeshGeometryFlag::eDOUBLE_SIDED` flag and the query's `PxHitFlag::eMESH_BOTH_SIDES` flag:

- if either `PxMeshGeometryFlag::eDOUBLE_SIDED` or `PxHitFlag::eMESH_BOTH_SIDES` is set, culling is disabled.
- if `PxMeshGeometryFlag::eDOUBLE_SIDED` is set, the reported normal is reversed for a back face hit.

For example a transparent glass window could be modeled as a double-sided mesh that a ray would hit either side with the reported normal facing opposite to the ray direction. A raycast tracing the path of a bullet that may penetrate the front face and emerge from the back could use `eMESH_BOTH_SIDES` to find both facing triangles even when the mesh is single-sided.

The following diagram shows what happens with different flags, for a single raycast intersecting a mesh in several places.
To use `PxHitFlag::eMESH_BOTH_SIDES` for selected meshes rather than all, set the flag inside the `PxQueryFilterCallback`.

If the start or end point of a ray is very close to the surface of a triangle, it may be treated as being on either side of the triangle.

If the start or end point of a ray is very close to the surface of a triangle, it may be treated as being on the either side of the triangle.

**Raycasts against Heightfields**

- Heightfields are treated the same way as triangle meshes with normals oriented (in shape space) in +y direction when thickness is <=0 and in -y direction when thickness is >0.
- Double-sided heightfields are treated the same way as double sided triangle meshes.
Overlaps

Overlap queries simply check whether two geometry objects overlap. One of the geometries must be a box, sphere, capsule or convex, and the other may be of any type.

The following code illustrates how to use an overlap query:

```cpp
bool isOverlapping = overlap(geom0, pose0, geom1, pose1);
```

Overlaps do not support hit flags and return only a boolean result.

- A plane is treated as a solid half-space: that is, everything behind it is considered part of the volume.
- Triangle meshes are treated as thin triangle surfaces rather than solid objects.
- Heightfields are treated as triangle surface extruded by their thickness. Overlap geometries that do not intersect with the heightfield surface but are within the extruded space will report a hit.

If more than a boolean result is needed for meshes and heightfields, use the `PxMeshQuery` API instead (see `PxMeshQuery`).
Penetration Depth

When two objects are intersecting, PhysX can compute the minimal distance by which the objects must be translated to separate them (this quantity is sometimes referred to as MTD, for *minimum translational distance*, as it is the vector by which translation will separate the shapes). One geometry object must be a box, sphere, capsule or convex mesh, and the other may be of any type.

The following code illustrates how to use a penetration depth query:

```cpp
bool isPenetrating = PxGeometryQuery::computePenetration(direction geom0, pose0, geom1, pose1);
```

The arguments are interpreted as follows:

- *direction* is set to the direction in which the first object should be translated to depenetrate from the second.
- *distance* is set to the distance by which the first object should be translated to depenetrate from the second.
• *geom0* is the first geometry.
• *pose0* is the transform of the first geometry.
• *geom1* is the second geometry.
• *pose2* is the transform of the second geometry.

The function returns true if the objects are penetrating, in which case it sets the direction and depth fields. Translating the first object by the depenetration vector will separate the two objects. If the function returns true, the values of the direction and distance fields are undefined.

For simple (convex) shapes, returned results are accurate.

For meshes and heightfields, an iterative algorithm is used and dedicated functions are exposed in *PxExtensions*:

```cpp
PxVec3 direction = PxComputeMeshPenetration(direction, depth, geom, geomPose, meshGeom, meshPose, maxIter, nb);
PxVec3 direction = PxComputeHeightFieldPenetration(direction, depth, geom, geomPose, heightFieldGeom, maxIter, nb);
```

Here, *maxIter* is the maximum number of iterations for the algorithm, and *nb* is the output argument which will be set to the number of iterations performed. If no overlap is detected, *nb* is set to zero. The code will attempt at most *maxIter* iterations but may exit earlier if a depenetration vector is found. Usually *maxIter* = 4 gives good results.

These functions only compute an approximate depenetration vector, and if the amount of overlap between the geometry object and the mesh/heightfield is small, in particular, an intersection with a triangle will be ignored when the object is in front of the triangle, and if this holds for all intersecting triangles then no overlap is detected and the functions do not compute an MTD vector.
A sweep query traces one geometry object through space to find the second geometry object, and reports information concerning the impact found. PhysX only supports sweep queries where the first geometry object (the one that is traced through space) is a sphere, box, capsule or convex geometry object may be of any type.

The following code illustrates how to use a sweep query:

```cpp
PxSweepHit hitInfo;
PxHitFlags hitFlags = PxHitFlag::ePOSITION|PxHitFlag::eNORMAL|PxHitFlag::eNORMAL;
PxReal inflation = 0.0f;
PxU32 hitCount = PxGeometryQuery::sweep(unitDir, maxDist, geomToSweep, poseToSweep, geomSweptAgainst, poseSweptAgainst, hitInfo, hitFlags, inflation);
```
• **unitDir** is a unit vector defining the direction of the sweep.
• **maxDist** is the maximum distance to search along the sweep. It must be in the range, and is clamped by SDK code to at most `PX_MAX_SWE` sweep of length 0 is equivalent to an overlap check.
• **geomToSweep** is the geometry to sweep. Supported geometries are capsule or convex mesh.
• **poseToSweep** is the initial pose of the geometry to sweep.
• **geomSweptAgainst** is the geometry to sweep against (any geometry can be used here).
• **poseSweptAgainst** is the pose of the geometry to sweep against.
• **hitInfo** is the returned result. A sweep will return at most one hit.
• **hitFlags** determines how the sweep is processed, and which data is returned if an impact is found.
• **inflation** inflates the first geometry with a shell extending outward from the object surface, making any corners rounded. It can be used to ensure a minimum margin of space is kept around the geometry when using sweeps to test whether movement is possible.

As with raycasts, fields will be filled in the output structure if the corresponding flags were set in the input hitFlags. The fields of `PxSweepHit` are as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>PxRigidActor*</code></td>
<td>actor;</td>
</tr>
<tr>
<td><code>PxShape*</code></td>
<td>shape;</td>
</tr>
<tr>
<td><code>PxVec3</code></td>
<td>position;</td>
</tr>
<tr>
<td><code>PxVec3</code></td>
<td>normal;</td>
</tr>
<tr>
<td><code>PxF32</code></td>
<td>distance;</td>
</tr>
<tr>
<td><code>PxHitFlags</code></td>
<td>flags;</td>
</tr>
<tr>
<td><code>PxU32</code></td>
<td>faceIndex;</td>
</tr>
</tbody>
</table>

• **actor** and **shape** are not filled (these fields are used only in scene
  *Scene Queries*).
• **position** (` PxHitFlag::ePOSITION`) is the position of the intersecting multiple impact points, such as two boxes meeting face-to-face, PhysX would select one.
point arbitrarily. More detailed information for meshes or height field using the functions in \textit{PxMeshQuery}.

- \textit{normal} (\texttt{PxHitFlag::eNORMAL}) is the surface normal at the point of impact, pointing outwards from the hit object and backwards along the sweep direction (in the sense that the dot product between the sweep direction and the impact normal is negative).
- \textit{distance} (\texttt{PxHitFlag::eDISTANCE}) is the distance along the intersection was found.
- \textit{flags} specifies which fields of the structure are valid.
- \textit{faceIndex} is the index of the face hit by the sweep. This is a face index from the hit object, not from the swept object. For triangle mesh and height field intersections it is a triangle index. For convex mesh intersections it is a polygon index. For other shapes it is always set to 0xffffffff. For convex meshes the face index computation is expensive. The face index computation can be disabled by not providing the query hit flag \texttt{PxHitFlag::eFACE_INDEX}. If needed the face index can also be computed externally using the function \texttt{PxFindFaceIndex} which is part of the PhysX extensions library.

Unlike raycasts, \(u,v\) coordinates are not supported for sweeps.

For the geometry object swept against:

- A plane is treated as a solid half-space: that is, everything behind the plane is considered part of the volume to sweep against.
- The same backface-culling rules as for raycasts apply for sweeps with the notable difference that \texttt{eMESH_MULTIPLE} is not supported.

\textbf{Initial Overlaps}

Similarly to a raycast starting inside an object, a sweep may start with the swept object initially intersecting. By default PhysX will detect and report \texttt{PxSweepHit::hadInitialOverlap()} to see if the hit was generated by an intersection.
For triangle meshes and height fields, backface culling is performed before overlap checks, and thus no initial overlap is reported if a triangle is culled.

Depending on the value of \texttt{PxHitFlag::eMTD}, PhysX may also calculate \texttt{PxHitFlag::eMTD} is not set:

- the distance is set to zero, and the \texttt{PxHitFlag::eDISTANCE} flag is set in the \texttt{PxSweepHit} result structure.
- the normal is set to be the opposite of the sweep direction, and the \texttt{PxHitFlag::eNORMAL} flag is set in the \texttt{PxSweepHit} result structure.
- the position is undefined, and the \texttt{PxHitFlag::ePOSITION} flag is set in the \texttt{PxSweepHit} result structure.
- the face index is a face from the second geometry object. For a heightfield, it is the index of the first overlapping triangle found. For other geometry types, the index is set to 0xffffffff.

If \texttt{PxHitFlag::eMTD} is set, the hit results are defined as follows:

- the distance is set to the penetration depth, and the \texttt{PxHitFlag::eDISTANCE} flag is set in the \texttt{PxSweepHit} result structure.
- the normal is set to the depenetration direction, and the \texttt{PxHitFlag::eNORMAL} flag is set in the \texttt{PxSweepHit} result structure.
- the position is a point on the sweep geometry object (i.e. the first geometry object), and the \texttt{PxHitFlag::ePOSITION} flag is set in the \texttt{PxSweepHit} result structure.
- the face index is a face from the second geometry object:
  - For triangle meshes and heightfields it is the last penetrated triangle.
  - The last iteration of the depenetration algorithm.
  - For other geometry types, the index is set to 0xffffffff.

This flag will incur additional processing overhead in the case of an initial overlap. In addition, the following restrictions apply:
• \textit{PxHitFlag::eMTD} is incompatible with \textit{PxHitFlag::ePRECISE}\textit{\_\_\_SWEEP} \textit{PxHitFlag::eASSUME\_NO\_INITIAL\_OVERLAP} (see below). Using in conjunction with either of these flags will result in a warning being issued, and the flag(s) that are incompatible with \textit{PxHitFlag::eMTD} being ignored.

Testing for initial overlaps sometimes uses a specialized code path at a performance penalty. If it is possible to guarantee that geometry objects are not overlapping, the check for overlaps can be suppressed with \textit{PxHitFlag::eASSUME\_NO\_INITIAL\_OVERLAP}. There are some restrictions on the use of this flag (also, see \textit{Pitfalls}).

• Using \textit{PxHitFlag::eASSUME\_NO\_INITIAL\_OVERLAP} flag when the geometries initially overlap produces undefined behavior.

• \textit{PxHitFlag::eASSUME\_NO\_INITIAL\_OVERLAP} in combination with zero sweep distance produces a warning and undefined behavior.

\textbf{Note:} sweeps with \textit{PxHitFlag::eMTD} use two kinds of backface culling. First, the triangles are culled based on sweep direction to determine whether there is an overlap. If an overlap is detected, they are further culled by whether the centroid is behind the triangle, and if no triangles are found, the direction will be set opposite to the sweep direction and the distance to 0.

\textbf{Note:} in most cases, translating the first geometry object by `-normal\_distance` will separate the objects. However, an iterative depenetration algorithm is used for MTD for triangle meshes and height fields, and the MTD result may not provide complete depenetration from the mesh in extreme cases. In this case the query should be called a second time after the translation has been applied.

\textbf{Note:} a known issue in PhysX 3.3 is that the face index for a sweep against a mesh is undefined when the eMTD flag is not set.

\textit{Precise Sweeps}
PxHitFlag::ePRECISE_SWEEP enables more accurate sweep code (by default a potentially faster but less accurate solution is used). The ePRECISE_Sweep flag is compatible with the inflation parameter, or with the flag PxHitFlag::eMTI

**Sweeps against Height Fields**

- Height fields are treated as thin triangle surfaces rather than solid objects.
- Thickness magnitude has no effect on initial overlap detection or point of impact.
- For single-sided height fields the normal of the hit will face in +y local space direction if thickness is < 0 and -y when thickness is > 0.
- Height fields are treated as double sided if either one of eDOUBLE_SIDED and eMESH_BOTH_SIDES flags are used.
  - The returned hit normal will always face the sweep direction.
- eMESH_ANY flag has no effect.
- ePRECISE_Sweep flag has no effect.

**Pitfalls**

There are some pitfalls to be aware of when using sweeps:

- Due to numerical precision issues, incorrect results may be returned for objects having very large size disparities.
- Due to algorithmic differences, a sweep query may detect a different set of overlapping shapes than an overlap query. In particular, it is not sufficient to perform an overlap check in order to determine the PxHitFlag::eIGNORE_INITIAL_OVERLAP flag. Applications that need consistent overlap/sweep/penetration depth information should use sweep
overlap testing and the \textit{PxHitFlag::eMTD} flag.
The following function computes the distance between a point and a geometry object. Only solid objects (box, sphere, capsule, convex) are supported:

```cpp
PxReal dist = PxGeometryQuery::pointDistance(point, geom, pose, closestPoint);
```

`closestPoint` is an optional output argument which returns the closest point.

The following function computes the axis-aligned bounding box (AABB) of a geometry object, given its pose:
The bounding box is scaled by the *inflation* value, which defaults to 1 specified.
PxMeshQuery

PhysX provides additional functionality for obtaining multiple results for height field overlaps, and for sweeping against arrays of triangles. Only boxes, spheres, and capsules may be tested against meshes or heightfields using these functions.

Mesh Overlaps

The following code illustrates how to process the mesh triangles that overlap a given spherical volume:

```cpp
PxU32 triangleIndexBuffer[bufferSize];
PxU32 startIndex = 0;
bool bufferOverflowOccured = false;
PxU32 nbTriangles = PxMeshQuery::findOverlapTriangleMesh(sphereGeom, meshGeom, triangleIndexBuffer, startIndex);
for(PxU32 i=0; i < nbTriangles; i++)
{
    PxTriangle tri;
    PxU32 vertexIndices[3];
    PxMeshQuery::getTriangle(meshGeom, meshPose, triangleIndexBuffer, startIndex, i, tri, vertexIndices);
    // process triangle info
}
```

The `findOverlapTriangleMesh` method is used to extract the indices of the triangles:

- `sphereGeom` and `spherePose` specify the region to test for overlap.
- `meshGeom` and `meshPose` specify the mesh and its pose.
- `triangleIndexBuffer` and `triangleSize` specify the output buffer and its size.
- `startIndex` is used to restart the query if the buffer size is exceeded.
- `bufferOverflowOccured` is set if more triangles would be returned for the query.
would fit in the buffer.

Similar query functionality exists for height fields.

**Sweeps against Triangles**

Sometimes, for example, when using the mesh overlap API, it is convenient to sweep against groups of triangles. PhysX provides a function specifically with the following signature:

```cpp
bool sweep(const PxVec3& unitDir,
            const PxReal distance,
            const PxGeometry& geom,
            const PxTransform& pose,
            PxU32 triangleCount,
            const PxTriangle* triangles,
            PxSweepHit& sweepHit,
            PxHitFlags hitFlags = PxHitFlag::eDEFAULT,
            const PxU32* cachedIndex = NULL,
            const PxReal inflation = 0.0f,
            bool doubleSided = false);
```

The arguments are interpreted as follows:

- `unitDir`, `distance`, `geom` and `pose` function identically to the first four parameters of `PxGeometryQuery::sweep()`. `distance` is clamped to `PX_MAX_SWEEP_DISTANCE`.
- `triangleCount` is the number of triangles contained in the buffer against which to sweep.
- `triangles` is the buffer of triangles.
- `hitFlags` specifies the required information in the output.
- `cachedIndex`, if set, specifies the index of a triangle to test first. This can be a useful optimization when repeatedly sweeping against the same set of triangles.
- `inflation` functions identically to the inflation parameter of `PxGeometryQuery::sweep()`.
- `doubleSided` indicates whether the input triangles are double-sided or not. This is equivalent to the `PxMeshGeometryFlag::eDOUBLE_SIDED` flag, which suppresses backface culling, and for any hit the returned normal faces opposite to the.
sweep direction (see *Raycasts against Triangle Meshes*).

This function has extra limitations compared to the other sweep queries:

- the geometry type must be either a sphere, a capsule or a box. Convex geometry is not supported.
- the function returns a single hit. Multiple hits (ar PxHitFlag::eMESH_MULTIPLE) are not supported.
- The function always returns the closest hit.
- The only supported flags are PxHitFlag::eDEFAULT, PxHitFlag::eASSUME_NO_INITIAL_OVERLAP, PxHitFlag::eMESH_BOTH_SIDES and PxHitFlag::eMESH_ANY.

The function tests each input triangle in the order they are given. By default, it will test all triangles and return the closest sweep hit (if a hit has been found). If PxHitFlag::eMESH_ANY is used, the function will return as soon as a hit is found (skipping the remaining untested triangles). This flag can also be used to emulate PxHitFlag::eMESH_MULTIPLE, by calling the function PxHitFlag::eMESH_ANY, using as a starting point the previously returned hit (whose index, between 0 and 'triangleCount', is available in sweepHit.faceIndex).
Applications commonly need to efficiently query volumes in space or trace objects through space to determine what might be there. PhysX supports this, one for objects already in a scene, and one for querying against AABBs. The scene query system is discussed in *Scene Queries*. 
PxSpatialIndex

PxSpatialIndex is a BVH data structure that allows spatial queries to be performed without the need to instantiate a PxScene. It supports insertion, removal and updating of objects defining a bounding box, and raycasts, sweeps, and overlap queries against those bounds.

Spatial index has been marked as deprecated in 3.4 and will be removed in future releases.

SnippetSpatialIndex shows an example of how to use this class.

PxSpatialIndex has no internal locking, and there are special considerations when using it from multiple threads. Query operations (marked const in the interface) in parallel with update (non-const) operations, or update operations in parallel, are not allowed. When issuing query operations in parallel, it is important to be aware that PxSpatialIndex defers some updates to its internal data structures until a query is issued. In a single-threaded context this does not affect correctness or safety, but from multiple threads simultaneously the internal updates may cause order to avoid these, call the flush() method to force the updates immediately. Between a call to flushUpdates() and any subsequent queries may be safely issued in parallel.

A query against a PxSpatialIndex structure will result in a callback for the query, allowing filtering or precise intersection as desired. The PxGeometryQuery class can be used to perform these intersection tests. Results will typically be in approximately sorted order, and when looking for the closest object in a raycast or sweep query against PxSpatialIndex, a useful optimization is to clip the length of the query inside the callback. For example, in SnippetSpatialIndex:

```cpp
PxAgain onHit(PxSpatialIndexItem& item, PxReal distance, PxReal& distance) {
    PX_UNUSED(distance);
    Sphere& s = static_cast<Sphere&>(item);
    PxRaycastHit hitData;
```
// the ray hit the sphere's AABB, now we do a ray-sphere intersection
// the ray hit the sphere

PxU32 hit = PxGeometryQuery::raycast(position, direction,
  PxSphereGeometry(s.radius, 1e6, PxHitFlag::eDEFAULT, 1, &hitData));

// if the raycast hit and it's closer than what we had before of the raycast
if (hit && hitData.distance < closest)
{
  closest = hitData.distance;
  hitSphere = &s;
  shrunkDistance = hitData.distance;
}

// and continue the query
return true;
Introduction

PhysX provides methods in PxScene to perform collision queries against attached shapes in the scene. There are three types of queries: raycasts, sweeps, and overlaps, and each can return either a single result, or multiple results. Each query traverses a culling structure containing the scene objects, performs a precise test using the GeometryQuery functions (see Geometry Queries), and accumulates the results. Filtering may occur before or after precise testing.

The scene uses two different query structures, one for PxRigidStatic actors and the other for PxRigidBody actors (PxRigidDynamic and PxArticulationLink.) These structures can be configured to use different culling implementations depending on the speed/space characteristics (see PxPruningStructureType.)
Basic queries

Raycasts

A `PxScene::raycast()` query intersects a user-defined ray with the simplest use case for a raycast() query is to find the closest hit along a given ray as follows:

```cpp
PxScene* scene;
PxVec3 origin = ...; // [in] Ray origin
PxVec3 unitDir = ...; // [in] Normalized ray direction
PxReal maxDistance = ...; // [in] Raycast max distance
PxRaycastBuffer hit; // [out] Raycast results

// Raycast against all static & dynamic objects (no filtering)
// The main result from this call is the closest hit, stored in the hit structure
bool status = scene->raycast(origin, unitDir, maxDistance, hit);
if (status)
    applyDamage(hit.block.position, hit.block.normal);
```

In this code snippet a PxRaycastBuffer object is used to receive results of a raycast query. A call to raycast() returns true if there was a hit. hit.hadBlock is true if there was a hit. The distance for raycasts has to be in the [0, inf) range.

Raycasts results include position, normal, hit distance, shape and actor with UV coordinates for triangle meshes and heightfields. Before using a PxHitFlag::ePOSITION, eNORMAL, eDISTANCE, eUV flags first, as in some cases they are not set.

Sweeps

A `PxScene::sweep()` query is geometrically similar to a raycast(): a PxGeometry shape is swept from a specified initial pose in a direction `unitDir` with specified maximum length to find the points of impacts of the geometry with scene objects. The maximum length for sweeps has to be in the [0, inf) range, and will be...
PX_MAX_SWEEP_DISTANCE, defined in file PxScene.h.

Allowed shapes are box, sphere, capsule and convex.

A PxSweepBuffer object is used to receive results from sweep() queries

```cpp
PxSweepBuffer hit; // [out] Sweep results
PxGeometry sweepShape = ...; // [in] swept shape
PxTransform initialPose = ...; // [in] initial shape pose (at di
PxVec3 sweepDirection = ...; // [in] normalized sweep directio
bool status = scene->sweep(sweepShape, initialPose, sweepDirectio
```

Sweeps results include position, normal, hit distance, shape and actor for triangle meshes and heightfields.

### Overlaps

**PxScene::overlap()** query searches a region enclosed by a specific overlapping objects in the scene. The region is specified as a transformed box, capsule or convex geometry.

A PxOverlapBuffer object is used to receive results from overlap() queries

```cpp
PxOverlapBuffer hit; // [out] Overlap results
PxGeometry overlapShape = ...; // [in] shape to test for overlap
PxTransform shapePose = ...; // [in] initial shape pose (at di
```

Overlaps results only include actor/shape and faceIndex since there is no intersection.
Touching and blocking hits

For queries with multiple results we distinguish between touching and blocking. The choice of whether a hit is touching or blocking is made by the user-implemented logic. Intuitively a blocking hit prevents further progress of a raycast or path, and a touching hit is recorded but allows the ray or sweep to continue. So a multiple-hit query will return the closest blocking hit if one exists, together with any touching hits that are closer. If there are no blocking hits, all touching hits will be returned.

See the Filtering section for details.
Query modes

**Closest hit**

The default mode of operation for all three query types is "closest hit". All blocking hits, picks the one with the minimum distance and PNotifyBuffer::block member.

- For overlap() queries an arbitrary blocking hit is chosen as the reported blocking hit (distance is treated as zero for all overlap() hits).

**Any hit**

All three query types can operate in "any hit" mode. This is a performance hint to the query system indicating that there is no need to look for the closest hit encountered will do. This mode is most often used for boolean block queries. Performance improvement may be a factor of 3 or more, depending on scenario.

To activate this mode use PxQueryFlag::eANY_HIT filter data flag PxQueryFilterData object, for instance:

```cpp
PxQueryFilterData fd;
fd.flags |= PxQueryFlag::eANY_HIT; // note the OR with the default
bool status = scene->raycast(origin, unitDir, maxDistance, hit, PxHitFlags(PxHitFlag::eDEFAULT), fdAny
```

**Multiple hits**

All three query types (raycast, overlap, sweep) can also report multiple hits with objects in the scene.

- To activate this mode for raycasts use the PxRaycastBuffer constructor provided buffer for touching hits.
- In this mode all hits default to 'touching' type and are
PxRaycastBuffer::touches array.

For instance:

```cpp
PxScene* scene;
PxVec3 origin = ...; // [in] Ray origin
PxVec3 unitDir = ...; // [in] Normalized ray direc
PxReal maxDistance = ...; // [in] Raycast max distance

const PxU32 bufferSize = 256; // [in] size of 'hitBuffer'
PxRaycastHit hitBuffer[bufferSize]; // [out] User provided buffe
PxRaycastBuffer buf(hitBuffer, bufferSize); // [out] Blocking and

// Raycast against all static & dynamic objects (no filtering)
// The main result from this call are all hits along the ray, sto
scene->raycast(origin, unitDir, maxDistance, buf);
for (PxU32 i = 0; i < buf.nbTouches; i++)
    animateLeaves(buf.touches[i]);
```

The same mechanism is used for overlaps (use PxOverlapBuffer with PxOverlapHit[]) and sweeps (PxSweepBuffer with PxSweepHit[]).

**Multiple hits with blocking hit**

In the snippet for multiple hits above we only expected touching hits. If encountered along with touching hits, it will be reported in PxHitBuffer:: the touch buffer will contain only touching hits which are closer. This can in scenarios such as bullets going through windows (breaking them on t of a tree (making them rustle) until they hit a blocking object (a concrete

```cpp
// same initialization code as in the snippet for multiple hits
bool hadBlockingHit = scene->raycast(origin, unitDir, maxDistance
if (hadBlockingHit)
    drawWallDecal(buf.block);
for (PxU32 i = 0; i < buf.nbTouches; i++)
{
    assert(buf.touches[i].distance <= buf.block.distance);
    animateLeaves(buf.touches[i]);
}
```
- By default, hits are assumed to be touching when a touch buffer is provided. The filter callback should return PxQueryHitType::eBLOCK to denote that a hit is blocking. See *Filtering* for details.
- For overlap() queries all touching hits will be recorded even if a blocking hit was encountered and PxQueryFlag::eNO_BLOCK flag is set.
Filtering

Filtering controls how shapes are excluded from scene query results and how results are reported. All three query types support the following filtering parameters:

- a `PxQueryFilterData` structure, containing both `PxQueryFlags` and `PxFilterData`
- an optional `PxQueryFilterCallback`

**PxQueryFlag::eSTATIC, PxQueryFlag::eDYNAMIC**

`PxQueryFlag::eSTATIC` and `PxQueryFlag::eDYNAMIC` flags control whether the query should include shapes from the static and/or dynamic query structures. This is the most efficient way to filter out all static/dynamic shapes. For example, an explosion effect that applies forces to all dynamics in a region could use a spherical overlap `PxQueryFlag::eDYNAMIC` flag to exclude all statics since forces cannot be applied to static objects. By default both statics and dynamics are included in query results.

For instance:

```cpp
PxScene* scene;
PxVec3 origin = ...;          // [in] Ray origin
PxVec3 unitDir = ...;         // [in] Normalized ray direction
PxReal maxDistance = ...;     // [in] Raycast max distance
PxRaycastBuffer hit;          // [out] Raycast results

// [in] Define filter for static objects only
PxQueryFilterData filterData(PxQueryFlag::eSTATIC);

// Raycast against static objects only
// The main result from this call is the boolean 'status'
bool status = scene->raycast(origin, unitDir, maxDistance, hit, PxHitFlag::ePREFILTER, PxQueryFlag::ePOSTFILTER);
```

**PxQueryFlag::ePREFILTER, PxQueryFlag::ePOSTFILTER**

Scene queries are performed in three phases: broad phase, midphase and narrow phase.
- Broad phase traverses the global scene spatial partitioning structure to find candidates for mid and narrow phases.
- Mid phase traverses the triangle mesh and heightfield internal culling structures, to find a smaller subset of the triangles in a mesh reported by the broad phase.
- Narrow phase performs exact intersection tests (ray test for raycast() queries, exact sweep shape tests or overlap tests for sweep() and overlap())

To implement custom filtering in queries, set the `PxQueryFlag::ePREFILTER` and `PxQueryFlag::ePOSTFILTER` flags and subclass `PxQueryFilterCallback` filtering logic.

- Pre-filtering happens before midphase and narrow phase and allows efficiently discarded before the potentially expensive exact collision tests are more expensive for triangle meshes, heightfields, convexes than raycast and overlap tests involving only simple shapes (spheres, capsules and boxes.)
- Post-filtering happens after the narrow phase test and can therefore use the test (such as `PxRaycastHit::position`) to determine whether discarded or not. These results can be accessed via the `hit` input argument to the post-filtering callback (`PxQueryFilterCallback::postFilter`).

The implementation of a filtering callback returns a `PxQueryHitType` result:

- `eNONE` indicates that the hit should be discarded.
- `eBLOCK` indicates that the hit is blocking.
- `eTOUCH` indicates that the hit is touching.

Whenever a raycast(), sweep() or overlap() query was called, that are no further (touchDistance <= blockDistance) than the closest
will be reported. For example, to record all hits from a raycast query:

\texttt{eTOUCH}.

\textbf{Note:} Returning \texttt{eTOUCH} from a filter callback requires the hit buffer to have a non-zero `\texttt{::touches}` array, otherwise PhysX will generate an error in builds and discard any touching hits.

\textbf{Note:} \texttt{eBLOCK} should not be returned from user filters for \texttt{overlap()}. Doing so will result in undefined behavior, and a warning will be issued. If the \texttt{PxQueryFlag::eNO_BLOCK} flag is set, the \texttt{eBLOCK} will instead be automatically converted to an \texttt{eTOUCH} and the warning suppressed.

\textbf{PxQueryFlag::eANY_HIT}

Use this flag to force the query to report the first encountered hit (which may not be the closest) as a blocking hit. Performance may be more than three times faster, depending on the scenario. Best gains can be expected for long raycasts/sweeps with a nearby intersecting object, or overlaps with multiple intersecting objects.

- Also see \texttt{PxHitFlag::eMESH_ANY}

\textbf{PxQueryFlag::eNO_BLOCK}

Use this flag when you want to override the \texttt{eBLOCK} value returned \texttt{eTOUCH} or in cases when no blocking hits are expected (in this case this flag serves as a performance hint.) All hits will then be reported as touching regardless of the return value. The hit callback/buffer object provided to the query is required to have a non-zero `\texttt{PxHitBuffer::touches}` buffer when this flag is used. Significant performance gains should only be expected for scenarios where the touching hit buffer overflows.

\textbf{Note:} this flag overrides the return value from pre and post-filter functions. Hits that were previously returned as blocking will instead be returned as touching.
**PxFilterData fixed function filtering**

A fast, fixed-function filter is provided by *PxFilterData*, a 4*32-bit bitmask in filtering equation. Each shape has a bitmask (set via `PxShape::setQueryFilterData`) and the query also has a bitmask.

The query data is used differently by batched and unbatched queries. For unbatched queries, the following rules are applied:

- If the query's bitmask is all zeroes, custom filtering and intersection testing proceed as normal.
- Otherwise, if the bitwise-AND value of the query's bitmask and the zero, the shape is skipped

Or in other words:

```cpp
 PxU32 keep = (query.word0 & object.word0) |
              (query.word1 & object.word1) |
              (query.word2 & object.word2) |
              (query.word3 & object.word3);
```

This hardcoded equation can provide simple filtering while avoiding overhead of the filtering callback. For example, to emulate the behavior of PhysX 2 active groups, define the groups as follows:

```cpp
enum ActiveGroup
{
    GROUP1  = (1<<0),
    GROUP2  = (1<<1),
    GROUP3  = (1<<2),
    GROUP4  = (1<<3),
    ...,
};
```

When shapes are created, they can be assigned to a group, for example:

```cpp
PxShape* shape;                        // Previously created shape
```
PxFilterData filterData;
filterData.word0 = GROUP1;
shape->setQueryFilterData(filterData);

Or to multiple groups, for example GROUP1 and GROUP3:

PxShape* shape; // Previously created shape
PxFilterData filterData;
filterData.word0 = GROUP1|GROUP3;
shape->setQueryFilterData(filterData);

When performing a scene query, select which groups are active for example GROUP2 and GROUP3 - as follows:

PxScene* scene;
PxVec3 origin = ...; // [in] Ray origin
PxVec3 unitDir = ...; // [in] Normalized ray direction
PxReal maxDistance = ...; // [in] Raycast max distance
PxRaycastBuffer hit; // [out] Raycast results

// [in] Define what parts of PxRaycastHit we're interested in
const PxHitFlags outputFlags = PxHitFlag::eDISTANCE | PxHitFlag::

// [in] Raycast against GROUP2 and GROUP3
PxQueryFilterData filterData = PxQueryFilterData();
filterData.data.word0 = GROUP2|GROUP3;

bool status = scene->raycast(origin, unitDir, maxDistance, hit, outputFlags);
User defined hit callbacks for unbounded results

Queries can sometimes return a very large number of results (for example, very large objects or in areas with high object density), and it can be expensive to reserve a sufficiently large memory buffer. The classes PxRaycastCallback, PxSweepCallback and PxOverlapCallback provide efficient callback based solutions for such scenarios. For instance a raycast query with a PxRaycastCallback will return all touch hits via multiple virtual PxHitCallback::processTouches()

```cpp
struct UserCallback : PxRaycastCallback
{
    UserData data;

    virtual PxAgain processTouches(const PxRaycastHit* buffer, Px)
        // This callback can be issued multiple times and can be
        // to process an unbounded number of touching hits.
        // Each reported touching hit in buffer is guaranteed to
        // the final block hit after the query has fully executed
    {
        for (PxU32 i = 0; i < nbHits; i++)
            animateLeaves(buffer[i], data);
    }

    virtual void finalizeQuery()
    {
        drawWallDecal(this->block, data);
    }
};
```

PxScene* scene;
PxVec3 origin = ...;       // [in] Ray origin
PxVec3 unitDir = ...;      // [in] Normalized ray direction
PxReal maxDistance = ...;  // [in] Raycast max distance

UserCallback cb; cb.data = ...;
scene->raycast(origin, unitDir, maxDistance, cb); // see UserCallback

In this code snippet the raycast() query will potentially invoke processTouches multiple times, with all touching hits already clipped to the globally nearest block.

- Note that the query can be up to twice as expensive in case all e
not fit in the provided touches buffer and a blocking hit was also fou

- Also see PxQueryFlag::eNO_BLOCK
PhysX supports batching of scene queries via the *PxBatchQuery* interface. Using this API may simplify multi-threaded implementations.

The batched query feature has been deprecated in PhysX version 3.4.

- *PxBatchQuery* interface facilitates batching and execution of multiple queries together. *PxBatchQuery* buffers raycast, overlap and sweep queries until *PxBatchQuery::execute()* is called.
- Use *PxScene::createBatchQuery(const PxBatchQueryDesc& desc)* to create a *PxBatchQuery* object.
- The hardcoded filtering equation is not used for batched queries. Instead, two filter shaders, respectively running before (*PxBatchQueryPreFilterShader*) and after (*PxBatchQueryPostFilterShader*) the exact per-shape collision test, are used. The shaders are specified via the *PxBatchQueryDesc::preFilterShader* and *PxBatchQueryDesc::postFilterShader*.
- *BatchQueryFilterData::filterShaderData* will be copied and passed to the filter shader via the *constantBlock* parameter.
- Results are written to user-defined buffers *PxBatchQueryMemory* in the same order queries were queued in a *PxBatchQueryDesc*, in the same order queries were queued in an object.
- The results and hits buffers for the each query type used (raycast, overlap, sweep) are specified separately.
- These buffers can be changed before each batch query execute call. The SDK will produce a warning for batched queries with NULL results or hits for the corresponding query type (raycast, overlap or sweep).
Volume Caching

*PxVolumeCache* provides a mechanism for accelerating scene queries by implementing caching for objects within a specified volume and providing *PxScene* for executing raycasts, overlaps, and sweeps. *PxVolumeCache* implements caching for objects within a specified volume and provides an API similar to *PxScene* for executing raycasts, overlaps, and sweeps.

The volume cache feature has been deprecated in PhysX version 3.4.

Some expected use cases for *PxVolumeCache* are:

- A particle system with many raycasts performed for each particle localized cloud.
- Multiple short range character controller raycasts within the same area around the character.
- Caching query results across multiple frames, the cache can be filled using a larger volume on previous frame (possibly extruded in the anticipated direction of movement) and then queried with a smaller volume.

The cache has a maximum capacity, specified separately for dynamic objects in *PxScene::createVolumeCache()*. For purposes of multithreaded access, any operation on the cache counts as a read call on the scene.

**Filling the Cache**

To fill the cache, call *PxVolumeCache::fill()*.

This will query the overlapping with the volume defined by the geometry and transform and store the results in an internal buffer up to the maximum sizes for static and dynamic objects. Only *PxBoxGeometry*, *PxSphereGeometry* and *PxCapsuleGeometry* are supported in *cacheVolume*. The call will always refill both the static and dynamic internal buffers.
if the new volume lies entirely within the previous cached volume. It returns
\textit{PxVolumeCache::FillStatus}.

Subsequent queries against the cache (raycasts, overlaps, sweeps, foreach) will refill the cache automatically using the same volume if the scene query subsystem has been updated since the last fill. The update status is tracked independently for statics and dynamics, so a query might only refill the cache for dynamics while reusing valid cached results for statics. If any attempt to fill or refill fails, the cache is invalid and any subsequent query will attempt to fill it.

**Querying the Cache**

\textit{PxVolumeCache} provides an API for raycasts, sweeps and overlaps that is similar to the scene query API. The main difference in signatures is that \textit{Single Obj} is supported for \textit{PxVolumeCache} queries. Query results are returned via the \textit{PxVolumeCache::Iterator::shapes()} callback, and the query may invoke the callback multiple times to deliver multiple batches of results.

- Raycasts, overlaps and sweeps against a valid cache will return results which overlap the cache volume, but is guaranteed to return all such volumes.
- Raycasts, overlaps and sweeps against an invalid cache will fall back to scene queries. In this case results may be returned which do not overlap the cache volume.

Since the cache refills automatically on any query where the scene has changed, these two conditions guarantee that a query against the cache that lies entirely within the volume will always return exactly the same shapes as querying the scene, so long as the query does not lie entirely within the cache volume (and the cache is valid). Of all volumes which overlap the cache volume will be returned. If a query is issued against a cache for which \textit{fill()} has never been called, an error is reported.

The cache also provides a low-level \textit{forEach()} mechanism that iterates over objects. If \textit{forEach()} is executed on a cache for which \textit{fill()} has never been called, it will return without reporting an error. If the cache is invalid, \textit{forEach()} will retrieve the shapes that overlap the cached volume directly from the scene. This process
allocation of a temporary buffer, and if the allocation fails, `forEach()` message and return.

This code snippet shows how to use PxVolumeCache:

```cpp
PxScene* scene;
PxVec3 poi = ...; // point of interest
PxVec3 origin = ...; // [in] Ray origin
PxVec3 unitDir = ...; // [in] Normalized ray direc
PxReal maxDistance = ...; // [in] Raycast max distance
PxRaycastBuffer hit; // [out] Raycast results
const PxU32 maxStatics = 32, maxDynamics = 8;

// persistent cache, valid until invalidated by object movement,
// insertion or deletion
PxVolumeCache* cache = scene->createVolumeCache(maxStatics, maxDynamics);
    cache->setMaxNbStaticShapes(64); cache->setMaxNbDynamicShapes(16)

// fill the cache using a box geometry centered around the point
cache->fill(PxBoxGeometry(PxVec3(1.0f)), PxTransform(position));
...

// Perform multiple raycast queries using the cache
PxRaycastBuffer hit;
const bool status = cache->raycast(origin, unitDir, maxDistance,

// low level iterator for stored actor/shape pairs
struct UserIterator : PxVolumeCache::Iterator
{
    UserData userData;
    virtual void shapes(PxU32 count, const PxActorShape* actorSha
    {
        for (PxU32 i = 0; i < count; i++)
            doSomething(actorShapePairs[i].actor, actorShapePairs[
    }
    iter;

    // invoke UserIterator::shapes() callback for all actor/shape pai
cache->forEach(iter);
```
Single Object Caching

Another special case mechanism for accelerating scene queries is single-object caching using *PxQueryCache*.

- This cache can provide additional speedups and memory savings for sweep queries in any operation mode.
- The cache object defines which shape should be tested first. For temporal coherence, this can provide significant performance gains.
- Note that it is likely incorrect to use a past touching hit (recorded with *eTOUCH* flag) for caching since it will be interpreted as blocking and override any eBLOCK result.

For example, there is a good chance that an AI visibility query will return the same line-of-sight blocking shape for several frames. Using a *raycast* query with a *PxQueryCache* object will allow PhysX to test a single shape - before traversing the internal spatial partitioning structures, and in case of a "cache hit" the traversal can be bypassed entirely. For instance:

```cpp
PxScene* scene;
PxVec3 origin = ...; // [in] Ray origin
PxVec3 unitDir = ...; // [in] Normalized ray direction
PxReal maxDistance = ...; // [in] Raycast max distance
PxRaycastBuffer hit; // [out] Raycast results

// Per-raycast persistent cache, valid from one frame to the next
static PxQueryCache persistentCache;

// Define cache for current frame:
// - if there was a hit in the previous frame, use the cache.
// - otherwise do not (PhysX requires given cache has a valid shape)
const PxQueryCache* cache = persistentCache.shape ? &persistentCache.shape : nullptr;

// Perform a raycast query using the cache
const bool status = scene->raycast(origin, unitDir, maxDistance, hit, PxHitFlags(PxHitFlag::eDEFAULT
```
if(status)
{
    // We hit a shape. Cache it for next frame.
    persistentCache.shape = hit.block.shape;
    persistentCache.faceIndex = hit.block.faceIndex;
}
else
{
    // We did not hit anything. Reset the cache for next frame.
    persistentCache = PxQueryCache();
}

Caching can also be useful in queries looking for the closest blocking hit or when using the eANY_HIT flag. In this case, testing the previously closest object first can shorten the query distance very early, leading to fewer total narrow phase collision tests and early out from the traversal.

**Note:** PhysX does not detect stale pointers, so the application is responsible for cached object validity when shapes are deleted.

**Note:** Overlaps do not support single hit blocking caches.
PhysX SDK offers different pruning structures which are used to accelerate queries. This paragraph describes the differences between them.

**Generalities**

The Scene Query system uses two different acceleration structures, a hierarchical grid and an AABB tree.

The grid builds quickly, in \(O(n)\) time, with queries executing in between \(O(1)\) and \(O(N)\) time depending on how uniformly the objects are distributed in space, with pathological worst case performance of \(O(N)\) when all objects are clustered in the same grid cell.

The tree builds in \(O(n \log(n))\) time, but queries with a single result typically run in \(O(\log(n))\) time. Queries returning multiple results will traverse more of the tree, though a query returning all of the objects in the scene in \(O(n)\) time. The tree is vulnerable to degeneration when the same topology is maintained too long as object positions change, and in pathological cases query performance may degrade to \(O(n)\) time.

Acceleration structures must be continually modified in accordance with objects being added or removed, or object AABB updates due to changes in position. To minimize the cost, modifications are deferred for as long as possible. Adding or removing objects or updating AABBs occurs in amortized constant time, and modifications deferred until the changes 'commit'. This happens on the next query or the next fetchResults(). To force an immediate commit, call the PxScene::flushQueryUpdates() function.

The exact details of the commit process depend on the values of staticStructure and dynamicStructure specified in PxSceneDesc.

To avoid automatic resizing triggered by insertions into internal data structures, reserve the space in advance. See PxSceneDesc::maxNbStaticShapes, PxSceneDesc::maxNbDynamicShapes.
**PxPruningStructureType::eNONE**

The acceleration structure is similar to a hierarchical grid. Committing changes requires a full rebuild. This is a good choice if you expect to rarely or never update the objects in this structure.

**PxPruningStructureType::eSTATIC_AABB_TREE**

The acceleration structure is a tree. Committing changes requires a full rebuild. It is generally recommended, but can be a good choice for static structure if the static actors in your scene are created on initialization, and not modified thereafter. If you frequently add or remove static geometry, the default eDYNAMIC_AABB_TREE setting is usually a better choice, although it has a higher memory footprint than that of eSTATIC_AABB_TREE.

**PxPruningStructureType::eDYNAMIC_AABB_TREE**

In this case, both the tree and the grid are used, and each query searches both the tree and the grid.

The tree is initially built by the first commit. Once a tree is built, committing changes proceeds as follows:

* the tree is refitted in accordance with updates and removals of object it contains.
* added objects are inserted into the grid. Such additions, removals of objects currently in the grid, or changes to AABBs of objects in the grid, cause the grid to be rebuilt.

In addition, a new tree is incrementally built during fetchResults(), frames controlled by PxScene’s dynamicTreeRebuildRateHint attribute. When the build starts, it includes all of the objects in the current tree and grid. When some frames later, the new tree is refitted in accordance with any AABB changes since the build started, and then replaces the current tree. Any objects that were added since the start of the build remain in the grid.

To force a full immediate rebuild, call PxScene::forceDynamicTreeRebuild(). This can be useful in cases such as the following:
• a slow rebuilt rate is typically desirable, but occasionally a large additions creates high occupancy in the grid, especially if the add so as to put pressure on just a few of the grid cells.
• you are moving many objects across large distances, since refitting degrade the quality of the current tree
PxPruningStructure

Provides access to precomputed pruning structure used to accelerate scene queries against newly added actors.

A pruning structure can be provided to PxScene::addActors. The actor shapes will then be directly merged into the scene's AABB tree, without the need for an AABB tree recompute:

```cpp
// Create pruning structure from given actors.
PxPruningStructure* ps = PxPhysics::createPruningStructure(&actor);
// Add actors into a scene together with the precomputed pruning
PxScene::addActors(*ps);
ps->release();
```

A PxPruningStructure object can be serialized into a collection together with its actors.

For usage of PxPruningStructure please refer to the snippet SnippetPrunerSerialization.

A typical use case for PxPruningStructure is a large world scenario where blocks of closely positioned actors get streamed in.

Merge process

The merge process into the scene query acceleration structure `PxPruningStructureType`: *
- **eSTATIC_AABB_TREE** - the pruning structure is merged directly into scene's AABB tree. This might unbalance the tree and it is recommended to recompute the static tree at some point.
- **eDYNAMIC_AABB_TREE** - the pruning structure is merged into a temporary pruning structures until the scene's new optimized AABB tree is computed.
Introduction

PhysX support for vehicles has been significantly reworked in 3.x. NxWheelShape class of 2.8.x, a more optimal integration of the core vehicle simulation code has been developed. More specifically, the vehicle now sits outside the core SDK in a manner similar to PhysXExtensions allowing vehicles to be updated in a single pass as well as promoting an intuitive approach to modeling vehicle data. Vehicles support has been extended from the suspension/wheel/tire modeling of 2.8.x to a more complete model that couples modular vehicle components including engine, clutch, gears, autobox, differential, suspensions, and chassis. A quick glance at the data PxVehicleComponents.h will provide a flavor of the behaviors supported by vehicles.
The PhysX Vehicle SDK models vehicles as collections of sprung masses. Each sprung mass represents a suspension line with associated wheel and tire data. The collections of sprung masses have a complementary representation as rigid body actors whose mass, center of mass, and moment of inertia matches exactly the masses and coordinates of the sprung masses. This is illustrated below.

Figure 1a: Vehicle representation as a rigid body actor with shapes for wheels. Note that the wheel rest offsets are specified relative to the
Figure 1b: Vehicle representation as a collection of sprung masses of mass M1 and M2.

The relationship between the sprung mass and rigid body vehicle representations can be mathematically formalized with the rigid body center of mass equations:

\[ M = M_1 + M_2 \]

\[ X_{cm} = \frac{(M_1 \times X_1 + M_2 \times X_2)}{(M_1 + M_2)} \]

where \( M_1 \) and \( M_2 \) are the sprung masses; \( X_1 \) and \( X_2 \) are the sprung mass coordinates in actor space; \( M \) is the rigid body mass; and \( X_{cm} \) is the rigid body center of mass offset.

The purpose of the PhysX Vehicle SDK update function is to compute suspension forces using the sprung mass model and then to apply the aggregate forces to the PhysX SDK rigid body representation in the form of a modified velocity and angular velocity. Interaction of the rigid body actor with other scene objects and global pose update is then managed by the PhysX SDK.

The update of each vehicle begins with a raycast for each suspension start just above the top of the tire at maximum compression and along the direction of suspension travel to a position just below the base maximum droop. This is shown in the diagram below.
The suspension force from each elongated or compressed spring is computed and added to the aggregate force to be applied to the rigid body. Additionally, the suspension force is used to compute the load that is bearing down on the tire. This load is then used to calculate the tire forces that will be generated in the contact plane and then added to the aggregate force to be applied to the rigid body. The tire force computation actually depends on a number of factors including steer angle, camber angle, friction, wheel rotation speed, and rigid body momentum. The aggregated force of all tire and suspension forces is then applied to the rigid body actor associated with the vehicle so that the transform may be modified accordingly in the next PhysX SDK update.

In addition to being collections of sprung masses, PhysX vehicles also support drive models. The center of the drive model is a torsion clutch, which couples the wheels and the engine via forces that arise from differences in rotational speeds at both sides of the clutch. At one side of the clutch is the engine, which is powered by the accelerator pedal. The engine is modeled as a rigid body whose motion is purely rotational and limited to a single degree of rotational freedom. At the other side of the clutch are the gearing system, the differential and the wheels. The effective rotational speed of the other side of the clutch can be computed directly from the rotational speed of the wheels that are coupled to the clutch through
This model naturally allows engine torques to propagate to the wheels to propagate back to the engine, just as in a standard car.

The data describing each component of the PhysX vehicle can be found in the Guide.
**First Code**

### Vehicle SDK Initialization

Before using the vehicle SDK it must first be initialized in order to set threshold values from various tolerance scales. This is as straightforward as calling the following function:

```c
PX_C_EXPORT bool PX_CALL_CONV PxInitVehicleSDK(
    PxPhysics& physics, PxSerializationRegistry* serializationRegistry)
```

This function should be called after setting up the required PxPhysics instances. If vehicle serialization is required a PxSerializationRegistry instance needs to be specified. A PxSerializationRegistry instance can be created with PxSerialization::createSerializationRegistry(), see *Serialization*.

The basis vectors of the vehicle simulation must also be configured so that longitudinal and lateral tire slips may be unambiguously computed:

```c
void PxVehicleSetBasisVectors(const PxVec3& up, const PxVec3& forward)
```

This function can be called at any time prior to the first execution of PxVehicleUpdates.

The rigid body actors associated with vehicles can be updated either with velocity modifications or updated with an acceleration that is applied in the next PhysX SDK simulate call. The following function can be used to select the required update mode:

```c
void PxVehicleSetUpdateMode(PxVehicleUpdateMode::Enum vehicleUpdateMode)
```

As expected, the vehicle SDK also has a shutdown process which needs to be called:

```c
PX_C_EXPORT void PX_CALL_CONV PxCloseVehicleSDK(
    PxSerializationRegistry* serializationRegistry = NULL);
```
released; that is, the order of shutdown is the reverse of the initialization
if serialization is required the PxSerializationRegistry specified for PxInit
must be passed to PxCloseVehicleSDK. If vehicle serialization is used
without serialization it must be called before closing the PhysXExtensions.

As an illustration of the usage of these functions, SnippetVehicle4W
initialization code:

```cpp
PxInitVehicleSDK(*gPhysics);
PxVehicleSetBasisVectors(PxVec3(0,1,0), PxVec3(0,0,1));
PxVehicleSetUpdateMode(PxVehicleUpdateMode::eVELOCITY_CHANGE);
```

The shutdown code in SnippetVehicle4W is as follows:

```cpp
PxCloseVehicleSDK();
```

### Introduction To Vehicle Creation

The following pseudo-code illustrates the basic process of setting up a
vehicle instance:

```cpp
const PxU32 numWheels = 4;
PxVehicleWheelsSimData* wheelsSimData = PxVehicleWheelsSimData::allocateWheelsSimulationData(wheelsSimData);
PxVehicleDriveSimData4W driveSimData;
setupDriveSimData(driveSimData);
PxRigidDynamic* vehActor = myPhysics.createRigidDynamic(startPose);
setupVehicleActor(vehActor);
myScene.addActor(*vehActor);
PxVehicleDrive4W* vehDrive4W = PxVehicleDrive4W::allocate(numWheels, vehDrive4W->setup(physics, veh4WActor, *wheelsSimData, driveSimData);
wheelsSimData->free();
```

The code above first instantiates a PxVehicleWheelsSimData instance
that are large enough to store configuration data for four wheels. This
includes fields such as suspension strength and damping rate, wheel and suspension travel direction. The next step is to create a PxVehicle instance. This structure stores the configuration of the drive model and includes such as engine peak torque, clutch strength, gearing ratios, and Ackermann correction. Following this, a PxRigidDynamicActor is instantiated with geometry for the wheels and chassis as well as dynamic properties such as mass, moment of inertia, and center of mass. The final step is to instantiate an instance and associate it with the actor and the vehicle configuration data.

The functions setupWheelsSimulationData, setupDriveSimData and setupVehicleActor are actually quite involved and shall be discussed in Section setupWheelsSimulationData, setupDriveSimData and setupVehicleActor.

## Introduction To Vehicle Update

The PhysX Vehicles SDK utilizes batched scene queries to query the geometry under each tire. A more detailed discussion of PhysX batched scene queries can be found in Section Batched queries.

The following pseudo-code initializes a batched scene query with buffers large enough for a single vehicle with four wheels:

```cpp
PxRaycastQueryResult sqResults[4];
PxRaycastHit sqHitBuffer[4];
PxBatchQueryDesc sqDesc(4, 0, 0);
sqDesc.queryMemory.userRaycastResultBuffer = sqResults;
sqDesc.queryMemory.userRaycastTouchBuffer = sqHitBuffer;
sqDesc.queryMemory.raycastTouchBufferSize = 4;
sqDesc.preFilterShader = myFilterShader;
PxBatchQuery* batchQuery = scene->createBatchQuery(sqDesc);
```

The PxBatchQuery instance is typically instantiated as part of the initialization phase and then reused each frame. It is possible to instantiate a PxBatchQuery instance for each vehicle or to instantiate a single PxBatchQuery instance with buffers large enough for all wheels of a batched array of vehicles. The only restriction is that all batched array of vehicles and associated buffers configured at the start of a vehicle simulation frame must persist until the end of the vehicle simulation frame.
PhysX vehicles make use of scene query filter shaders to eliminate intersections with the vehicle issuing the raycast and with any geometry that is not to be considered as drivable surface. More details for how to set up "myFilterShader" about Filter Section Filtering.

For a batch containing just a single 4-wheeled vehicle the suspension raycasts can be performed with the following pseudo-code:

```cpp
PxVehicleWheels* vehicles[1] = {myVehicle};
PxBatchSuspensionRaycasts(batchQuery, 1, vehicles, 4, sqResults);
```

The function PxVehicleSuspensionRaycasts performs suspension raycasts for all vehicles in the batched array of vehicles. Each element in the sqResults array corresponds to a raycast report for a single suspension. Pointers to contiguous blocks within the memory blocks are stored by each vehicle in turn as the function iterates through the vehicles array. As a consequence, the sqResults array must persist until at least the end of PxVehicleUpdates and must have length at least as large as the total number of wheels in the vehicles array.

The vehicles are updated with the following function call:

```cpp
PxVehicleUpdates(timestep, gravity, frictionPairs, 1, vehicles, NULL);`

The function PxVehicleUpdates updates the internal dynamics of each wheel shapes of the vehicle's actor and applies either velocity or acceleration to the actor, depending on the update mode chosen with PxVehicleSetUpdateMode. More details can be found in Section Wheel Pose and Section Vehicle Update. The frictionPairs is basically a lookup table that associates unique combinations of tire type and PxMaterial. The idea here is to allow the friction to be tuned for each surface type. This shall be discussed in more depth in Section on Drivable Surfaces.
Snippets

Four snippets are currently implemented to illustrate the operation of the SDK. These are:

1. SnippetVehicle4W
2. SnippetVehicleTank
   3. SnippetNoDrive
3. SnippetVehicleScale
4. SnippetVehicleMultiThreading
   5. SnippetVehicleWheelContactMod

Code snippets from each of these is used throughout the guide.

SnippetVehicle4W

SnippetVehicle4W demonstrates how to instantiate and update PxVehicleDrive4W. It creates a vehicle on a plane and then controls the vehicle to perform a number of choreographed maneuvers such as accelerate, handbrake, and turn.

SnippetVehicleTank

SnippetVehicleTank demonstrates how to instantiate and update PxVehicleDriveTank. It creates a tank on a plane and then controls the tank to perform a number of choreographed maneuvers such as accelerate, and hard turns.

SnippetVehicleNoDrive

SnippetVehicleNoDrive demonstrates how to instantiate and update PxVehicleNoDrive. It creates a vehicle on a plane and then controls the vehicle to perform a number of choreographed manoeuvres such as accelerate, and hard turns.
**SnippetVehicleScale**

SnippetVehicleScale demonstrates how to configure a PhysX vehicle with the chosen length scale. The snippet sets up a vehicle with meters as scale and then modifies the vehicle parameters so that they represent but with centimeters as the chosen length scale.

**SnippetVehicleMultiThreading**

SnippetVehicleMultiThreading demonstrates how to implement multi-threading. The snippet creates multiple vehicles on a plane and then concurrently simulates them across multiple threads.
Advanced Concepts

Vehicle Creation

This Section discusses the configuration of vehicle simulation data and set up an actor that will represent the vehicle in the PhysX SDK. Section Vehicle Creation identified three distinct phases of vehicle configuration: wheel simulation data, configuration of drive simulation data and actor configuration of these phases is discussed in turn.

setupWheelsSimulationData

The following code, taken from SnippetVehicle4W, PxVehicleWheelsSimData:

```cpp
void setupWheelsSimulationData(const PxF32 wheelMass, const PxF32 wheelRadius, const PxF32 wheelWidth, const PxU32 numWheels const PxVec3* wheelCenterActorOffsets, const PxVec3& chassisCMOffset const PxF32 chassisMass, PxVehicleWheelsSimData* wheelsSimData { //Set up the wheels. PxVehicleWheelData wheels[PX_MAX_NB_WHEELS];

//Set up the wheel data structures with mass, moi, radius for(PxU32 i = 0; i < numWheels; i++)
{
    wheels[i].mMass = wheelMass;
    wheels[i].mMOI = wheelMOI;
    wheels[i].mRadius = wheelRadius;
    wheels[i].mWidth = wheelWidth;
}

    //Enable the handbrake for the rear wheels only. wheels[PxVehicleDrive4WWheelOrder::eREAR_LEFT].mMaxHandBrakeTorque = 500.0f;
    wheels[PxVehicleDrive4WWheelOrder::eREAR_RIGHT].mMaxHandBrakeTorque = 500.0f;

    //Enable steering for the front wheels only. wheels[PxVehicleDrive4WWheelOrder::eFRONT_LEFT].mMaxSteer = 90.0f;
    wheels[PxVehicleDrive4WWheelOrder::eFRONT_RIGHT].mMaxSteer = 90.0f;
}
```
//Set up the tires.
PxVehicleTireData tires[PX_MAX_NB_WHEELS];
{
    //Set up the tires.
    for(PxU32 i = 0; i < numWheels; i++)
    {
        tires[i].mType = TIRE_TYPE_NORMAL;
    }
}

//Set up the suspensions
PxVehicleSuspensionData suspensions[PX_MAX_NB_WHEELS];
{
    //Compute the mass supported by each suspension spring.
    PxF32 suspSprungMasses[PX_MAX_NB_WHEELS];
    PxVehicleComputeSprungMasses
        (numWheels, wheelCenterActorOffsets,
         chassisCMOffset, chassisMass, 1, suspSprungMasses);

    //Set the suspension data.
    for(PxU32 i = 0; i < numWheels; i++)
    {
        suspensions[i].mMaxCompression = 0.3f;
        suspensions[i].mMaxDroop = 0.1f;
        suspensions[i].mSpringStrength = 35000.0f;
        suspensions[i].mSpringDamperRate = 4500.0f;
        suspensions[i].mSprungMass = suspSprungMasses[i];
    }

    //Set the camber angles.
    const PxF32 camberAngleAtRest=0.0;
    const PxF32 camberAngleAtMaxDroop=0.01f;
    const PxF32 camberAngleAtMaxCompression=-0.01f;
    for(PxU32 i = 0; i < numWheels; i+=2)
    {
        suspensions[i + 0].mCamberAtRest = camberAngleAtRest
        suspensions[i + 1].mCamberAtRest = -camberAngleAtRest
        suspensions[i + 0].mCamberAtMaxDroop = camberAngleAtMaxDroop
        suspensions[i + 1].mCamberAtMaxDroop = -camberAngleAtMaxDroop
        suspensions[i + 0].mCamberAtMaxCompression = camberAngleAtMaxCompression
        suspensions[i + 1].mCamberAtMaxCompression = -camberAngleAtMaxCompression
    }
}

//Set up the wheel geometry.
PxVec3 suspTravelDirections[PIX_MAX_NB_WHEELS];
PxVec3 wheelCentreCMOffsets[PIX_MAX_NB_WHEELS];
PxVec3 suspForceAppCMOffsets[PIX_MAX_NB_WHEELS];
PxVec3 tireForceAppCMOffsets[PIX_MAX_NB_WHEELS];
{
    //Set the geometry data.
    for (PxU32 i = 0; i < numWheels; i++)
    {
        //Vertical suspension travel.
        suspTravelDirections[i] = PxVec3(0, -1, 0);

        //Wheel center offset is offset from rigid body center.
        wheelCentreCMOffsets[i] =
            wheelCenterActorOffsets[i] - chassisCMOffset;

        //Suspension force application point 0.3 metres below
        //rigid body center of mass.
        suspForceAppCMOffsets[i] =
            PxVec3(wheelCentreCMOffsets[i].x, -0.3f, wheelCentreCMOffsets[i].z);

        //Tire force application point 0.3 metres below
        //rigid body center of mass.
        tireForceAppCMOffsets[i] =
            PxVec3(wheelCentreCMOffsets[i].x, -0.3f, wheelCentreCMOffsets[i].z);
    }
}

//Set up the filter data of the raycast that will be issued by
PxFilterData qryFilterData;
setupNonDrivableSurface(qryFilterData);

//Set the wheel, tire and suspension data.
//Set the geometry data.
//Set the query filter data
for (PxU32 i = 0; i < numWheels; i++)
{
    wheelsSimData->setWheelData(i, wheels[i]);
    wheelsSimData->setTireData(i, tires[i]);
    wheelsSimData->setSuspensionData(i, suspensions[i]);
    wheelsSimData->setSuspTravelDirection(i, suspTravelDirection[i]);
    wheelsSimData->setWheelCentreOffset(i, wheelCentreCMOffset[i]);
    wheelsSimData->setSuspForceAppPointOffset(i, suspForceAppOffset[i]);
    wheelsSimData->setTireForceAppPointOffset(i, tireForceAppOffset[i]);
    wheelsSimData->setSceneQueryFilterData(i, qryFilterData);
    wheelsSimData->setWheelShapeMapping(i, i);
}
The function PxVehicleComputeSprungMasses computes the sprung mass of each suspension so that they collectively match the rigid body center of mass in the frame of the actor. It makes sense to perform PxVehicleComputeSprungMasses in the frame of the actor because the rigid body center of mass is always specified in the actor's frame. The vehicle suspension system, on the other hand, is specified in the center of mass frame. As a consequence, the functions setSuspForceAppPointOffset and setTireForceAppPointOffset all describe offsets from the rigid body center of mass. The directness of this approach can make changes to the rigid body center of mass a bit more involved than might be expected. To solve this problem, the function PxVehicleUpdateCMassLocalPose has been introduced, though not used in the code above. This function recomputes and sets all suspension offsets, sprung masses and sets them in a way that preserves the natural frequency and damping ratio of each spring.

Details of many of the parameters and functions above can be found in Section Guide. The function setupNonDrivableSurface, which sets up scene query filter data for each suspension raycast, shall be discussed in more detail in Section the link between TIRE_TYPE_NORMAL and tire friction shall be made clear in Section Tire Friction on Drivable Surfaces. Finally, the use of the function setWheelShapeMapping shall be clarified in Section Wheel Pose.

setupDriveSimData

The following code, taken from SnippetVehicle4W, PxVehicleDriveSimData4W:

```cpp
PxVehicleDriveSimData4W driveSimData;
{
  //Diff
  PxVehicleDifferential4WData diff;
  diff.mType=PxVehicleDifferential4WData::eDIFF_TYPE_LS_4WD;
  driveSimData.setDiffData(diff);

  //Engine
  PxVehicleEngineData engine;
  engine.mPeakTorque=500.0f;
  engine.mMaxOmega=600.0f;//approx 6000 rpm
  driveSimData.setEngineData(engine);
```
Details of many of the parameters and functions above can be found in the 

*Guide*.

Configuring PxVehicleDriveSimDataNW and PxVehicleDriveSimDataTank

... a very similar procedure, albeit with slightly different components. More details can be found, for example, in SnippetVehicleTank.

**setupVehicleActor**

The following code, common to all vehicle snippets, sets up a rigid dynamic actor with geometry, filter and dynamics data:

```cpp
PxRigidDynamic* createVehicleActor
(const PxVehicleChassisData& chassisData,
 PxMaterial** wheelMaterials, PxConvexMesh** wheelConvexMeshes,
 PxMaterial** chassisMaterials, PxConvexMesh** chassisConvexMeshes,
```
PxPhysics& physics) {
    // We need a rigid body actor for the vehicle.
    // Don't forget to add the actor to the scene after setting
    PxRigidDynamic* vehActor = physics.createRigidDynamic(PxT

    // Wheel and chassis query filter data.
    // Optional: cars don't drive on other cars.
    PxFilterData wheelQryFilterData;
    setupNonDrivableSurface(wheelQryFilterData);
    PxFilterData chassisQryFilterData;
    setupNonDrivableSurface(chassisQryFilterData);

    // Add all the wheel shapes to the actor.
    for(PxU32 i = 0; i < numWheels; i++) {
        PxConvexMeshGeometry geom(wheelConvexMeshes[i]);
        PxShape* wheelShape = PxRigidActorExt::createExclusive
        wheelShape->setQueryFilterData(wheelQryFilterData
        wheelShape->setSimulationFilterData(wheelSimFilterData
        wheelShape->setLocalPose(PxTransform(PxIdentity))
    }

    // Add the chassis shapes to the actor.
    for(PxU32 i = 0; i < numChassisMeshes; i++) {
        PxShape* chassisShape = PxRigidActorExt::createExclusive
        chassisShape->setQueryFilterData(chassisQryFilterData
        chassisShape->setSimulationFilterData(chassisSimFilterData
        chassisShape->setLocalPose(PxTransform(PxIdentity)
    }

    vehActor->setMass(chassisData.mMass);
    vehActor->setMassSpaceInertiaTensor(chassisData.mMOI);
    vehActor->setCMassLocalPose(PxTransform(chassisData.mC MOF

    return vehActor;
}
Filtering

In this Section the concepts behind vehicle query and vehicle simulation filtering shall be described.

The key goal of scene query and simulation filtering for vehicles is to ensure that vehicles are supported by suspension spring forces without interference from wheel shape intersection. The requirements for filtering are then as follows:

1. wheel shapes must not hit drivable surfaces
2. suspension raycasts can hit drivable surfaces
3. suspension raycasts must not hit the shapes of the vehicle issuing

Ensuring that wheel shapes don't hit drivable surfaces can be achieved with filtering. This is discussed in more detail in Section Collision Filtering. The snippets use the following simulation filter shader:

```cpp
PxFilterFlags VehicleFilterShader
(PxFilterObjectAttributes attributes0, PxFilterData filterData0, PxPairFlags& pairFlags, const void* constantBlock, PxU32 constantBlockSize
{
    PX_UNUSED(attributes0);
    PX_UNUSED(attributes1);
    PX_UNUSED(constantBlock);
    PX_UNUSED(constantBlockSize);

    if (0 == (filterData0.word0 & filterData1.word1)) && (0
        return PxFilterFlag::eSUPPRESS;

    pairFlags = PxPairFlag::eCONTACT_DEFAULT;
    pairFlags |= PxPairFlags(PxU16(filterData0.word2 | filterData1.word2);

    return PxFilterFlags();
}
```

The snippets also apply simulation filter data to wheel shapes as follows:

```cpp
PxFilterData wheelSimFilterData;
wheelSimFilterData.word0 = COLLISION_FLAG_WHEEL;
```
Finally, the following simulation filter data is applied to drivable surfaces:

```cpp
wheelSimFilterData.word1 = COLLISION_FLAG_WHEEL_AGAINST;
...
wheelShape->setSimulationFilterData(wheelSimFilterData);
```

The combination of collision flags (COLLISION_FLAG_WHEEL_AGAINST etc) and filter shader ensures that wheel shapes don't collide with drivable surfaces.

A remarkably similar process may be employed to configure the complementary scene query filters. This is accomplished in the vehicle snippets with the following code:

```cpp
PxFilterData simFilterData;
simFilterData.word0 = COLLISION_FLAG_GROUND;
simFilterData.word1 = COLLISION_FLAG_GROUND_AGAINST;
...
shapes[0]->setSimulationFilterData(simFilterData);
```

```cpp
void setupDrivableSurface(PxFilterData& filterData)
{
    filterData.word3 = (PxU32)DRIVABLE_SURFACE;
}

void setupNonDrivableSurface(PxFilterData& filterData)
{
    filterData.word3 = UNDRIVABLE_SURFACE;
}

PxQueryHitType::Enum WheelRaycastPreFilter
(PxFilterData filterData0, PxFilterData filterData1,
 const void* constantBlock, PxU32 constantBlockSize,
 PxHitFlags& queryFlags)
{
    //filterData0 is the vehicle suspension raycast.
    //filterData1 is the shape potentially hit by the raycast.
    PX_UNUSED(constantBlockSize);
    PX_UNUSED(constantBlock);
    PX_UNUSED(filterData0);
```
Each vehicle wheel is given filter data configured with setupNonDrivableSurface passed to the vehicle with:

```cpp
wheelsSimData->setSceneQueryFilterData(i, qryFilterData);
```

The parameter filterData0 in WheelRaycastPreFilter corresponds to the vehicle PxBVehiceWheelsSimData::setSceneQueryFilterData. The parameter, on the other hand, corresponds to the query filter data of a shape potentially hit by the vehicle snippets the shape of the drivable ground plane has scene filter data configured with the function setupDrivableSurface. This satisfies the requirement that suspension raycasts can hit drivable surfaces. Vehicle shapes, on the other hand, are configured with setupNonDrivableSurface. This satisfies the restriction that suspension raycasts must not hit the vehicle issuing the raycasts but also prevent driving on any other vehicles that might be added to the scene. This extra restriction could readily be avoided by employing a more complex filter shader that perhaps IDs encoded in both the shape filter data and the filter data applied to the query itself. Care must be taken, however, to configure the filters to ensure that suspension raycasts only interact with the shapes of other vehicles.

**Note:** It is vital that WheelRaycastPreFilter returns PxQueryHitType::eBLOCK if a raycast hit is allowed for the filter data pair. Using PxQueryHitType::eBLOCK guarantees that each raycast returns either no hits or just the hit closest to the start point of the raycast. This is important because PXVehicleSuspensionRaycasts and PXVehicleUpdates expect a one-to-one correspondence between each element in the PxRaycastQueryResult and PxRaycastHit arrays passed to the query.

**Tire Friction on Drivable Surfaces**
In this Section setting up tire types, drivable surface types, or combinations of tire and surface type shall be discussed.

To implement a unique friction value for each combination of tire type and first necessary to assign tire types to tires. In Section `setupWheelsSimulat` type was assigned to each tire:

```cpp
//Set up the tires.
PxVehicleTireData tires[PX_MAX_NB_WHEELS];
{
    //Set up the tires.
    for(PxU32 i = 0; i < numWheels; i++)
    {
        tires[i].mType = TIRE_TYPE_NORMAL;
    }
}
```

Assigning a type to each surface is a little more complex. The basic suspension raycast hit returns the PxMaterial of the shape hit by knowledge of a PxMaterial array it is possible to associate the type of a index of the PxMaterial array element that matches the material hit by lookup and the table of friction values is managed `PxVehicleDrivableSurfaceToTireFrictionPairs`. To make the feature m element of the PxMaterial array is actually associates `PxVehicleDrivableSurfaceToTireFrictionPairs` instance. This allows multiple PxMaterial share the same surface type.

In the vehicle snippets the following code makes the association between surface type and then associates each combination of tire and surface value:

```cpp
PxVehicleDrivableSurfaceToTireFrictionPairs* createFrictionPairs(
    const PxMaterial* defaultMaterial)
{
    PxVehicleDrivableSurfaceType surfaceTypes[1];
    surfaceTypes[0].mType = SURFACE_TYPE_TARMAC;

    PxMaterial* surfaceMaterials[1];
    surfaceMaterials[0] = defaultMaterial;
```
PxVehicleDrivableSurfaceToTireFrictionPairs* surfaceTirePairs =
PxVehicleDrivableSurfaceToTireFrictionPairs::allocate(MAX_NUM_SURFACE_TYPES);

surfaceTirePairs->setup(MAX_NUM_TIRE_TYPES, MAX_NUM_SURFACE_TYPES,
surfaceMaterials, surfaceTypes);

for(PxU32 i = 0; i < MAX_NUM_SURFACE_TYPES; i++)
{
    for(PxU32 j = 0; j < MAX_NUM_TIRE_TYPES; j++)
    {
        surfaceTirePairs->setTypePairFriction(i, j, gTireFrictionMultipliers);
    }
}
return surfaceTirePairs;

**Note:** It is not necessary to provide an exhaustive array of all materials. 
PxVehicleDrivableSurfaceToTireFrictionPairs has no knowledge of the materials and assumes a value of zero for the surface type.

There is no upper bound on the friction values used in the PhysX vehicle model. The maximum value of friction that obeys the laws of physics is 1.0, but the PhysX Vehicles SDK purposefully does not enforce this rule. One reason for this is that a vehicle model is far from a complete description of a real vehicle, meaning that some liberties need to be taken with friction values to generate the desired behavior. A more complete model would certainly provide greater accuracy given a specific set of vehicle parameters, but it also has clear that it would provide a greater range of editable and controllable behaviors. Another reason that friction is not clamped at 1.0 is that games typically simulate the physics update at 60 Hz, which comes at a cost to numerical accuracy, especially when there are transient tire effects that require KHz update frequencies. One source of numerical instability is the amplitude of oscillation of the suspension, which is governed in turn by the vehicle's distance that it falls under gravity between each update. At KHz update frequencies, this simulation artifact is acceptably small, but not at 60 Hz. The last reason is simply no need to impose the strict rules of friction on the vehicles SDK: interesting behaviors to be generated that would perhaps be impossible
by the laws of rigid body and tire dynamics. Having said all this, however, the model simulated at 60Hz ought to have enough integrity that only small tweaks should be necessary. If very large friction values are required, say greater than 2.0, it is likely that something is wrong with the update order or perhaps very data has been used.

A PxVehicleDrivableSurfaceToTireFrictionPairs instance is passed as a for each call to PxVehicleUpdates. Each PxVehicleDrivableSurfaceToTireFrictionPairs need only persist for PxVehicleUpdates. It is perfectly legal to edit the tire types, materials and between calls to PxVehicleUpdates. Editing any of these values while P still executing will lead to undefined behavior.

**Vehicle Controls**

In this Section setting the control values used to drive a vehicle shall be discussed. The simplest and most direct way to set vehicle control values is to function:

```cpp
void PxVehicleDriveDynData::setAnalogInput(const PxReal analogVal)
```

One of the difficulties with vehicle dynamics in games is knowing how to filter the controller data in a way that results in pleasing handling. Players, for example, accelerate by pressing very quickly on the accelerator trigger in a way that would never happen in a real car. This rapid acceleration can have a counter-productive effect because the resulting wheel spin reduces the lateral and longitudinal forces that can be generated by the tire. To help overcome some of these problems some optional code has been provided to filter the control data from keyboard and gamepad.

A solution to the problem of filtering controller input data is to assign a rise and fall rate to each button or pad. For analog values under digital control it is possible to increase or decrease the analog value at a specified rate depending on whether the digital input is on or off. For analog values under analog control it makes more sense
previous input value to the current input at a specified rate. A slight complication to this simple model is that the difficulty of achieving a large steer angle at large speed must also be modeled. One technique to achieve this would be to model the forces from aligning moments and apply these to a steering linkage model. This sounds rather complicated and quite difficult to tune. A simpler solution might be to scale the steer value by another value in range (0,1) that decreases at high speed.

Rise and fall rates for digital and analog control have been implemented in the SnippetVehicle4W:

```cpp
PxVehicleKeySmoothingData gKeySmoothingData =
{    
{        3.0f,  //rise rate eANALOG_INPUT_ACCEL 
        3.0f,  //rise rate eANALOG_INPUT_BRAKE 
        10.0f, //rise rate eANALOG_INPUT_HANDBRAKE 
        2.5f,  //rise rate eANALOG_INPUT_STEER_LEFT 
        2.5f,  //rise rate eANALOG_INPUT_STEER_RIGHT 
    },
    
{        5.0f,  //fall rate eANALOG_INPUT__ACCEL 
        5.0f,  //fall rate eANALOG_INPUT__BRAKE 
        10.0f, //fall rate eANALOG_INPUT__HANDBRAKE 
        5.0f,  //fall rate eANALOG_INPUT__STEER_LEFT 
        5.0f   //fall rate eANALOG_INPUT__STEER_RIGHT 
    }
};

PxVehiclePadSmoothingData gPadSmoothingData =
{    
{        6.0f,  //rise rate eANALOG_INPUT_ACCEL 
        6.0f,  //rise rate eANALOG_INPUT_BRAKE 
        12.0f, //rise rate eANALOG_INPUT_HANDBRAKE 
        2.5f,  //rise rate eANALOG_INPUT_STEER_LEFT 
        2.5f,  //rise rate eANALOG_INPUT_STEER_RIGHT 
    },
    
{        10.0f, //fall rate eANALOG_INPUT_ACCEL 
        10.0f, //fall rate eANALOG_INPUT_BRAKE 
        12.0f, //fall rate eANALOG_INPUT_HANDBRAKE 
        5.0f,  //fall rate eANALOG_INPUT_STEER_LEFT 
```
A look-up table has also been specified to describe the maximum steer speed:

```cpp
PXFixedSizeLookupTable<8> gSteerVsForwardSpeedTable(gSteerVsForwardSpeedData[2*8]=
{
    0.0f,    0.75f,
    5.0f,    0.75f,
    30.0f,   0.125f,
    120.0f,  0.1f,
    PX_MAX_F32, PX_MAX_F32,
    PX_MAX_F32, PX_MAX_F32,
    PX_MAX_F32, PX_MAX_F32,
    PX_MAX_F32, PX_MAX_F32
};
```

Using a PxVehicleDrive4WRawInputData instance it is straightforward inputs in the event a keyboard is used:

```cpp
gVehicleInputData.setDigitalAccel(true);
gVehicleInputData.setDigitalBrake(true);
gVehicleInputData.setDigitalHandbrake(true);
gVehicleInputData.setDigitalSteerLeft(true);
gVehicleInputData.setDigitalSteerRight(true);
gVehicleInputData.setGearUp(true);
gVehicleInputData.setGearDown(true);
```

or in the event that a gamepad is used:

```cpp
gVehicleInputData.setAnalogAccel(1.0f);
gVehicleInputData.setAnalogBrake(1.0f);
gVehicleInputData.setAnalogHandbrake(1.0f);
gVehicleInputData.setAnalogSteer(1.0f);
gVehicleInputData.setGearUp(1.0f);
gVehicleInputData.setGearDown(1.0f);
```

Here, gVehicleInputData is an instance of the vehicle SDK PxVehicleDrive4WRawInputData.
The vehicle SDK offers two optional functions to smooth the keyboard and apply the smoothed input values to the PhysX vehicle. If the vehicle is controlled by digital inputs then the following function is used:

```cpp
PxVehicleDrive4WSmoothDigitalRawInputsAndSetAnalogInputs(gKeySmoothingData, gSteerVsForwardSpeedTable, carRawInputs, timestep, isInAir, (PxVehicleDrive4W))
```

while gamepad controllers employ the following code:

```cpp
PxVehicleDrive4WSmoothAnalogRawInputsAndSetAnalogInputs(gCarPadSmoothingData, gSteerVsForwardSpeedTable, carRawInputs, timestep, (PxVehicleDrive4W))
```

The code above smoothes the controller inputs and applies them to a instance. For other vehicle types the process is remarkably similar with complementary classes and functions designed for each vehicle type.

**Vehicle Update**

It has already been mentioned that vehicles are updated in two stages:

1. specific vehicle code that updates the vehicle internal dynamic forces/torques to apply to the vehicle's rigid body representation
2. an SDK update that accounts for the applied forces/torques as well as collision with other scene bodies.

In Section *Introduction To Vehicle Update* the functions used to perform vehicle updates were introduced. In this Section these separate update phases will be discussed in more detail.

**Raycast and Update Ordering**

Prior to the first time that a vehicle is updated in PxVehicleUpdates, it performed suspension line raycasts at least once with PxVehicleSuspensionRaycasts. Subsequent updates it is not strictly necessary to issue fresh raycasts.
vehicle caches raycast hit planes that can be re-used. It is recommended there be
one-to-one correspondence between raycast completion and update except for the case of vehicles that only require a low level of detail. For cars that are far from the camera or where it is known that the vehicle geometry with high spatial coherence. Support for vehicles that require high detail is discussed in Section Level of Detail.

There is some freedom in the order in which raycasts can be issued relative to the vehicle dynamics update. In a real-world situation it might be that raycasts can be issued on a separate thread at the end of the update loop so that they are ready for use at the beginning of the next. However, this really all depends on the threading environment and the ordering of rigid body updates.

Wheel Pose

PxVehicleUpdates poses the wheels shapes of the vehicle's actor to take into account the steer, camber, and rotation angles. The computed pose also attempts to place the wheel geometry exactly on the contact plane identified by the raycast that was issued along the suspension line. To perform this function the PhysX Vehicles SDK needs to know which shapes of the actor correspond to each wheel of the vehicle. This is achieved with the function PxVehicleWheelsSimData::setWheelShapeMapping.

**Note:** The vehicle SDK has a default mapping for each wheel that is equivalent to PxVehicleWheelsSimData::setWheelShapeMapping(i,i). This needs to be corrected if the layout of the shapes is different from the default pattern.

**Note:** PxVehicleWheelsSimData::setWheelShapeMapping(i,-1) can be used to disable setting the local wheel pose. This is particularly useful if a wheel has no corresponding actor geometry.

The wheel pose is always within the limits PxVehicleSuspensionData::mMaxDroop and PxVehicleSuspensionData::mMaxCompression. If the suspension requires the wheel to be placed beyond the compression limit the wheel will be placed at
the compression limit and a rigid body constraint will handle the difference simulate() call.

Vehicle State Queries

Each vehicle stores persistent simulation data that is updated each time PxVehicleUpdates is called. Examples of persistent data include wheel rotation angle, and wheel rotation speed. Additionally, a large amount of non-persistent data is computed during each update. This non-persistent data is not stored in the vehicle's own data structures. Instead, a data buffer is passed to and queried after PxVehicleUpdates completes. Examples of non-persistent data include suspension jounce, tire force and raycast hit actor. The combination of these data types allows an almost complete snapshot of the state of the vehicle and can trigger secondary effects such as skid marks, engine and clutch audio, and smoke particles.

Persistent wheel data is stored in PxVehicleWheelsDynData, while persistent drive model data is stored in PxVehicleDriveDynData. The most useful functions are:

```cpp
PX_FORCE_INLINE PxReal PxVehicleDriveDynData::getEngineRotationSpeed()
PxReal PxVehicleWheelsDynData::getWheelRotationSpeed(const PxU32 wheelIdx)
PxReal PxVehicleWheelsDynData::getWheelRotationAngle(const PxU32 wheelIdx)
```

To record non-persistent simulation data so that it may be later be queried, a function argument must be passed to PxVehicleUpdates. The following code records non-persistent data for a single 4-wheeled car:

```cpp
PxWheelQueryResult wheelQueryResults[4];
PxVehicleWheelQueryResult vehicleWheelQueryResults[1] = {{wheelQueryResults}};
PxVehicleUpdates(timestep, gravity, frictionPairs, 1, vehicles, vehicleWheelQueryResults[0]);
```

Here, a PxVehicleWheelQueryResult array, whose length equals at least the number of vehicles in the batched vehicles array, is passed to PxVehicleUpdates. Each PxVehicleWheelQueryResult instance has a pointer to a PxWheelQueryResult buffer, whose length equals at least the number of wheels in the vehicle. After
is complete the state of each vehicle wheel may be inspected.

It is not obligatory to record non-persistent data for later query. Indeed, associate a vehicle with a NULL data block to avoid storing non-persistent data. This feature allows memory budgets to be targeted at the vehicles of highest interest.
Vehicle Telemetry

The purpose of telemetry data is to expose the inner dynamics of the car tuning through the use of telemetry graphs. In this Section initialization and rendering of telemetry data shall be discussed.

Telemetry data is recorded by calling the following function:

```cpp
void PxVehicleUpdateSingleVehicleAndStoreTelemetryData
(const PxReal timestep, const PxVec3& gravity,
 const PxVehicleDrivableSurfaceToTireFrictionPairs& vehicleDriv,
 PxVehicleWheels* focusVehicle, PxVehicleWheelQueryResult* ve,
 PxVehicleTelemetryData& telemetryData);
```

The function above is identical to PxVehicleUpdates with the exception that it can only update a single vehicle at a time and takes an extra function argument telemetryData.

Setting up the telemetry data is relatively straightforward. In addition to storing the telemetry data streams, the PxVehicleTelemetryData structure also stores the size, position, and color scheme of the graph. The following pseudo code initializes and configures telemetry data for a 4-wheeled vehicle:

```cpp
PxVehicleTelemetryData* myTelemetryData = PxVehicleTelemetryData::
const PxF32  graphSizeX=0.25f;
const PxF32  graphSizeY=0.25f;
const PxF32  engineGraphPosX=0.5f;
const PxF32  engineGraphPosY=0.5f;
const PxF32  wheelGraphPosY[4]={0.75f,0.25f,0.75f,0.25f};
const PxF32  wheelGraphPosY[4]={0.75f,0.75f,0.25f,0.25f};
const PxVec3 backgroundColor(255,255,255);
const PxVec3 lineColorHigh(255,0,0);
const PxVec3 lineColorLow(0,0,0);
myTelemetryData->setup
    (graphSizeX,graphSizeY,
     engineGraphPosX,engineGraphPosY,
     engineGraphPosY[0],engineGraphPosY[1],engineGraphPosY[2],engineGraphPosY[3],
     lineColorHigh,lineColorLow,backgroundColor);
```
The sizes, positions, and colors are all values that will be used to render the graphs. The exact values of these fields will depend on the coordinate system and color coding used to visualize the telemetry data.

In the above example, the coordinates have been configured to render a graph in the center of the screen under the assumption that (1,1) is the top left-hand side of the screen and (0,0) the bottom right-hand side of the screen. Screen coordinates have also been specified for rendering data associated with each of the four wheels.

The following enumerated lists detail the telemetry data that is collected:

```c
enum
{
    eCHANNEL_JOUNCE=0,
    eCHANNEL_SUSPFORCE,
    eCHANNEL_TIRELOAD,
    eCHANNEL_NORMALISED_TIRELOAD,
    eCHANNEL_WHEEL_OMEGA,
    eCHANNEL_TIRE_FRICTION,
    eCHANNEL_TIRE_LONG_SLIP,
    eCHANNEL_NORM_TIRE_LONG_FORCE,
    eCHANNEL_TIRE_LAT_SLIP,
    eCHANNEL_NORM_TIRE_LAT_FORCE,
    eCHANNEL_NORM_TIRE_ALIGNING_MOMENT,
    eMAX_NUM_WHEEL_CHANNELS
};
enum
{
    eCHANNEL_ENGINE_REVS=0,
    eCHANNEL_ENGINE_DRIVE_TORQUE,
    eCHANNEL_CLUTCH_SLIP,
    eCHANNEL_ACCEL_CONTROL,
    eCHANNEL_BRAKECONTROL,
    eCHANNEL_HANDBRAKE_CONTROL,
    eCHANNEL_STEER_CONTROL,
    eCHANNEL_GEAR_RATIO,
    eMAX_NUM_ENGINE_CHANNELS
};
```
Data is collected for suspension jounce, suspension force, tire load, normalized tire load, wheel rotation speed, tire friction, tire longitudinal slip, tire longitudinal force, tire lateral slip, tire lateral force, and tire aligning moment. Data is also collected for engine revs, engine drive torque, clutch slip, applied acceleration/brake, and gear ratio. For each graph all associated data is collected in separate channels that can be accessed after the update is complete.

Prior to rendering the graph of a particular wheel and channel the following pseudo-code is required:

```cpp
PxF32 xy[2*PxVehicleGraph::eMAX_NB_SAMPLES];
PxVec3 color[PxVehicleGraph::eMAX_NB_SAMPLES];
char title[PxVehicleGraph::eMAX_NB_TITLE_CHARS];
myTelemetryData->getWheelGraph(wheel).computeGraphChannel(PxVehicleWheelGraphChannel xy, color, title);
```

This code computes a sequence of screen coordinates \([x_0,y_0,x_1,y_1,x_2,y_2,\ldots,x_n,y_n]\) that represent the points of the specified graph channel of the engine’s graph data. It also stores a color for each sample by choosing between lineColorHigh and lineColorLow depending on the value of the sample. The channel stores the last 256 samples so that a history of each parameter can be rendered on the screen.

The PhysX Vehicles SDK does not render the graphs. This is an exercise left to the application because each has its own system for rendering debug information.

**Vehicle Update Multi-Threaded**

The PhysX Vehicles SDK can be used in a multi-threaded environment to take advantage of performance improvements arising from parallelism. The update steps proceed exactly as described in Section *Vehicle Update* but with an extra sequential call to `PxVehiclePostUpdates` after all concurrent calls to `PxVehicleSuspensionRaycasts` and `PxVehicleUpdates` are complete. `PxVehiclePostUpdates` performs write operations normally executed in `PxVehicleUpdates` but which are not possible to efficiently or safely call when concurrency is employed.
PxVehicleSuspensionRaycasts is a thread-safe function and can be called concurrently without any modifications to the calling code with the exception, of course, of managing the tasks and threads that will execute the raycasts concurrently. On the other hand, PxVehicleUpdates as used in Section Vehicle Update is not thread-safe and requires an extra PxVehicleConcurrentUpdateData array to be specified for it to be concurrently executed. When this extra data is specified PxVehicleUpdates defers a number of writes to PhysX actors that are involved in the vehicle updates. These writes are stored in the PxVehicleConcurrentUpdateData array during calls to PxVehicleUpdates and then executed sequentially in PxVehiclePostUpdates.

Sample code can be found in SnippetVehicleMultiThreading.

**Tire Shaders**

It is possible to replace the default tire model used by PhysX vehicles with custom models. This requires a shader function that can be set per-vehicle along with shader data that must be set per-wheel:

```cpp
void PxVehicleWheelsDynData::setTireForceShaderFunction(
PxVehicleComputeTireForce tireForceShaderFn)
void PxVehicleWheelsDynData::setTireForceShaderData(
    const PxU32 tireId, const void* tireForceShaderData)
```

The shader function must implement this function prototype:

```cpp
typedef void (*PxVehicleComputeTireForce)(
    const void* shaderData,
    const PxF32 tireFriction,
    const PxF32 longSlip, const PxF32 latSlip, const PxF32 camber,
    const PxF32 wheelOmega, const PxF32 wheelRadius, const PxF32 recipWheelRadius,
    const PxF32 restTireLoad, const PxF32 normalisedTireLoad, const PxF32 gravity,
    const PxF32& wheelTorque, PxF32& tireLongForceMag, PxF32& tireLatForceMag)
```

The vehicle update code will call the shader function for each wheel with the shader data for that wheel.
Vehicle Types

The PhysX Vehicle SDK supports four types of vehicle: PxVehicleDriveNW, PxVehicleDriveTank and PxVehicleNoDrive. PxVehicleDrive4W will be the best choice for rally cars, street cars and racing cars. PxVehicleDriveNW is very similar to PxVehicleDrive4W except that it allows all wheels to be coupled to the differential. This general differential models of PxVehicleDriveNW cannot match the range or effect of PxVehicleDrive4W. PxVehicleDriveTank implements a simple but efficient tank model by constraining the left and right wheel speeds to mimic the effect of tank tracks. PxVehicleNoDrive implements a vehicle that is simply a rigid body with wheels and tires. The idea here is to allow custom drive models such as skateboards and hovercraft to be implemented using PhysX vehicles.

PxVehicleDrive4W

The class PxVehicleDrive4W has already been discussed in some detail but the discussion so far has focused on 4-wheeled vehicles. In the following sections PxVehicleDrive4W shall be discussed with special reference to instances with less than and more than 4 wheels.

3-Wheeled Cars

Utility functions have been provided to quickly configure 3-wheeled cars to start with a 4-wheeled car and then disable one of the wheels:

```cpp
void PxVehicle4WEnable3WTadpoleMode(PxVehicleWheelsSimData& wheelsSimData, PxVehicleWheelsDynData& wheelsDynData, PxVehicleDriveSimData4W driveSimData)
void PxVehicle4WEnable3WDeltaMode(PxVehicleWheelsSimData& wheelsSimData, PxVehicleWheelsDynData& wheelsDynData, PxVehicleDriveSimData4W driveSimData)
```

These functions ensure that no raycast hits are returned for the disabled wheel and additionally do some other work to decouple the disabled wheel from the axle, disable ackermann correction, re-position the opposite remaining wheel to the center of the axle, and adjust the suspension of the opposite remaining wheel to...
missing suspension of the disabled wheel. Further wheels could in theo
custom code to create a vehicle with 1 or 2 effective wheels. At that po-balancing code would be required to prevent the vehicle falling over.

Some care must be taken when removing a wheel because the function has a number of requirements that must be satisfied for all requirement is that any wheel that has been disabled must not be PxShape. This is a safety feature that prevents PxVehicleUpdates at local pose of a PxShape that may no longer be valid. PxVehicleWheelsSimData::setWheelShapeMapping can be used to satisfied this requirement. The second requirement is that any wheel that has been disabled must have zero wheel rotation speed. This can be satisfied by calling PxVehicleWheelsDynData::setWheelRotationSpeed for the relevant wheel. The final requirement is that disabled wheels must receive no drive torque. This requirement can actually be ignored because it is automatically enforced by the PxVehicleUpdates function. For vehicles of type PxVehicleNoDrive the requirement on drive torque is fulfilled by ensuring that PxVehicleNoDrive::setDriveTorque is never called with a non-zero torque value. Further, the drive torque requirement can be readily fulfilled for vehicles of type PxVehicleDriveNW by ensuring that the differential is disconnected from the disabled wheel. This is achieved usingPxVehicleDifferentialNWData::setDrivenWheel.

Configuring the differential of a PxVehicle4W to ensure that no drive torque is delivered to a disabled wheel is a little more complex because there are many ways to achieve this. If the wheel is not a driven wheel then disabling the wheel satisfies the drive torque requirement because such wheels can never be connected to the differential. On the other hand, if the wheel has index eFRONT_LEFT or eFRONT_RIGHT or eREAR_LEFT or eREAR_RIGHT then the differential does need to enforce the requirement. One way to do this is to set up the differential to deliver torque to only the rear(front) wheels if a front(rear) wheel has been disabled. This is achieved using:

```
PxVehicleDifferential4WData diff = myVehicle.getDiffData();
if(PxVehicleDrive4WWheelOrder::eFRONT_LEFT == wheelToDisable ||
```
In some situations limiting the drove torque to just the front or rear wheels might not be acceptable. If only a single wheel has been disabled then it is possible to engage a drive mode where 3 wheels are driven. This can be achieved by modifying a differential that delivers torque to all four wheels (eDIFF_TYPE_LS_4WD or eDIFF_TYPE_OPEN_4WD) so that torque is only delivered to 3 wheels:

```cpp
PxVehicleDifferential4WData diff = myVehicle.getDiffData();
if(PxVehicleDrive4WWheelOrder::eFRONT_LEFT == wheelToDisable ||
  PxVehicleDrive4WWheelOrder::eFRONT_RIGHT == wheelToDisable)
{
  if(PxVehicleDifferential4WData::eDIFF_TYPE_LS_4WD == diff.mType)
    { diff.mBias = 1.3f;
      diff.mRearLeftRightSplit = 0.5f;
      diff.mType = PxVehicleDifferential4WData::eDIFF_TYPE_LS_REARWD;
      //could also be PxVehicleDifferential4WData::eDIFF_TYPE_OPEN_REARWD;
    }
}
myVehicle.setDiffData(diff);
```
In some situations it will make sense to disable Ackermann steer correction if the disabled wheel was able to steer. In particular, if the remaining wheel of the front or rear axle is repositioned so that it is at the center of the axle then it would almost certainly follow that Ackermann correction would be disabled. This can be achieved by setting the accuracy to zero (PxVehicleAckermannGeometryData::mAccuracy). The role of the Ackermann correction, however, really needs to be determined on a case by case basis.

N-Wheeled Cars

In addition to removing wheels from a vehicle, it is also possible to construct a PxVehicleDrive4W with more than 4 wheels but with the caveat that only 4 wheels may be driven. As a consequence of this caveat the functionality of the extra wheels is limited compared to the first 4 wheels. More specifically, only the first block of 4 wheels is connected to the differential or the steering; that is, only the first block of 4 wheels can experience a drive torque or a steer angle and only the first block of 4 wheels...
the Ackermann steering correction. As a consequence, the extra wheel role to the rear wheels of a 4-wheeled car that has front-wheel drive or a 4-wheeled car that has rear-wheel drive. Adding extra wheels does ability to call PxVehicle4WEnable3WTadpoleMode or PxVehicle4WEnable. These functions, however, are hard-coded to disable one of the 4 wheels connected to the steering and driven through the differential.

The following pseudo-code illustrates the key steps in the creation of a PxVehicleDrive4W vehicle:

```cpp
PxVehicleWheelsSimData* wheelsSimData=PxVehicleWheelsSimData::all;
PxVehicleDriveSimData4W driveSimData;
setupSimData(wheelsSimData, driveSimData);
PxVehicleDrive4W* car = PxVehicleDrive4W::allocate(6);
PxRigidDynamic* vehActor=createVehicleActor6W();
car->setup(&physics, vehActor, *wheelsSimData, driveSimData, 2);
```

**PxVehicleDriveNW**

While the PxVehicleDrive4W allows cars with any number of wheels simulated it only allows 4 of those wheels to be driven by engine torque. The vehicle type PxVehicleDriveNW has been introduced to solve this limitation. This vehicle class makes use of the differential type PxVehicleDifferentialNW, a class that allows any or all of the vehicle's wheels to be coupled to the differential. The limitation that the torque available at the differential is always divided equally among the wheels that are coupled to the differential. The generality of PxVehicleNW precludes advanced features such as limited slip differentials and Ackermann steering, meaning that only a simple equal-split differential model can be provided.

The following pseudo-code illustrates the key steps in the creation of a PxVehicleDriveNW vehicle:

```cpp
PxVehicleWheelsSimData* wheelsSimData=PxVehicleWheelsSimData::all;
PxVehicleDriveSimDataNW driveSimData;
setupSimData(wheelsSimData, driveSimData);
PxVehicleDriveNW* car = PxVehicleDriveNW::allocate(6);
PxRigidDynamic* vehActor=createVehicleActorNW();
car->setup(&physics, vehActor, *wheelsSimData, driveSimData, 6);
```
The PhysX vehicle SDK also supports tanks through the use of the `PxVehicleDriveTank` class. Tanks are different to multi-wheeled vehicles in that the wheels are driven through the differential in a way that ensures that all the wheels on the left-hand side have the same speed, and all the wheels on the right-hand have the same speed. This constraint on wheel speed mimics the effect of the caterpillar tracks but avoids the expense of simulating the jointed track structure. Adding the geometry of the caterpillar tracks is as easy as adding an actor shape down each side and setting up the collision and query filters as appropriate for the tracks. The motion of the caterpillar tracks could be rendered with a scrolling texture, safe in the knowledge that all wheels have the same speed, just as though they were properly constrained by the track rotation.

Creating a `PxVehicleDriveTank` instance is very similar to creating a `PxVehicleDrive4W` instance with the exception that tanks have no concept of extra wheels not connected to the differential: all tank wheels are driven. The following code sets up a 12-wheeled tank:

```cpp
PxVehicleWheelsSimData* wheelsSimData = PxVehicleWheelsSimData::allocate();
PxVehicleDriveSimData4W driveSimData;
setupTankSimData(wheelsSimData, driveSimData);
PxVehicleDriveTank* tank = PxVehicleDriveTank::allocate(12);
PxRigidDynamic* vehActor= createVehicleActor12W();
tank->setup(&physics, vehActor, *wheelsSimData, tankDriveSimData, 12);
```

Controlling a tank is quite different to controlling a car because tanks have a different steering mechanism: the turning action of a tank arises from the difference in left and right wheel speeds, while cars turn by the action of a steering wheel that orients the front wheels relative to the forward motion of the vehicle. This requires a set of helper classes and functions to smooth the control inputs:

1. `PxVehicleDriveTankRawInputData`
2. `PxVehicleDriveTankSmoothDigitalRawInputsAndSetAnalogInputs`
3. `PxVehicleDriveTankSmoothAnalogRawInputsAndSetAnalogInputs`

PhysX tanks currently support two drive models: eSTANDARD and eS
model eSPECIAL allows the tank tracks to rotate in different directions; eSTANDARD does not. These two modes result in quite different turning actions. A model eSTANDARD simulates the usual turning action of a tank: pushing the left(right) stick drives the left(right) wheels forward, while pulling back on the right(left) stick applies the brake to the right(left) wheels. eSPECIAL, on the other hand, simulates a more exotic turning action where pushing back on the right(left) stick drives the left(right) wheels backwards. This can result in a turning circle focused at the center of the tank, which is the smallest possible turning circle of a tank in eSTANDARD. The turning circle will focus to a point along one of the caterpillar tracks, depending on whether the tank is turning left or right.

PxVehicleNoDrive

The class PxVehicleNoDrive has been introduced to provide a close approximation to the interface to the 2.8.x NxWheelShape class, essentially a rigid body with N suspension/wheel/tire units attached. It is identical to that of a PxVehicleDrive4W which is permanently in neutral gear so that the engine has no influence on the wheels and the wheels are coupled to the rig motion of the rigid body. This comes, of course, without the storage overhead of Ackermann steering correction data, engine torque curve data etc. The idea is that users can develop their own drive model on top of already existing vehicle code, the suspension raycasts, tire and suspension force computation, and PhysX integration.

The key functions are the application of per wheel drive and brake torques, and steer angles:

```cpp
/**
 \brief Set the brake torque to be applied to a specific wheel
 */
void setBrakeTorque(const PxU32 id, const PxReal brakeTorque);

/**
 \brief Set the drive torque to be applied to a specific wheel
 */
void setDriveTorque(const PxU32 id, const PxReal driveTorque);

/**
 \brief Set the steer angle to be applied to a specific wheel
 */
```
void setSteerAngle(const PxU32 id, const PxReal steerAngle);

### SI Units

The discussion so far has assumed that distance is measured in metres, mass is measured in kilograms, and that time is measured in seconds. Furthermore, all of the relevant vehicle components have been set under the assumption that SI Units will be adopted. An example of such a default parameter is the maximum braking torque. Inspection of the constructor for PxVehicleWheelData reveals a value of mMaxBrakeTorque. This number actually represents a value of 1500 "Kilogram Metres-Squared Per Second-Squared" (an alternative way of expressing this is "Newton Metres"). An important question is how to set up a vehicle with meaningful values if SI units are not adopted. The purpose of this Section is to illustrate the steps required, in particular, the case where distance is measured in centimeters rather than meters is used as an example. This particular deviation from the adoption of SI Units is probably the most common one in game development, arising from the units of distance in the chosen 3D modeling package.

Vehicle parameters whose value is dependent on the length scale fall into two categories: those that can theoretically be measured with a ruler and those with values involving combinations of other properties such as mass or time or distance. The former category includes data fields such as wheel radius or maximum suspension droop, while the latter category includes data fields such as maximum braking torque or wheel moment of inertia.

The following is an exhaustive list of vehicle parameters that can be measured solely from vehicle geometry:

- `PxVehicleChassisData::mCMOffset`
- `PxVehicleAckermannGeometryData::mFrontWidth`
- `PxVehicleAckermannGeometryData::mRearWidth`
- `PxVehicleAckermannGeometryData::mAxleSeparation`
- `PxVehicleWheelData::mRadius`
It is useful to note that all the above parameters have default values independent of length scale they must always be set with measured corresponding length scale if a legal vehicle is to be successfully instantiated.

Setting parameters that involve more complex combinations of length scale more thought than those featured in the list above. A simple rule of parameter that has units linear with distance must be scaled by the number that is equivalent to 1 meter, while any parameter that has units involving distance must be scaled by the square of the number of length units that are equivalent to 1 meter. A wheel braking torque of 1500 kilograms metres-squared per second, for example, is equivalent to 1500*100*100 kilograms centimeters-squared per second-squared. Consequently, when centimeters is used as the length scale as a good initial guess for wheel braking torque is 15000000 [kilograms centimeters-squared per second-squared]. If inches are used as the length scale then a good initial guess for braking torque would be 1500*39.37*39.37 (= 2324995.35) [kilograms inches-squared per second-squared].

Each non-dimensionless parameter has been described with the corresponding Units in PxVehicleComponents.h. The following is an exhaustive list of vehicle parameters that are indirect expressions of distance scale:
All but the last three of the above parameters have non-zero initial values in their associated constructors. This means that a good guess for their initial value can be found by multiplying the value expressed in SI Units with either the number of length units equivalent to 1 meter or the square of the number of length units that are equivalent to 1 meter.

It is important to note that the wheel handbrake torque has a default value of zero because not all wheels respond to the handbrake torque. A good guess for the handbrake torque is simply the value of the wheel braking torque, perhaps multiplied by between 1.0 and 2.0 to ensure that the handbrake is stronger than the brake.

The wheel moment of inertia and chassis moment of inertia are typically computed from the wheel radius and chassis dimensions so naturally reflect the length scale used in the simulation. If values are taken from manufacturer data it is important that the units of the manufacturer data are commensurate with the remainder of the vehicle data fields or to perform the appropriate unit conversion.

A number of functions also have parameters that are functions of length scale.

Following is an exhaustive list of such functions:

```
PxVehicleWheelsSimData::setSubStepCount
PxVehicleWheelsSimData::setMinLongSlipDenominator
```
Some care is required to set the threshold speed in PxVehicleWheels: Here, it is the case that the default threshold speed is 5.0 metres centimeters the chosen length scale a value of 500 [centimeters per passed to achieve the equivalent behavior, or with inches as the cho value of 5*39.37 (= 196.85) [inches per second] is required. The same be applied to PxVehicleWheelsSimData::setMinLongSlipDenominator. I 4.0 metres per second. If centimeters is the adopted scale then the equ [centimeters per second], while 4*39.37 (=157.48) [inches per second] i is the chosen scale. PxVehicleSetMaxHitActorAcceleration takes a linearly with the length scale. If the desired maximum acceleration second per second then that would be scaled to 10*100 centimetres second in centimetres scale. With inches as the length scale the equ be 10*39.37 inches per second per second.

The PhysX Vehicle SDK supports any system of units with the ca supplied must conform to the same unit system. Further, the default da strictly expressed in the SI unit system, can be used as a guide to values in any unit system for almost any conceivable vehicle. A quick w be to decide if, say, a truck would have a stronger handbrake than t family car. Now, the default data approximates that of a standard family a good estimate to start with the truck having a handbrake that is perf that is, 5000 kilograms metres-squared per second-squared. If centimet length scale then a quick conversion can be performed by noting that 100 centimeters, leading to the brake torque being set as 5000*: centimeters-squared per second-squared. If the natural unit of mass noting that 1 kilogram is 1000 grams leads to an equivalent value of metres-squared per second-squared. This rule can be repeated for all by simply noting the default value and the SI units in the relevant cla then performing the conversion to the chosen unit system.

The PhysX Vehicle SDK depends on a number of threshold values t length scale. These are set with the function PxInitVehicleSD
PxTolerancesScale values that have already been configured for the PhysX SDK. If PxInitVehicleSDK is not called prior to the first call to PxVehicleUpdates, a warning will be passed to the PhysX error stream.

**Level of Detail**

It seems sensible to attempt to save valuable clock cycles for vehicles visible on the screen or are sufficiently far from the camera that it is motion is exactly in step with the world geometry. The PhysX vehicle number of options for reducing the computational load for vehicles the levels of detail.

**Extrapolation**

The most obvious strategy for a vehicle that requires only a low level of detail is simply to stop performing raycasts (PxVehicleSuspensionRaycasts) and updates (PxVehicleUpdates) for that vehicle. Instead of computing the ground vehicle's tires and computing the suspension and tire forces each and every frame, it might be acceptable to avoid these steps completely and let the PhysX SDK update the rigid body with the legacy momentum of the rigid body. After several frames, the vehicle's wheels will likely either be hovering above the ground or intersecting the ground. There needs to be a strategy to decide how many PhysX SDK updates can the vehicle be once more updated properly by including it in the vehicle's simulation? PxVehicleSuspensionRaycasts/PxVehicleUpdates. The details of any such strategy are left to users of the vehicles SDK because it depends on a number of factors such as distance from the camera; the spatial coherence of the world geometry; the speed of the vehicle; and whether the audio or graphics fx for the vehicle play an important role.

**Disable Wheels**

If there exist vehicles with large wheel counts it might also be possible to reduce the number of wheels that participate in the simulation by calling PxVehicleWheelsSimData::disableWheel. An example might be a truck...
Now, such a truck will clearly need to perform 18 raycasts, 18 tire force updates of wheel rotation speed in order to complete the vehicle update. If it can be reduced to just 4 enabled wheels then it is clear that less computational work is required. It is important to note that when wheels are disabled they no longer support the mass of the vehicle's rigid body. In the extreme case of a truck reduced to just 4 active wheels this will mean that the remaining enabled springs are only configured to support approximately 4/18 of the mass of the vehicle's rigid body. To remedy this problem the mass of the rigid body will need to be re-distributed among the enabled wheels and suspensions, using PxVehicleComputeSprungMasses. A more complete description of the disabled wheels can be found in Section 3-Wheeled Cars.

Swapping Multiple Vehicle Versions

Instead of disabling wheels, perhaps a simpler and more effective way to reduce the computational cost is to instantiate two versions of the vehicle with different wheel counts. The two vehicles can be easily swapped in the vehicles array passed to PxVehicleSuspensionRaycasts/PxVehicleUpdates as the required level of detail increases and decreases. It is worth considering how this might work in the case of the 18-wheeled truck mentioned earlier. The simplest strategy would be to first construct the required rigid body and attach a PxShape instance for each of the 18 wheels of the 18-wheeled truck. Instantiating the required 18-wheeled version of the truck with PxVehicleNW::create or PxVehicleNW::setup will automatically pose the shapes of all 18 wheels. The next step is to choose 4 of the 18 wheels to form the 4-wheeled version. Many choices are available but the most obvious choice would be the front-left/front-right/rear-left/rear-right wheels of the 18-wheeled truck. The 4-wheeled version can then be instantiated using the same rigid body as for the 18-wheeled version by passing the PxShape instances to the rest pose of the 4-wheeled truck. If the 4-wheeled version have been set up correctly the rest poses ought to be identical to their counterparts in the 18-wheeled version. A key point to note is that both versions of the vehicle apply forces to the same rigid body. Another key point to note is that if the 4-wheeled vehicle is chosen only 4 of the 18 PxShape instances will be updated, leaving 14 PxShape instances at either the rest local pose or the local pose given to them when the 18-wheeled version was last used. In terms of
these unposed shapes are the main disadvantage of the lower differences in handling are much harder to gauge.

A number of useful functions are available to make it easy to swap between versions of the same vehicle:

```cpp
void PxVehicleComputeSprungMasses(const PxU32 nbSprungMasses, const PxVec3* sprungMassCoordinates, const PxVec3& centreOfMass, const PxU32 gravityDirection, PxReal* sprungMasses);
void PxVehicleWheelsSimData::copy(const PxVehicleWheelsSimData& src, const PxU32 trgWheel);
void PxVehicleSuspensionData::setMassAndPreserveNaturalFrequency(const PxVehicleCopyDynamicsData &src, PxVehicleWheels& trg);
```

The following pseudo-code hopefully makes clear how to apply these functions:

```cpp
PxVehicleDriveNW* instantiate4WVersion(const PxVehicleDriveNW& vehicle18W) {
    // Compute the sprung masses of the 4-wheeled version.
    PxReal sprungMasses[4];
    {
        const PxReal rigidBodyMass = vehicle18W.getRigidDynamicActor().getTotalMass();
        const PxVec3 wheelCoords[4] = {vehicle18W.mWheelsSimData.getWheelCentreOffset(0), vehicle18W.mWheelsSimData.getWheelCentreOffset(1), vehicle18W.mWheelsSimData.getWheelCentreOffset(2), vehicle18W.mWheelsSimData.getWheelCentreOffset(3)};
        const PxU32 upDirection = 1;
        PxVehicleComputeSprungMasses(4, wheelCoords, PxVec3(0,0,0), sprungMasses);
    }

    // Set up the wheels simulation data.
    PxVehicleWheelsSimData* wheelsSimData4W = PxVehicleWheelsSimData::get()._data;
    for(PxU32 i = 0; i < 4; i++) {
        wheelsSimData4W->copy(vehicle18W.mWheelsSimData, i, i);
    }
    PxVehicleSuspensionData suspData = wheelsSimData4W->getSuspensionData();
}
```
suspData.setMassAnd PreserveNaturalFrequency(sprungMasses[
    wheelsSimData4W->setSuspensionData(i, suspData);
]
wheelsSimData4W->setTireLoadFilterData(vehicle18W.mWheelsSimData4W);

//Make sure the correct shapes are posed.
wheelsSimData4W->setWheelShapeMapping(0, 0);
wheelsSimData4W->setWheelShapeMapping(1, 1);
wheelsSimData4W->setWheelShapeMapping(2, 2);
wheelsSimData4W->setWheelShapeMapping(3, 3);

//Set up the drive simulation data.
PxVehicleDriveSimDataNW driveSimData4W = vehicle18W.mDriveSimDataNW;
PxVehicleDifferentialNWData diff4W;
diff4W.setDrivenWheel(0, true);
diff4W.setDrivenWheel(1, true);
diff4W.setDrivenWheel(2, true);
diff4W.setDrivenWheel(3, true);
driveSimData4W.setDiffData(diff4W);

//Instantiate the 4-wheeled version.
PxRigidDynamic* rigidDynamic =
    const_cast<PxRigidDynamic*>(vehicle18W.getRigidDynamicActor);
PxVehicleDriveNW* vehicle4W =
    PxVehicleDriveNW::create(&physics, rigidDynamic, *wheelsSimData4W);

//Delete the wheels simulation data now that we have copied to the vehicle.
wheelsSimData4W->free();

//Finished.
return vehicle4W;
}

void swapToLowLodVersion(const PxVehicleDriveNW& vehicle18W, PxVehicleWheels** vehicles, PxU32 vehicleId) {
    vehicles[vehicleId] = vehicle4W;

    PxVehicleCopyDynamicsMap wheelMap;
    wheelMap.sourceWheelIds[0]=0;
    wheelMap.sourceWheelIds[1]=1;
    wheelMap.sourceWheelIds[2]=2;
    wheelMap.sourceWheelIds[3]=3;
    wheelMap.targetWheelIds[0]=0;
    wheelMap.targetWheelIds[1]=1;
    wheelMap.targetWheelIds[2]=2;
`wheelMap.targetWheelIds[3]=3;
PxVehicleCopyDynamicsData(wheelMap, vehicle18W, vehicle4W);`

```cpp
void swapToHighLowVersion(const PxVehicleDriveNW& vehicle4W, PxVehicleWheels** vehicles, PxU32 vehicleId)
{
    vehicles[vehicleId] = vehicle18W;

    PxVehicleCopyDynamicsMap wheelMap;
    wheelMap.sourceWheelIds[0]=0;
    wheelMap.sourceWheelIds[1]=1;
    wheelMap.sourceWheelIds[2]=2;
    wheelMap.sourceWheelIds[3]=3;
    wheelMap.targetWheelIds[0]=0;
    wheelMap.targetWheelIds[1]=1;
    wheelMap.targetWheelIds[2]=2;
    wheelMap.targetWheelIds[3]=3;

    PxVehicleCopyDynamicsData(wheelMap, vehicle4W, vehicle18W);
}
```

Disable Raycasts

In some scenes it might be possible not to issue raycasts for each vehicle update. Depending on the geometry, this can lead to significant gains.

The PhysX vehicles SDK provides a simple mechanism to disable or enable raycasts per vehicle by specifying an array of booleans as a function argument in `PxVehicleSuspensionRaycasts`. An alternative to disabling raycasts would be to alter the array of vehicles passed to `PxVehicleSuspensionRaycasts` so that some vehicles scheduled for update in `PxVehicleUpdates` do not participate in the batched raycast prior to the update. It is anticipated that using the boolean array will allow the same vehicle array to be passed to both the raycast and update functions, allowing simpler vehicle management.

Vehicles that participate in the batched raycast automatically store hit planes which are re-used each subsequent update until they are replaced by the next raycast. This means that it is not necessary to perform raycasting each update.
especially if the vehicle is moving slowly or the vehicle is far from the camera or the vehicle remains on the same plane for several updates in a row. As the frequency of updates preceded by a raycast decreases, the accuracy of the cached hit planes decreases, meaning that the likelihood of visibly poor wheel placement or intersecting the ground if raycasts are not performed prior to each update increases. It is left to users of the SDK to develop their own strategy to decide whether a fresh raycast or not.

If a raycast is not performed prior to an update then the vehicle will only report a partial description of its interaction with the scene. For example, as a consequence of deletion the actor or shape or material hit by the last suspension raycast may exist in the scene several updates later. For this reason, the vehicle reports NULL pointers for the shapes/actors/materials if a cached plane is used instead of a fresh raycast. The documentation for PxWheelQueryResult describes this.

The first update of any vehicle requires that a raycast is performed prior to the update. If a raycast is not performed prior to the first update then the vehicle will not have an opportunity to cache its raycast hit planes. Further, after each call to setToRestState the vehicle also needs to perform a raycast prior to the next update. This is because that setToRestState clears the cached hit planes, meaning that they need to be recomputed once more.

Use The Clutch in Estimate Mode

The vehicle SDK implements a mathematical model for the clutch that has two modes of operational accuracy: eESTIMATE and eBEST_POSSIBLE. eBEST_POSSIBLE is chosen the SDK attempts to accurately update wheel and engine rotation speeds from their coupling through the clutch. It is worth noting that the clutch model in PxVehicleDriveTank reduces to a particularly simple set of equations that have fast analytical solution. As a consequence, the vehicle SDK uses the eBEST_POSSIBLE accuracy model for tanks and instead always opts to compute the best solution. In the case of PxVehicle4W only marginal performance gains can be achieved by switching to eESTIMATE because at most only 4 wheels can ever be coupled to the clutch. The real performance gains from the estimated solution are
PxVehicleNW instances with high wheel count.

If eESTIMATE is chosen the quality of the estimate can be tuned with PxVehicleClutchData::mEstimateIterations. As the value of this variable increases the computational cost also increases and the estimated solution approaches the best possible solution. At particularly large values of mEstimateIterations the estimated solution might even exceed that of the best possible solution but without any precision. On the other hand, particularly low values such as 1 might result in inaccurate coupling between the engine and wheels. This can be particularly noticeable after a gear change or at standing starts or when the brakes are aggressively applied. Such situations large angular velocity differences at the clutch result in computational effort to resolve. A poor estimate might, for example, result in oscillating engine rotation speeds after a gear change instead of the expected smooth transitions. The magnitude of accuracy loss and its subsequent effect on vehicle behavior are very difficult to quantify and really need tested for each vehicle and scene.

It is recommended that eBEST_POSSIBLE is chosen for vehicles that require high level of detail and that eESTIMATE is only chosen for vehicles that require lower levels of detail. Care must be taken when tuning PxVehicleClutchData::mEstimateIterations to ensure that the loss of accuracy is acceptable for the required level of detail. In many cases the lowest possible value of 1 will turn out to provide perfectly acceptable. Smooth and physically believable behavior, however, is only guaranteed if eBEST_POSSIBLE is chosen.

**Wheel Contact Beyond Raycasts**

This Section describes the steps required to simulate wheel volumes, sweeps and contact modification. Sample code can be found in SnippetVehicleContactMod.

Section *Algorithm* described how scene query raycasts are used to compute vehicle suspension forces. Expanding on this theme, Section *Filtering* described how scene query and simulation filtering to categorise scene shapes as either drivable or non-drivable surfaces: drivable surfaces interact only with suspension raycasts, non-drivable surfaces interact with wheels only through rigid body contact.
A variety of issues arise from the system of raycasts and filtering. One problem is that it may be impractical to author every shape in the scene as being either drivable or non-drivable: it is easy to imagine a landscape modelled with a single mesh that is partially drivable and partially non-drivable. Another problem is that raycasts ignore the extent of the wheel in the lateral and longitudinal directions. Figures 2a and 2b.

Figure 2a: The raycast ignores the overlap of the wheel's volume with the ground plane.
Figure 2b: The wheel rolls towards a wall in Frame 1 and is immediately pushed up to the elevated surface in Frame 2.

The problem illustrated in Figure 2a can be solved by replacing raycasts with sweeps. Instead of performing a raycast along the suspension direction through the wheel, the shape representing the wheel is swept from its transform at maximum compression to its transform at maximum elongation. Sweeping a volume through the scene means that all possible contact planes are considered. This is illustrated in Figure 3.
Figure 3: Sweeps pick up all contact planes under the wheel.

In Figure 3, it is easy to see that there are multiple contact points under the wheel with a different normal. A decision needs to be made about which of these contacts to accept as the driving surface and which to ignore. In some scenarios it is sufficient just to take the first contact encountered by the sweep and ignore all others. For such cases it is recommended to issue a blocking sweep. PhysX supports two types of scene query: blocking and non-blocking. A detailed description of blocking and non-blocking can be found in Section Filtering. In summary, however, a blocking sweep will return the first contact encountered by the swept volume, while non-blocking sweeps will return all contacts encountered by the sweep. The scenario in Figure 3 suggests that a blocking sweep will be sufficient because it will return the inclined plane rather than the horizontal plane. As a consequence, the vehicle will start to drive on the inclined plane. Some scenarios, such as those depicted in Figure 2b, are more complex and require a non-blocking sweep.

Figure 4: Judicious selection of sweep contacts and rigid body contacts is required to navigate a wheel through a complex scene.

Figure 4 shows a wheel rolling along a horizontal plane towards a vertical plane. The expected behavior is that the wheel continues to drive on the horizontal plane and is blocked by the vertical plane. It turns out that this can be readily achieved by judicious choice of sweep contacts and rigid body contacts. The first thing to not
will return the three contact planes labelled A, B and C in Figure 4. If rigid body contact between the wheel and the environment we will see contact planes B and C as rigid body contacts. The next step is to develop a strategy that accepts contact plane B for the sweep and contact plane C for rigid body contact. This combination will ensure that the wheel bounces off the vertical plane and continues to drive on the lower horizontal plane. The strategy adopted by PhysX categorises sweep and rigid body contacts by comparing contact normals with the suspension direction. The aim is to divide contact with the environment into drivable contact planes and non-drivable contact planes. This can be achieved by introducing threshold angles to categories contact points and normals.

Figure 5: The position of sweep and rigid body contact points relative to the suspension direction is used to filter the sweep and rigid body contacts. Sweep contacts in the light blue zone are accepted as driving planes, while rigid body contacts in the pink zone are accepted as rigid body contact planes.
Figure 6: The angle between contact normal and the suspension direction is used to categorise contact planes as either rigid body contacts or sweep contacts. Normals close to the suspension direction are accepted as driving planes, while normals far from the suspension direction are accepted as rigid body contacts.

Figures 5 and 6 introduced two threshold angles that together allow sweep contacts to be categorised using their position and normal. Having a numerical test for drivable and non-drivable contact points and normals allows a relaxation of the filtering rules described in Section Filtering. The idea now is to set up so that wheel shapes sweep against and collide with pretty much everything in the scene. The two threshold angles will filter and categorise sweep and rigid body contacts to generate the desired behavior.

The threshold angles shown in Figure 5 and Figure 6 are configured with the following function call:

```cpp
void PxVehicleSetSweepHitRejectionAngles(const PxF32 pointRejectAngle, const PxF32 planeRejectAngle)
```

The code snippet SnippetVehicleContactMod demonstrates how to configure blocking and non-blocking sweeps. This snippet can be configured to run with either type of sweep by modifying the BLOCKING_SWEEPS define. Running the
BLOCKING_SWEEPS demonstrates that the situation depicted in Figure 4 requires non-blocking sweeps to ensure that the elevated horizontal plane is not chosen as the driving surface.

Suspension sweeps are issued with the following code:

```cpp
//Suspension sweeps (instead of raycasts).
//Sweeps provide more information about the geometry under the wheel.
PxVehicleWheels* vehicles[NUM_VEHICLES] = {gVehicle4W[0], gVehicle4W[1]};
PxSweepQueryResult* sweepResults = gVehicleSceneQueryData->getSweepResults();
const PxU32 sweepResultsSize = gVehicleSceneQueryData->getQueryResultBufferSize();
PxVehicleSuspensionSweeps(gBatchQuery, NUM_VEHICLES, vehicles, sweepResultsSize);
```

In the event that non-blocking sweeps are implemented, the function `PxVehicleSetSweepHitRejectionAngles` rejects and accepts sweep hits using the threshold angles set in `PxVehicleSetSweepHitRejectionAngles`. When blocking sweeps are implemented, only a single sweep contact is recorded. As a consequence, `PxVehicleUpdateSweeps` threshold angles and automatically works with the blocking sweep, whether to use blocking or non-blocking sweeps is left to the developer, depending on knowledge about the kinds of geometry that will be encountered by the vehicle. In some applications it will be sufficient to opt for the computationally cheaper option of blocking sweeps, while other applications may expect the vehicle to encounter complex geometry and are prepared to accept the extra cost of non-blocking sweeps.

Categorisation of rigid body contacts is implemented using contact modification callbacks. Contact modification is described in Section Contact Modification. The PhysX Vehicles SDK provides the function `PxVehicleModifyWheelContacts` to accept or reject contact points using the defined threshold angles. This function should be called from the contact modification callback, which is owned by the application. Configuring contact modification callbacks involves a combination of simulation filter data and simulation shader. The implementation details, therefore, are left to application developers. The implementation details are illustrated one way to implement a contact modification callback using simulation filter data and the userdata pointers of `PxShape` and `PxRigidDynamic`. Other techniques are available using local knowledge.

In addition to adding sweeps and contact modification, the snippet also applies continuous collision detection (CCD) to the wheel shapes. CCD is introduced in Section...
Collision Detection.
Tuning Guide

This Sections describes the effect of the editable vehicle parameters of in PxVehicleComponents.h.

PxVehicleWheelData

mRadius:

This is the distance in metres between the center of the wheel and the tire. It is important that the value of the radius closely matches the render mesh of the wheel. Any mismatch will result in the wheels either above the ground or intersecting the ground. Ideally, this parameter will be exported from the 3D modeler.

mWidth:

This is the full width of the wheel in metres. This parameter has no bearing on handling but is a very useful parameter to have when trying to render data relating to the wheel/tire/suspension. Without this parameter it would be difficult to compute coordinates for render points and lines that ensure their visibility. Ideally, this parameter will be exported from the 3D modeler.

mMass:

This is the combined mass of the wheel and the tire in kg. Typically, a mass between 20Kg and 80Kg but can be lower and higher depending on the vehicle.

mMOI:

This is the component of the wheel's moment of inertia about the rolling axis. Higher values make it harder for the wheel to rotate about this axis, while lower values make it easier for the wheel to rotate about the rolling axis. Another way of thinking about it is that a high MOI will result in less wheel spin when stamping on the accelerator because it is harder to make the wheel spin. Conversely, lower values will result in more wheel spin when stamping on the accelerator.
If the wheel is approximately cylindrical then a simple formula can be used to compute MOI:

$$\text{MOI} = 0.5 \times \text{Mass} \times \text{Radius} \times \text{Radius}$$

There is no reason, however, to rely on equations to compute this value. A strategy for tuning this number might be to start with the equation above, make small tweaks to the value until the handling is as desired.

**mDampingRate:**

This value describes how quickly a freely spinning wheel will come to rest. The damping rate describes the rate at which a freely spinning wheel loses speed. Here, a freely spinning wheel is one that experiences no forces except for the damping forces arising from the wheel's internal bearings. Higher damping rates will result in the wheel coming to rest in shorter times, while lower damping rates will allow the wheel maintaining speed for longer. Values in range (0.25, 2) seem sensible. Experimentation is always a good idea, even outside this range. Exercise some caution with very small damping rates. In particular, a damping rate of exactly 0 should be avoided.

**mMaxBrakeTorque:**

This is the value of the torque applied to the wheel when the brakes are maximally applied. Higher torques will lock the wheel quicker when braking, while lower torques will take longer to lock the wheel. This value is strongly related to the wheel's MOI because the MOI determines how quickly the wheel will react to applied torques. A value of around 1500 is a good starting point for a vanilla wheel but a web search will reveal typical braking torques. One difficulty is that these are often expressed by manufacturers as braking horsepower or in "pounds inches". The values here are in "Newton metres".

**mMaxHandBrakeTorque:**

This is the same as the max brake torque except for the handbrake rather than the brake. Typically, for a 4-wheeled car, the handbrake is stronger than the
only applied to the rear wheels. A value of 4000 for the rear wheels is a good starting point, while a value of 0 is necessary for the front wheels to make sure they do not react to the handbrake.

**mMaxSteer:**

This is the value of the steer angle of the wheel (in radians) when the steering wheel is at full lock. Typically, for a 4-wheeled car, only the front wheels respond to steering. In this case, a value of 0 is required for the rear wheels. More exotic cars might wish front and rear wheels to respond to steering. A value in radians to somewhere between 30 degrees and 90 degrees seems like a good starting point, but it really depends on the vehicle being simulated. Larger values of max steer will result in tighter turns, while smaller values will result in wider turns. Be aware, though, that large steer angles at large speeds are likely to result in the car losing traction and spinning out of control, just as would happen with a real car. A good value is to filter the steer angles passed to the car at run-time to generate smaller angles at larger speeds. This strategy will simulate the difficulty of achieving large steer angles at high speeds (at high speeds the wheels resist the turning forces applied by the steering wheel).

**mToeAngle:**

This is the angle of the wheel (in radians) that occurs with no steer applied. This angle can be used to help the car straighten up after coming out of a turn. A good number to experiment with but is best left at 0 unless detailed tweaks are required.

To help the car straighten up apply a small negative angle to one of the front wheels and a small positive angle to the other front wheel. By choosing which wheel has the positive angles, and which the negative, it is straightforward to make either "toe-in" or "toe-out". A "toe-in" configuration, the front wheels will point towards each other, should help the car straighten up after a turn but at the expense of making it a little harder to turn in the first place. A "toe-out" configuration will have the opposite effect. Toe angles greater than a few degrees are best avoided.

**PxVehicleWheelsSimData**
void setSuspTravelDirection(const PxU32 id, const PxVec3& dir):

  This is the direction of the suspension in the downward direction in the configuration of the vehicle. A vector that points straight downwards is a good starting point.

void setSuspForceAppPointOffset(const PxU32 id, const PxVec3& offset):

  This is the application point of the suspension force, expressed as an offset vector from the center of mass of the vehicle's rigid body. Another way of expressing this is to start at the center of mass of the rigid body, then move along the offset vector. The point at the end of the offset vector is the point at which suspension forces are applied.

In a real vehicle the suspension forces are mediated through the suspension strut. These are often incredibly complex mechanical systems that are computationally expensive to simulate. As a consequence, instead of modeling the suspension strut, it makes sense to assume that the suspension strut has an effective point at which it applies the force to the rigid body. Choosing that point, however, needs careful consideration. At the same time, it opens up all sorts of possibilities, freed from the constraints of the real world.

Deciding on the suspension force application point requires some thought. The suspension is very close to the wheel so the wheel center is a good starting point. Consider a line through the wheel center and along the suspension travel direction. Somewhere along this line seems like an even better idea for the application point. For a standard 4-wheeled car it makes sense that the application point is somewhere above the wheel center but below the center of mass of the rigid body. It is probably above the wheel center because the suspension is mostly above this point. It can be assumed that it is somewhere below the center of mass because otherwise vehicles would lean out of the turn rather than into the turn. This narrows down the application point to really quite a small known line.

When editing the suspension force application point it is important to keep in mind that lowering the app point too far will result in cars leaning more into the turn.
have a negative effect on handling because the inner wheel can take so much load that the response saturates, while the outer wheel ends up with reduced turning force. The result is poor cornering. Conversely, setting too high will result in cornering that looks unnatural. The aim is to achieve a good balance.

```cpp
void setTireForceAppPointOffset(const PxU32 id, const PxVec3& offset);

This is almost the same as the suspension force app point except for longitudinal forces that develop on the tire. A good starting point is to duplicate the suspension force application point. Only for really detailed editing is it advised to start tweaking the tire force app offset independently of the suspension force offset.
```

```cpp
void setWheelCentreOffset(const PxU32 id, const PxVec3& offset):

This is the center of the wheel at rest position, expressed as an offset vector from the vehicle's center of mass.
```

**PxVehicleSuspensionData**

```cpp
mSprungMass:

This is the mass in kg that is supported by the suspension spring.

A vehicle with rigid body center of mass at the center of the four wheels typically be equally supported by each of the suspension springs; each suspension spring supports 1/4 of the total vehicle mass. If the center of mass was moved forward then it would be expected that the front wheels would need to support more mass than the rear wheels. Conversely, a center of mass nearer the rear wheels ought to result in the rear suspension springs supporting more mass.

---

**Note:** In order to achieve stability at the desired rest pose it is recommended that the collection of sprung masses matches the mass and center of mass of the rigid body. There are two strategies that can be employed to accomplish this. The first approach is to decide upon values for the individual sprung masses and work forwards to compute an equivalent value for the rigid body.
center of mass. More specifically, the rigid body mass and center of mass can be computed using the equations presented in Section Algorithm and then applied to the vehicle's PxRigidDynamic instance. The second approach starts with the rigid body mass and center of mass of the vehicle's PxRigidDynamic instance and works backwards to compute and set the sprung masses, which makes use of the function PxVehicleComputeSprungMasses that was introduced in Section setupWheelsSimulationData.

mMaxCompression:

mMaxDroop:

These values describe the maximum compression and elongation in metres that the spring can support. The total travel distance along the spring direction is the sum of mMaxCompression and mMaxDroop.

A simple way to illustrate the maximum droop and compression values is to consider a car that is suspended in mid-air so that none of the wheels are touching the ground. The wheels will naturally fall downwards from their rest position until the maximum droop is reached. The spring cannot be elongated beyond this point, so that the wheel is pushed upward, first to its rest position, then further until the spring can no longer be compressed. The displacement from the rest position to the maximum compression of the spring.

It is important to choose the maximum compression value so that the wheel is never placed where the visual mesh of the wheel intersects the visual mesh of the car chassis. Ideally, these values will be exported from the 3d modeler.

mSpringStrength:

This value describes the strength of the suspension spring. The spring strength has a profound influence on handling by modulating the time it takes for the vehicle to respond to bumps in the road and on the amount of load experienced by the tire.

Key to understanding the effect of spring strength is the concept of a spring's natural frequency. Consider a simple spring system, such as a pendulum swinging...
forth. The number of trips per second that the pendulum makes from right and then back again is called the natural frequency of the pendulum. A more powerful pendulum spring will result in the pendulum swinging faster, thereby increasing the natural frequency. Conversely, increasing the pendulum mass will result in a slower oscillation, thereby reducing the natural frequency.

In the context of a suspension spring supporting a fixed portion of vehicle mass, the strength of the spring will affect the natural frequency; that is, the spring can respond to changes in load distribution. Consider a car taking a corner. The car corners it leans in to the turn, putting more weight on the suspensions on the outside of the turn. The speed at which the spring reacts by applying forces to redistribute the load is controlled by the natural frequency. Very high natural frequencies, such as those on a racing car, will naturally produce very rapid movements because the load on the tires, and therefore the forces they can generate, is very rapidly. Very low natural frequencies, on the other hand, will result in the car taking a long time to straighten up even after the turn is complete. This will produce sluggish and unresponsive handling.

Another effect of strength and natural frequency is the response of a car to a bump in the road. High natural frequencies can result in the car responding strongly and quickly to the bump, with the wheel possibly even leaving the road for a short while. This not only creates a bumpy ride but also periods of time when the tire is generating no forces. Weaker springs will result in a smoother trip with weaker but more constant tire forces. A balance must be found to tune the car for the expected types of turn and terrain.

The natural frequency of the spring presents a challenge for computer simulation. A smooth and stable simulation requires that the spring is updated at a frequency much greater than the spring's natural frequency. An alternative way of expressing this is to consider the period of the spring relative to the timestep of the simulation. The period of the spring is the time the spring takes to complete a single oscillation, mathematically equal to the reciprocal of the natural frequency. In order to achieve a stable simulation the spring must be sampled at several points during each oscillation. A natural consequence of this observation is that the simulation timestep must be significantly smaller than the period of the spring. To discuss this further...
introduce a ratio that describes the number of simulation updates during each spring oscillation. This ratio is simply the spring period divided by the timestep

\[ \alpha = \frac{\sqrt{\frac{m_{\text{sprung mass}}}{m_{\text{spring strength}}}}}{\text{timestep}} \]

where \( \sqrt{\frac{m_{\text{sprung mass}}}{m_{\text{spring strength}}}} \) is the period of the spring. A value of 1.0 means that the chosen timestep and spring properties only allow a single sample of the spring during each oscillation. As described above, this guarantees to produce unstable behavior. In fact, the argument presented so far suggests a value of \( \alpha \) significantly greater than 1.0 is essentially essential to produce a smooth simulation. The exact value of \( \alpha \) at which stability emerges is very difficult to predict and depends on many other parameters. As a guide, it is recommended that the timestep and spring properties are chosen to produce an \( \alpha \) value greater than 5.0; that is, a minimum of five simulation updates per spring cycle.

When tuning a suspension spring it can be very useful to use manufacturer data to discover typical values used across a range of vehicle types. This data is not always readily available. An alternative strategy would be to think in terms of the natural frequency of the spring by imagining how quickly the car would oscillate if it was dropped onto the ground from a height of, say, 0.5m. The springs of a typical family car have natural frequency somewhere between 5 and 10; that is, such a car would make 5-10 oscillations per second if gently dropped to the ground. If the sprung mass supported by the spring is already known then the spring strength can be calculated from the following equation

\[ m_{\text{spring strength}} = \text{natural frequency} \times \text{natural frequency} \times m_{\text{sprung mass}} \]

**Note:** To achieve a spring that is theoretically correct, the values of \( m_{\text{sprung mass}}, m_{\text{spring strength}} \) and \( m_{\text{max droop}} \) should be chosen so that they obey the equation \( m_{\text{spring strength}} \times m_{\text{max droop}} = m_{\text{sprung mass}} \times g \). When this equation is satisfied the spring is guaranteed to provide exactly zero force at maximum elongation, also to support the sprung mass at the rest pose (the rest pose is defined as...
PxVehicleWheelsSimDta::setWheelCentreOffset). It is often the case that the visual requirements of the car are in conflict with its handling requirements. An example might be a visual requirement, imposed on both the rest pose and the suspension travel limits. In order to satisfy this visual requirement and achieve a theoretically correct spring, the value of mSpringStrength must be equivalent to mSprungMass*gravitationalAcceleration/mMaxDroop. If this value of mSpringStrength does not meet the handling requirements of the game, there is a conflict that cannot be easily resolved. For this reason, the Vehicles module does not require the spring to be a theoretically perfect spring. The consequences of an imperfect spring are that the spring either stops providing upward force before it hits maximum elongation or that it still provides a non-zero force at maximum elongation. The effect on handling or the visual appearance of the vehicle is often quite difficult to spot. In particular, tire load filtering, discussed in Section PxVehicleTireLoadFilterData, further disguises any imperfection.

mSpringDamperRate:

This describes the rate at which the spring dissipates the energy stored in it.

Key to the understanding of damper rate are the concepts of under-damping, and critical damping. An over-damped pendulum displaced from rest is unable to make a single back-and-forth trip before it dissipates all its energy, while an under-damped pendulum would be able to make at least a single back-and-forth trip. A critically damped pendulum makes exactly a single back-and-forth trip before expending all its energy.

For vehicle suspension springs, it is typically important to make sure the spring has a damper rate that produces over-damping but not by too much. For example, it is important that the spring doesn't over-respond by shifting the weight from the left suspension to the right suspension then back again. If this happens, the tire load, and the forces generated, would be extremely variable, resulting in twitchy and uncontrollable handling. A very heavily over-damped spring, on the other hand, will feel sluggish and unresponsive.
The concept of critical damping can be used to help tune the damping of the spring. It is helpful to introduce a value known as the damping ratio, which mathematically describe the under-damping, critical damping and over-damping regimes.

\[
\text{dampingRatio} = \text{mSpringDamperRate} / [2 \times \sqrt{\text{mSpringStrength} \times \text{mSprungMass}}]
\]

A dampingRatio with value greater than 1.0 produces over-damping, exactly 1.0 generates critical damping, and a value less than 1.0 is under-damping. It can be useful to first think about whether the spring will be under-damped, critical damping, or over-damped, then think about how far it will be from critical damping. This allows a number to be subjectively applied to the damping ratio. From here, the damping rate can be directly computed by rearranging the equation above

\[
\text{mSpringDamperRate} = \text{dampingRatio} \times 2 \times \sqrt{\text{mSpringStrength} \times \text{mSprungMass}}
\]

A typical family car is probably slightly over-damped, having damping ratios perhaps just over 1.0. A guideline would be that values very far from critical damping are likely to be unrealistic and will either produce sluggish or twitchy handling. It is difficult to put an exact figure on this but somewhere between 0.8 and 1.2 seems like a good starting point for the damping ratio.

\[\text{mCamberAtRest}:\]
\[\text{mCamberAtMaxCompression}:\]
\[\text{mCamberAtMaxDroop}:\]

These values describe the camber angle of the wheels as a function of the spring compression. It is typical for the wheels of extended springs to camber inward; that is, the left and right wheels almost seem to form the edges of a V shape when viewed from the front or rear along the forward axis of the vehicle. Springs, on the other hand, typically camber outwards; that is, they almost form the outer edges of an A shape when viewed from the front or rear along the forward axis.
axis of the vehicle.

These three values allow the camber angle to be computed for any compression using simple linear interpolation. At rest, when the spring is neither elongated or compressed, the camber angle is equal to mCamberAtRest. When the spring is compressed the camber is computed as a linear interpolation between mCamberAtRest and mCamberAtMaxCompression. When the spring is elongated the camber is computed as a linear interpolation between mCamberAtRest and mCamberAtMaxDroop.

The camber angle is used by the default tire model and is passed as an argument to the tire shader. It is also used to set the local pose of the PxShape that geometrically represents the wheel.

**PxVehicleAntiRollBar**

When a vehicle takes a corner the turning force causes the car to roll. Suspension springs on the outside of the turn are compressed while springs on the inside of the turn are elongated. If the roll is so severe that the inside wheels completely leave the ground then there is a danger that the driver will lose control of the vehicle. In such cases, there is even a danger that the vehicle will rotate onto its side. For less severe rolls there still remains a handling problem that arises from the distribution of load between the inside and outside tires. The issue there is that the imbalance of the vehicle can lead to under-steer or over-steer.

Anti-roll bars are commonly used to reduce the roll that naturally occurs when cornering. They typically work as a torsion spring that applies a torque in order to minimise the difference in spring displacement for a pair of wheels. A standard family car might feature a front and rear anti-roll bar. The front bar applies a torque to reduce the difference between the front-left and front-right wheels. Similarly, the rear bar applies a torque to reduce the difference between the rear-left and rear-right wheels.

The magnitude of the anti-roll torque is proportional to the difference in spring displacement of the two wheels that are connected by the bar. The magnitude is also proportional to a stiffness parameter: stiffer bars generate more anti-roll torque.
As a general rule, under-steer can be reduced by increasing the stiffness of the rear anti-roll bar. Increasing the stiffness of the front anti-roll bar typically reduces over-steer.

mWheel0: mWheel1:

The anti-roll bar connects two wheels described by the indices mW0 and mW1.

mStiffness:

This parameter describes the stiffness of the anti-roll bar.

**PxVehicleTireData**

The tire force computation is performed in two conceptual stages. The first stage of the computation independently computes the lateral and longitudinal components of the force using linear equations. These independent forces are computed by treating the tire as a linear system so that the force in each direction can be viewed as the product of a tire strength per unit slip and the slippage on the tire. The second stage of the computation applies the rule that the force is limited by the product of the tire load and friction. Just as with rigid bodies, tires are able to resist greater horizontal forces when they experience a large normal load on a surface with high friction value. With this in mind the maximum force for a tire can be approximated as the product of the normal load and friction value. The default PhysX Vehicle tire model employs a series of smoothing functions to implement the normalization of the combined tire forces.

In addition to the lateral and longitudinal components of force a camber thrust force, arising from the camber angle of the tire, is also computed. Typically only a small correction to the effect of the lateral and longitudinal components, the camber force participates in the normalization process.

The following tire parameters describe the computation of the independent lateral and longitudinal components; that is, the first conceptual stage of the force computation. Reference is made throughout to the handling consequences of the...
normalization process.

mLongitudinalStiffnessPerUnitGravity:

The longitudinal stiffness describes the longitudinal forces that develop per unit gravity. Here, a variable that represents the longitudinal slip (in radians). Here, a variable that represents the longitudinal stiffness per unit gravity has been introduced in order to make the variable robust against any edits to the value of gravitational acceleration. The longitudinal stiffness approximately the product of the longitudinal stiffness per unit gravity and the magnitude of gravitational acceleration:

\[
\text{longitudinalTireForce} = \text{mLongitudinalStiffnessPerUnitGravity} \times \text{longitudinalSlip} \times \text{gravity};
\]

Increasing this value will result in the tire attempting to generate more longitudinal force when the tire is slipping. Typically, increasing longitudinal stiffness will help the car accelerate and brake. The total tire force available is limited by the load on the tire so be aware that increases in this value might have no effect or even come at the expense of reduced lateral force.

mLatStiffX:

mLatStiffY:

These values together describe the lateral stiffness per unit lateral slip of the tire. The lateral stiffness of a tire has a role similar to the longitudinal stiffness (mLongitudinalStiffnessPerUnitGravity), except that it governs the lateral tire forces, and is a function of tire load. Typically, increasing lateral stiffness will help the car turn more quickly. The total tire force available is limited by the load on the tire so be aware that increases in this value might have no effect or even come at the expense of reduced longitudinal force.

Lateral stiffness is a little more complicated than longitudinal stiffness because tires typically provide poor response under heavy load. Typical for car tires is a graph of lateral force against load that has linear response close to zero load but saturates at greater loads. This means that at low tire loads the lateral stiffness...
response to load; that is, more load results in more stiffness and more force. At higher tire loads the tire has a saturated response and is in a regime where applying more load will not result in more tire stiffness. In this latter regime it would be expected that the tire would start slipping.

The combination of two values mLatStiffX and mLatStiffY describe a graph of lateral stiffness per unit load as a function of normalized tire load. The tire force computation employs a smoothing function which requires knowledge of the normalized tire load at which the tire has a saturated response to tire load along with the lateral stiffness per unit load that occurs at this saturation point. A typical curve can be seen below.

The parameter mLatStiffX describes the normalized tire load above which the tire has a saturated response to tire load. The normalized tire load is simply divided by the load that is experienced when the vehicle is perfectly at rest. For example, means that when the tire has a load more than twice its rest load it can deliver no more lateral stiffness no matter how much extra load is applied to the tire. In the graph below mLatStiffX has value 3.

The parameter mLatStiffY describes the maximum stiffness per unit of lateral slip (in radians) per unit rest load. The maximum stiffness is delivered when the tire is in the saturated load regime, governed in turn by mLatStiffX. In the graph below mLatStiffY has value 18.

The computation of the lateral stiffness begins by computing the load on the tire and then computing the normalized load in order to compute the number of rest loads experienced by the tire. This places the tire somewhere along the X-axis of the graph below. The corresponding value on the Y-axis of the curve parameterized by mLatStiffX and mLatStiffY is queried to provide the lateral stiffness per unit load that occurs at this saturation point. The final value for the lateral stiffness is then computed by multiplying the graph value by the rest load. This final value describes the lateral stiffness per unit lateral slip.
A good starting value for mLatStiffX is somewhere between 2 and 3. A value for mLatStiffY is around 18 or so.

mFrictionVsSlipGraph:

These six values describe a graph of friction as a function of longitudinal slip. Vehicle tires have a complicated response to longitudinal slip attempts to approximate this relationship.

Typically, tires have a linear response at small slips. This means when the tire is only slightly slipping it is able to generate a response force that grows as the slip increases. At greater values of slip, the force can actually decrease from the peak value that occurs at the optimum slip. At optimum slip the tire eventually starts behaving less and less efficiently and hits a plateau of inefficiency.

The friction value for the combination of surface type and tire type has already been discussed in Section *Tire Friction on Drivable Surfaces*. Friction versus longitudinal slip is used as a correction to the combination friction value. In particular, a final friction value is computed from the product of the combination friction value and the graph's correction value. The tire responds to the final friction value.
The first two values describe the friction at zero tire slip: $mFrictionVsSlipGraph[0][0] = 0$, and $mFrictionVsSlipGraph[0][1] = \text{friction at zero slip}$.

The next two values describe the optimum slip and the friction at optimum slip: $mFrictionVsSlipGraph[1][0] = \text{optimum slip}$, $mFrictionVsSlipGraph[1][1] = \text{friction at optimum slip}$.

The last two values describe the slip at which the plateau of inefficiency begins and the value of the friction available at the plateau of inefficiency: $mFrictionVsSlipGraph[2][0] = \text{slip at the start of the plateau of inefficiency}$, $mFrictionVsSlipGraph[2][1] = \text{the friction available at the plateau of inefficiency}$.

In the graph below the following values have been used:

- $mFrictionVsSlipGraph[0][0] = 0.0$
- $mFrictionVsSlipGraph[0][1] = 0.4$
- $mFrictionVsSlipGraph[1][0] = 0.5$
- $mFrictionVsSlipGraph[1][1] = 1.0$
- $mFrictionVsSlipGraph[2][0] = 0.75$
- $mFrictionVsSlipGraph[2][1] = 0.60$
The friction values described here are used to scale the friction of the ground surface. This means they should be in range (0,1) but this is not a strict requirement. The friction from the graph would be close to 1.0 in order to provide a small correction to the ground surface friction.

A good starting point for this is a flat graph of friction vs slip with these values:

- \( \text{mFrictionVsSlipGraph}[0][0] = 0.0 \)
- \( \text{mFrictionVsSlipGraph}[0][1] = 1.0 \)
- \( \text{mFrictionVsSlipGraph}[1][0] = 0.5 \)
- \( \text{mFrictionVsSlipGraph}[1][1] = 1.0 \)
- \( \text{mFrictionVsSlipGraph}[2][0] = 1.0 \)
- \( \text{mFrictionVsSlipGraph}[2][1] = 1.0 \)

\( \text{mCamberStiffnessPerUnitGravity} \):

The camber stiffness is analogous to the longitudinal and lateral stiffness, but it describes the camber thrust force arising per unit camber angle (in radians). To the longitudinal stiffness, a camber stiffness per unit gravity has been introduced.
make the camber stiffness robust across different values of gravitational acceleration. The independent camber force is computed as the camber angle multiplied by the camber stiffness multiplied by the gravitational acceleration:

\[
\text{camberTireForce} = \text{mCamberStiffnessPerUnitGravity} \times \text{camberAngle} \times \text{gravity};
\]

mType:

This parameter has been explained in Section *Tire Friction on Drivable Surfaces*.

**PxVehicleEngineData**

mMOI:

This the moment of inertia of the engine around the axis of rotation. Larger values make it harder to accelerate the engine, while lower values make it easier to accelerate the engine. A starting value of 1.0 is a good choice.

mPeakTorque:

This is the maximum torque that is ever available from the engine. This is expressed in Newton metres. A starting value might be around 600.

mMaxOmega:

This is the maximum rotational speed of the engine expressed in radians per second.

mDampingRateFullThrottle:

mDampingRateZeroThrottleClutchEngaged:

mDampingRateZeroThrottleClutchDisengaged:

These three values are used to compute the damping rate that is applied to the engine. If the clutch is engaged then the damping rate is an interpolation between mDampingRateFullThrottle and mDampingRateZeroThrottleClutchEngaged, where the interpolation is governed by the acceleration control value generated by the
gamepad or keyboard. At full throttle mDampingRateFullThrottle is applied, while mDampingRateZeroThrottleClutchEngaged is applied at zero throttle. The damping rate is an interpolation between mDampingRateFullThrottle and mDampingRateZeroThrottleClutchDisengaged.

The three values allow a range of effects to be generated: good acceleration that is not hampered by strong damping forces, tunable damping forces when neutral gear during a gear change, and strong damping forces that bring the vehicle quickly to rest when it is no longer being driven by the player.

Typical values in range (0.25,3). The simulation can become unstable at rates of 0.

mTorqueCurve:

This is a graph of peak torque versus engine rotational speed. Cars have a range of engine speeds that produce good drive torques, and other ranges of speed that produce poor torques. A skilled driver will make good use of the gears to ensure that the car remains in the "good" range where the engine is most responsive. Tuning this graph can have profound effects on gameplay.

The x-axis of the curve is the normalized engine speed; that is, the engine speed divided by the maximum engine speed. The y-axis of the curve is a multiplier in range (0,1) that is used to scale the peak torque.

**PxVehicleGearsData**

mNumRatios:

This is the number of the gears of the vehicle, including reverse and neutral. A standard car with 5 forward gears would, therefore, have a value of 7 for reverse and neutral.

mRatios:

Each gear requires a gearing ratio. Higher gear ratios result in more torque.
top speed in that gear. Typically, the higher the gear, the lower the gear ratio. gear must always be given a value of 0, while reverse gear must have a negative gear ratio. Typical values might be 4 for first gear and 1.1 for fifth gear.

mFinalRatio:

The gear ratio used in the simulator is the gear ratio of the current gear multiplied by the final ratio. The final ratio is a quick and rough way of changing the gearing without having to edit each individual entry. Further, quoted gearing values from manufacturers typically mention ratios for each gear along with a final ratio. A good value might be around 4.

mSwitchTime:

The switch time describes how long it takes (in seconds) for a gear change to be completed. It is impossible to change gear immediately in a real car for example, require neutral to be engaged for a short time before the desired target gear. While the gear change is being completed the car will be in neutral. A good trick might be to penalize players that use an automatic gear box by increasing the gear switch time.

If the autobox is enabled it is a good idea to set this value significantly lower than PxVehicleAutoBoxData::setLatency. If the autobox latency is smaller than the switch time then the autobox might decide to initiate a downward gear change immediately after an upward gear shift has been completed. This situation can leave the car cycling between neutral and first gear with very short interludes.

PxVehicleAutoBoxData

The autobox initiates gear changes up or down based on the rotation speed of the engine. If the engine is rotating faster than a threshold value stored in PxVehicleAutoBoxData then a gear increment will be initiated. On the other hand, if the engine is rotating slower than a threshold value then the autobox will initiate a gear decrement. The autobox only initiates gear changes upward or downward, single gear at a time.
It is worth noting that if the autobox initiates a gear change then the accelerator pedal is automatically disconnected from the engine for the entire duration of the gear change. Manual gear changes (PxVehicleDriveDynData::startGearChange / PxVehicleDriveDynData::mGearUpPressed / PxVehicleDriveDynData::mGearDownPressed) are not subject to this limitation. This is in keeping with typical real-world autobox behavior. The idea behind it is to stop the engine wildly accelerating during the neutral phase of the gear change, thereby avoiding damaging clutch slip when the clutch re-engages at the end of the gear change.

The autobox will not try to initiate a gear change while an automatic or manual gear change is still active.

If the autobox is too simplistic for the application's requirements, PxVehicleGearsData can be readily disabled. The choices following this are to revert to a manual gear model or to implement a custom autobox in the application. A transition to a specific gear can be initiated with PxVehicleDriveDynData::startGearChange, while single gear changes can be initiated with PxVehicleDriveDynData::mGearUpPressed / PxVehicleDriveDynData::mGearDownPressed.

The autobox can be enabled or disabled by toggling PxVehicleDriveDynData::mUseAutoGears.

PxReal mUpRatios[PxVehicleGearsData::eGEARSRATIO_COUNT]:

The autobox will initiate a gear increment if the ratio of the engine rotation speed to the maximum allowed engine rotation speed:

\[
\text{PxVehicleDriveDynData::getEngineRotationSpeed()} / \text{PxVehicleEngineData::mMaxOmega}
\]

is greater than the value stored in mUpRatios[PxVehicleDriveDynData::getCurrentGear()]

PxReal mDownRatios[PxVehicleGearsData::eGEARSRATIO_COUNT]:
The autobox will initiate a gear decrement if the ratio of the engine rotation speed to the maximum allowed engine rotation speed:

\[ \frac{\text{PxVehicleDriveDynData::getEngineRotationSpeed}()}{\text{PxVehicleEngineData::mMaxOmega}} \]

is less than the value stored in \( \text{mUpRatios[PxVehicleDriveDynData::getCurrentGear()]} \).

```cpp
void setLatency(const PxReal latency):
```

After the autobox has initiated a gear change it will not attempt to initiate another gear change until the latency time has passed. It is a good idea to set this value significantly higher than \( \text{PxVehicleGearsData::mSwitchTime} \). If the latency is smaller than the gear switch time then the autobox might decide to initiate a downwards gear change immediately after an upward gear shift has been completed. This situation can leave the car cycling between neutral and first gear with very short interludes in 2nd gear.

**PxVehicleClutchData**

- **mStrength:**

This describes how strongly the clutch couples the engine to the wheels and how quickly differences in speed are eliminated by distributing torque to the wheels.

Weaker values will result in more clutch slip, especially after stamping on the accelerator. Stronger values will result in reduced engine torque delivered to the wheels.

This value is to be edited only for very fine tweaking of the vehicle. Some is a natural consequence of driving the car in an overly aggressive manner. A value of 10 is a good starting point.

**PxVehicleAckermannGeometryData**
mAccuracy:

Ackermann correction allows better cornering by steering the left and with slightly different steer angles, as computed from simple trigonometry, it is impossible to engineer a steering linkage that will achieve the perfect steering correction. This value allows the accuracy of the Ackermann correction to be controlled. Choosing a value of 0 completely disables steer correction. A value of 1.0, on the other hand, achieves the impossible perfect Ackermann correction.

mFrontWidth:

This is the distance in metres between the two front wheels.

mRearWidth:

This is the distance in metres between the two rear wheels.

mAxleSeparation:

This is the distance in metres between the center of the front axle and the rear axle.

PxVehicleTireLoadFilterData

This is for very fine control of the handling, and corrects numerical issues in simulations at large timesteps.

At large simulation timesteps the amplitude of motion of the suspension is larger than it would be in real-life. This is unfortunately unavoidable; on a bumpy surface this could mean that the simulation lifts the car further from the ground than would really happen. This could be quickly followed by the springs being more compressed than would be experienced with a real vehicle. A consequence of this oscillation is that the load on the tire is more variable than expected, and the tire forces have more variability than expected. This filter aims to correct this numerical problem by smoothing the tire load with the aim of making the handling smoother and more predictable.
A key concept is that of normalized tire loads. A normalized tire load is the load divided by the load experienced when the vehicle is in its rest configuration. If a tire experiences more load than it does at rest then it has a normalized tire load greater than 1.0. Similarly, if a tire has less load than it does at rest then it has a normalized tire load less than 1.0. At rest, all tires obviously have a normalized load of exactly 1.0. The normalized tire load can never be less than zero.

The values here describe points on a 2d graph that generates filtered tire loads from raw tire loads. The x-axis of the graph is "normalized tire load", while the y-axis is "filtered normalized tire load". Normalized loads less than mMinNormalisedLoad produce a filtered normalized load of mMinFilteredNormalisedLoad. Normalized loads greater than mMaxNormalisedLoad produce a filtered normalized load of mMaxFilteredNormalisedLoad. Normalized loads between mMinNormalisedLoad and mMaxNormalisedLoad produce a filtered normalized load in-between mMinFilteredNormalisedLoad and mMaxFilteredNormalisedLoad, as computed by direct interpolation.

Choosing mMaxNormalisedLoad and mMaxFilteredNormalisedLoad limits the maximum load that will ever be used in the simulation. On the other hand, choosing mMinFilteredNormalisedLoad>0 and/or mMinNormalisedLoad>0 allows the tire to potentially generate a non-zero tire force even when touching the ground at maximum droop.
The filtered load can be made identical to the computed tire load by setting:

\[
\begin{align*}
    &m_{\text{Min Normalised Load}} = m_{\text{Max Filtered Normalised Load}} = 0 \\
    &m_{\text{Max Normalised Load}} = m_{\text{Max Filtered Normalised Load}} = 1000.
\end{align*}
\]

**Note:** Tires may only generate forces if the tire is touching the ground. If the tire cannot be placed on the ground then the tire force is always of zero magnitude. A tire touching the ground at maximum suspension droop, on the other hand, has zero measured load because the spring generates zero force at maximum droop. By editing \text{PxVehicleTireLoadFilterData} it is possible to generate tire forces even when there is very little load actually acting on the tire.

**PxVehicleDifferential4WData**

**mType:**

A number of differential types are supported: 4-wheel drive with open differential, 4-wheel drive with limited slip, front-wheel drive with open differential, front-wheel drive with limited slip, rear-wheel drive with open differential, rear-wheel drive with limited slip.

**mFrontRearSplit:**

If a 4-wheel drive differential is chosen (open or limited slip) this option allows the drive torque to be split unevenly between the front and rear wheels. Choosing a value of 0.5 delivers an equal split of the torque between the front and rear wheels. Choosing a value greater than 0.5 delivers more torque to the front wheels, while choosing a value less than 0.5 delivers more torque to the rear wheels. This value is ignored for front-wheel drive and rear-wheel drive differentials.

**mFrontLeftRightSplit:**

This is similar to the Front Rear Split but instead splits the torque that is available for the front wheels between the front-left and front-right wheels. A value
delivers more torque to the front-left wheel, while a value less than 0.5 delivers more torque to the front-right wheel. This parameter can be used to prevent any torque being delivered to a damaged or disabled wheel. This value is ignored for rear-wheel drive.

mRearLeftRightSplit:

This is similar to mFrontLeftRightSplit except that it applies to the rear wheels instead of the front wheels. This value is ignored for front-wheel drive.

mFrontBias:

Limited slip differentials work by only allowing a certain difference in wheel rotation speed to accumulate. This prevents the situation where one wheel ends up taking all the available power. Further, by allowing a small difference in wheel rotation speed to accumulate it is possible for the vehicle to easily corner by permitting the outside wheel to rotate quicker than the inside wheel.

This parameter describes the maximum difference in wheel rotation speed allowed to accumulate. The front bias is the maximum of the two front-wheel rotation speeds divided by the minimum of the two front-wheel rotation speeds. If this ratio exceeds the value of the front bias the differential diverts torque from the faster wheel to the slower wheel in an attempt to preserve the maximum allowed wheel rotation speed ratio.

This value is ignored except for front-wheel drive or four wheel drive with limited slip.

A good starting value is around 1.3.

mRearBias:

This is similar to mFrontBias except that it refers to the rear wheels.

This value is ignored except for rear-wheel drive or four wheel drive with limited slip.

A good starting value is around 1.3.
mCentreBias:

This value is similar to the mFrontBias and mRearBias, except that it refers to the sum of the front wheel rotation speeds and the sum of the rear wheel rotation speeds.

This value is ignored except for four wheel drive with limited slip.

A good starting value is around 1.3.

PxRigidDynamic

Moment of Inertia:

The moment of inertia of the rigid body is an extremely important parameter when editing vehicles because it affects the turning and rolling of the vehicle.

A good starting point for the moment of inertia of the rigid body is to work out the moment of inertia of the cuboid that bounds the chassis geometry. If the cuboid is W wide, H high, and L long then the moment of inertia for a vehicle of mass M is:

\[ (L^2 + H^2) \frac{M}{12}, (W^2 + L^2) \frac{M}{12}, (H^2 + W^2) \frac{M}{12} \]

However, this is only a rough guide. Tweaking each value will modify the motion around the corresponding axis, with higher values making it harder to induce rotational speed from tire and suspension forces.

Providing unphysical values for the moment of inertia will result in either behavior or extremely twitchy and perhaps even unstable behavior. Inertia must at least approximately reflect the length scales of the suspension force application points.

This parameter should be viewed as one of the first go-to editable values.

Center of mass:

Along with the moment of inertia, the center of mass is one of the first go-to editable values.
values and, as such, has a profound effect on handling.

To discuss the center of mass it is useful to consider a typical 4-wheeled chassis mesh whose origin is at the center of the four wheels but with the requirement on the origin being at the center of the four wheels but for the following discussion a little simpler. It might be expected that the center of mass lies somewhere near this origin because vehicles are designed in a way that the load is almost evenly distributed between the four wheels. More specifically, it might be expected that the center of mass needs to be a little above the base of the chassis rather than at the height of the wheels. After all, vehicles have higher mass density near the bottom of the chassis due to density of the engine and other mechanical systems. As a consequence, it is expected that the center of mass is nearer the bottom of the chassis than the top, but definitely above the bottom. Without a particular analysis of the chassis density distribution the exact location along the vertical axis is really a little arbitrary and subjective. Along the forward direction it might be expected that the center of mass is a little nearer the front wheels than the rear wheels due to the mass of the front-located engine. Thinking about these factors allows the center of mass to be tweaked along the vertical and forward directions.

Tweaking the center of mass is really all about making incremental changes to the handling towards a desired goal. Moving the center of mass forwards should help cornering because more load is distributed to the front tires. However, this comes at the expense of reduced load on the rear tires, meaning that the car might turn more quickly only to spin out because the rear tires lose grip more quickly, followed by tests on the handling are required.

When setting the center of mass it is important to bear in mind that the sprung mass values might require simultaneous updating. If the center of mass moves nearer the front this means that more mass is supported by the front suspensions and less by the rear suspensions. This change needs to be reflected in a consistent way. It is possible to mathematically describe the relationship between the center of mass and the mass split between the suspensions. However, the possibilities afforded by breaking this rigid link should allow more tweaking.
A typical car might have a mass of around 1500kg.
Troubleshooting

This Section introduces common solutions to common problems with vehicle tuning.

Jittery Vehicles

1. Have PxInitVehicleSDK and PxVehicleSetBasisVectors been called before the first execution of PxVehicleUpdates? Check the error stream for warnings.
2. Does the length scale of PxTolerancesScale match the length scale (e.g. 100 if centimeters are used)? Update PxTolerancesScale::length as appropriate.
3. Is the natural frequency of the spring too high/timestep of simulation too small for reliable simulation? See Section PxVehicleSuspensionData for more details and update the natural frequency or timestep accordingly. Remember that the timestep can be updated per vehicle with PxVehicleWheelsSimData::setSubStepCount.
4. Are the maximum suspension droop and compression set to values that allow some suspension motion?

The Engine Rotation Refuses To Spin Quickly

1. Are the tires resisting the engine motion through excessive friction? Place the car very high above the ground and accelerate the engine to see if the wheels start to spin round.
2. Do the engine's moment of inertia, peak torque and damping rate reflect the length scale? Note the documented SI units of each variable and recompute the values as appropriate.
3. Is the moment of inertia too large? A value of 1 or its equivalent in the relevant length scale is a good estimate for testing purposes.
4. Is the peak torque too small to drive the engine? Scale the default value with the mass of the vehicle with the knowledge that the default value will drive a standard car of around 1500kg.
5. Does the torque curve contain sensible values? Try a flat curve with all data points having a y-value of 1.0.

6. Is the maximum engine angular speed a realistic value? Consult manufacturer data for typical values or revert to the default value for testing purposes.

7. Are any of the damping rates too high? Reduce the damping rates.

**The Engine Spins But the Wheels Refuse To Spin**

1. Is the vehicle in neutral gear? Connect the engine to the wheels by setting the vehicle to first gear and disabling the autobox.

2. Does the differential deliver drive torque to the wheels (for PxVehicleNW only)? Make sure that the differential is properly configured.

3. Is the brake or handbrake engaged? Ensure that the brake and handbrake are both zero.

4. Do the wheels' moment of inertia and damping rates reflect the lengths and documented SI units of each variable and recomputed the values as appropriate.

5. Are the wheels' moments of inertia too high? Recompute the wheels' moment of inertia.

6. Are the wheels' damping rates too high? Reduce the wheels' damping rates.

7. Are the tires resisting the engine motion through excessive friction forces? Place the car very high above the ground and accelerate the engine to see if the wheels start to spin round.

**The Wheels Are Spinning But The Vehicle Does Not Move**

1. Is the filtering configured so that the vehicle is supported only by suspension forces? Check the filtering configuration for shapes attached to the vehicle's rigid body actor, search for contacts involving shapes attached to the vehicle's actor.

2. Is sufficient friction being delivered to the tire contact patch? Query experienced by the tires during the execution of PxVehicle.
PxVehicleWheelsDynData::getTireFriction.

3. Do the suspension forces (and the loads on the tires) reflect the mass of the rigid body actor? Query the suspension forces using PxVehicleWheelsDynData::getSuspensionForce. A 4-wheeled vehicle should generate suspension forces of approximately actorMass*gravity/4. Ensure that the masses of the vehicle suspensions to ensure that the driven wheels experience significant tire load.

4. Do the tires generate significant longitudinal tire forces? Check that the longitudinal slip of the tire is non-zero and approaches 1.0 when the wheels are spinning without forward motion. Ensure that PxVehicleSetBasisVectors has been called with the correct forward vector if the longitudinal slip is vanishingly small. If the forward vector has been set correctly, test that the longitudinal slip is non-zero.

5. Is the tire longitudinal stiffness too small? Adjust the longitudinal stiffness back to the default value and test.

6. Is the mass of the vehicle's rigid body actor too large to be driven by engine torque? Test that the mass of the actor is a sensible value and set accordingly.

7. Is the rigid body actor in a PhysX scene and is the scene being updated? The actor is not asleep and participates in the scene update.

---

**The Vehicle Does Not Steer/Turn**

1. Is the moment of inertia of the vehicle too large so that it resists turning motion? Check that the moment of inertia of the vehicle's rigid body actor is a sensible value. Use the moment of inertia of a box with width/height/length of the vehicle as a starting guess for the moment of inertia of the actor.

2. Are the steer wheels receiving a steer angle? Check the PxVehicleWheelsDynData::getSteer. If the steer angle is zero, check that a steer angle is being passed to the vehicle.
maximum steer angles of the steer wheels are sensible values.

3. Do the steer wheels have a sensible lateral slip? Use PxVehicleWheelsDynData::getLatSlip to query the slip angle. PxVehicleSetBasisVectors has been called with the correct forward and lateral slips are vanishingly small. Further test that the basis vectors are set correctly by using PxVehicleWheelsDynData::getTireLateralDir.

4. Is the lateral stiffness of the tire configured properly? Reset the default values and retest.

**The Acceleration Feels Sluggish**

1. Are the damping rates of the engine and wheels too large? First reduce the engine damping rate, then the wheel damping rates and retest each time.

2. Is the vehicle stuck in the same gear all the time? Disable the autobox and change gears manually to test if the autobox is failing to switch gear. Change vehicle settings to make sure that it will automatically increase the gear at sensible engine rotation speeds.

3. Is the engine powerful enough to quickly accelerate the car? Increase the peak torque of the engine.

4. Do the wheels have high moments of inertia that prevent significant longitudinal slips developing? Reduce the moments of inertia of the wheels.

**The Vehicle Does Not Slow Down When Not Accelerating**

1. Are the wheel and engine damping rates too small? First increase the engine damping rate, then the wheel damping rates and retest each time.

2. Does the vehicle's rigid body actor have a velocity damping value appropriate.

**The Vehicle Turns Too Quickly/Too Slowly**
1. Does the moment of inertia of the rigid body actor need tweaking? The component of the moment of inertia that corresponds to motion about the up vector. Increasing the moment of inertia will slow the turn rate, decreasing inertia will increase the turn rate.

The Wheels Spin Too Much Under Acceleration

1. Is the accelerator pedal value increasing too rapidly from 0 to 1? Slow down the rate of increase of the accelerator pedal value by filtering the controller. Remember that aggressively pressing the accelerator pedal on a powerful car ought to lead to wheel spin.

2. Are the wheel moments of inertia too low? Increase the wheel moment.

The Wheels Spin Too Much When Cornering

1. Does the vehicle have a limited slip differential? If applicable set the differential type to limited slip and adjust the differential biases accordingly.

The Vehicle Never Goes Beyond First Gear

1. Does the vehicle cycle between first gear and neutral? If the autobox is enabled the problem is probably that the latency of the autobox is shorter than the time spent performing a gear change. The autobox latency controls the minimum time between automated gear changes. After an automated gear change the autobox will not make another gear change decision until the latency time has passed. During a gear change the vehicle enters neutral gear and the accelerator pedal is uncoupled from the engine, meaning that the engine will slow down during the gear change. When the vehicle enters the target gear at the end of the gear change the autobox might decide immediately that the engine is too slow for the target gear and immediately initiate a downwards gear change. This will put the car back in neutral, meaning that the car spends a very long time in neutral.
and never reaches its target gear. This will not happen if the latency (PxVehicleAutoBoxData::setLatency) is set significantly larger than the gear switch time (PxVehicleGearsData::mSwitchTime).

The Vehicle Under-steers Then Over-steers

1. Is the vehicle on a bumpy surface? Edit the values in PxVehicleTireLoadFilterData so that the filtered normalized tire load has a flatter response to suspension compression.

The Vehicle Slows Down Unnaturally

1. Does the vehicle not slow down smoothly to rest? Take a look at the longitudinal slip values to see if they are oscillating between positive and negative. In oscillation then two options are available that can be used separately or in conjunction with each other. The first option is PxVehicleWheelsSimData::setSubStepCount to force more vehicle update sub-steps as the forward speed of the vehicle approaches zero. The second option is PxVehicleWheelsSimData::setMinLongSlipDenominator to ensure that the denominator of the longitudinal slip never falls below a specified value.

The Vehicle Climbs Too Steep Slopes

1. Are the front wheels slipping badly? Modify PxVehicleTireData::mF to reduce the available friction for slipping wheels.
References

Anti-roll Bar


Tire Modeling

The default tire model employed by PhysX vehicles is discussed in CarSimEd documentation:


PhysX vehicles allow any tire model to be simulated by specifying discussed in *Tire Shaders*. A tire model commonly used in engineering Pacejka tire model:


http://phors.locost7.info/phors22.htm

Engine Torque Curves


Differentials

http://www.howstuffworks.com/differential.htm

Clutch

http://auto.howstuffworks.com/clutch.htm
Ackermann Steer Correction

http://en.wikipedia.org/wiki/Ackermann_steering_geometry

Tanks


General

http://phors.locost7.info/intro.htm

http://www.millikenresearch.com/rcvd.html

Introduction

The character controller (CCT) SDK is an external component built on top of the PhysX SDK, in a manner similar to PhysXExtensions.

CCTs can be implemented in a number of ways: the PhysX implementation in the CCT module is only one of them.

By nature, CCTs are often very game-specific, and they can have a number of unique features in each game. For example the character's bounding volume may be a capsule in one game, and an inverted pyramid in another. The CCT SDK does not provide a one-size-fits-all solution that would work out-of-the-box for all possible games. But it provides the basic features common to all CCTs: character control and character interactions. It is a default starting point for users, a strong base that one can later modify or customize if needed.
Kinematic Character Controller

The PhysX CCT is a kinematic controller. Traditionally, character controllers can be either kinematic or dynamic. A kinematic controller directly works with input displacement vectors (1st order control). A dynamic controller works with input velocities (2nd order control) or forces (3rd order control).

In the past, games did not use a 'real' physics engine like the PhysX SDK. They used a character controller to move a player in a level. These games, even Doom, had a dedicated, customized piece of code to implement collision detection and response, which was often the only piece of physics in the whole game. It had little physics, but a lot of carefully tweaked values to provide a good controlling the player. The particular behavior it implemented is often called the 'collide and slide' algorithm, and it has been 'tweaked for more than a decade. The PhysX CCT module is an implementation of such an algorithm, providing a robust behavior for character control.

The main advantage of kinematic controllers is that they do not suffer issues, which are typical for dynamic controllers:

- (lack of) continuous collision detection: typical physics engines use discrete collision checks, leading to the notorious 'tunneling effect' that has plagued various commercial & non-commercial physics packages for years. This leads to three main problems:
  - the tunneling effect itself: if the character goes too fast it might tunnel through a wall
  - as a consequence, the character's maximum velocity be limited, limiting the game play possibilities
  - even if it does not tunnel, the character might jitter when pushed into a corner for example, because the physics engine keeps moving it back and forth to slightly different positions.
- No direct control: a rigid body is typically controlled with impulses; usually not possible to move it directly to its final position: instead the delta position vector to impulses/forces, apply them, and hope will end up at the desired position. This does not always work well the physics engine uses an imperfect linear solver.

- Trouble with friction: when the character is standing on a ramp, it should not slide. So infinite friction is needed here. When the character is moving forward on a ramp, it should not slow down. One does not need any friction here. When the character is sliding against a wall, it should not slow down either. Friction is usually either 0 or infinite. Unfortunately the friction in an engine might not be perfect, and it is easy to end up with either: friction (the character slows down a tiny bit) or a very-large-but-not-infinite friction (the character slides very slowly on that ramp no matter how artificially big the friction parameters are). The conflicting requirements for ramps also mean that is simply no way to perfectly model desired behavior.

- Trouble with restitution: typically, restitution should be avoided for characters. When the character moves fast and collides with a wall, it should not bounce. When the character falls from a height and lands on the ground, flexing its legs, any bounce should be prevented. But once again, even when the restitution is zero, a physics engine can nonetheless make the CCTs bounce a bit. This is not only related to the imperfect nature of the linear solver, it also has to do with how penetration-depth-based engines recover from overlap situations, sometimes applying excessive forces that separate the objects too much.

- Undesired jumps: characters must often stick to the ground, not physical behavior should be. For example characters in action games move fast, at unrealistic speeds. When they reach the top of a ramp, they often makes them jump a bit, in the same way a fast car would jump in San Francisco. But that is often not the desired behavior: instead the character should often stick to the ground regardless of its current velocity. This is sometimes implemented using fixed joints, but this is an unnecessarily complex problem that is easily prevented with kinematic controllers.
• Undesired rotations: a typical character is always standing up and never rotating. However physics engines often have poor support for that sort of constraint. A great deal of effort is often put into preventing a capsule around the character from falling (it should always stand up on its tip). This is often implemented using artificial joints, and the resulting system is neither very robust nor very fast.

To summarize, a lot of effort can be spent on tweaking and disabling the physics features simply to emulate what is otherwise a much less complex piece of custom code. It is natural to instead keep using that simple piece of custom code.
Creating a character controller

First, create a controller manager somewhere in your application. This object keeps track of all created controllers and allows characters from the same manager to interact with each other. Create the manager using the `PxCreateControllerManager` function:

```cpp
PxScene* scene; // Previously created scene
PxControllerManager* manager = PxCreateControllerManager(*scene);
```

Then, create one controller for each character in the game. At the time of writing, boxes (` PxBoxController`) and capsules (` PxCapsuleController`) are supported. A capsule controller for example, is created this way:

```cpp
PxCapsuleControllerDesc desc;
...<fill the descriptor here>
...
PxController* c = manager->createController(desc);
```

The manager class will keep track of all created controllers. They can be retrieved at any time using the following functions:

```cpp
PxU32 PxControllerManager::getNbControllers() const =
PxController* PxControllerManager::getController(PxU32 index) =
```

To release a character controller, simply call its release function:

```cpp
void PxController::release() = 0;
```

To release all created character controllers at once, either release the manager itself, or use the following function if you intend to keep using the manager:

```cpp
void PxControllerManager::purgeControllers() = 0;
```

The creation of a controller manager and its subsequent controller is illustrated in SampleBridges.
**Overlap Recovery Module**

Ideally, character should not be created in an initial overlap state, i.e. created in a position where they do not overlap the surrounding geometry. PxScene overlap functions can be used to check the desired volume of space is empty prior to creating the character. By default the CCT module does not check for overlaps itself, and creating a character that initially overlaps the world's static geometry can have undesired and undefined behavior - like the character going through the ground for example.

However, the overlap recovery module can be used to automatically correct the character's initial position. As long as the amount of overlap is reasonable, the recovery module should be able to relocate the character to a proper, collision-free position.

The overlap recovery module can be useful in several other situations:

- when the CCT is directly spawned or teleported in another object
- when the CCT algorithm fails due to limited FPU accuracy
- when the "up vector" is modified, making the rotated CCT shape overlap surrounding objects

When activated, the CCT module will automatically try to resolve the penetration, move the CCT to a safe place where it does not overlap other objects anymore. This only concerns static objects, dynamic objects are ignored by this module.

Enable or disable the overlap recovery module with this function:

```cpp
void PxControllerManager::setOverlapRecoveryModule(bool flag);
```

By default the character controllers use precise sweep tests, whose accuracy is enough to avoid all penetration - provided the contact offset is not too small. In most cases the overlap recovery module is not needed. When it is used though, the tests can be switched to less accurate but potentially faster versions, if
function:

```cpp
void PxControllerManager::setPreciseSweeps(bool flag);
```
Character Volume

The character uses a bounding volume that is independent from alrea
in the SDK. We currently support two different shapes around the chara

- An AABB, defined by a center position and an extents vector. Ti rotate. It always has a fixed rotation even when the player is (visi avoids getting stuck in places too tight to let the AABB rotate.
- A capsule, defined by a center position, a vertical height and a ra the distance between the two sphere centers at the end of the ca has a better behavior when climbing stairs, for example. It is defa default choice.

![Capsule Diagram](image)

Note: versions prior to 2.3 also supported a sphere. This has been | PxCapsuleController is more robust and provides the same functio capsule).

A small skin is maintained around the character's volume, to avoid nu would otherwise happen when the character touches other shapes. The user-defined. When rendering the character's volume for debug purp expand the volume by the size of this skin to get accurate debug visual defined in `PxControllerDesc::contactOffset` and later availa `PxController::getContactOffset()` function.
Volume Update

Sometimes it is useful to change the size of the character's volume at runtime. For example, if the character can crouch, it might be required to reduce the bounding volume so that it can then move to places he could not reach otherwise.

For the box controller, the related functions are:

```cpp
bool PxBoxController::setHalfHeight(PxF32 halfHeight)
bool PxBoxController::setHalfSideExtent(PxF32 halfSideExtent)
bool PxBoxController::setHalfForwardExtent(PxF32 halfForwardExtent)
```

And for the capsule controller:

```cpp
bool PxCapsuleController::setRadius(PxF32 radius) = 0;
bool PxCapsuleController::setHeight(PxF32 height) = 0;
```

Changing the size of a controller using the above functions does not change its position. So if the character is standing on the ground (touching it) and its height is suddenly reduced without updating its position, the character will end up levitating above the ground for a few frames until gravity makes it fall and touch the ground again. This happens because the controllers positions are located at the center of the shapes, rather than the bottom. Thus, to modify a controller's height and preserve its bottom position, one must change both the height and position of a controller. The following helper function does that automatically:

```cpp
void PxController::resize(PxF32 height) = 0;
```
It is important to note that volumes are directly modified without any extra tests, and thus it might happen that the resulting volume overlaps some geometry nearby. For example, when resizing the character to leave a crouch pose, i.e., when the size of the character is increased, it is important to first check that the character can indeed 'stand up': the volume of space above the character must be empty (collision free). It is recommended to use the various PxScene overlap queries for this purpose:

```cpp
bool PxScene::overlap(...) = 0;
```

Updating the character's volume at runtime to implement a 'crouch' motion is illustrated in SampleNorthPole. Using overlap queries to leave the crouch pose is done in the SampleNorthPole::tryStandup() function.
Moving a Character Controller

The heart of the CCT algorithm is the function that actually moves characters around:

```cpp
PxControllerCollisionFlags collisionFlags = PxController::move(const PxVec3& disp, PxF32 minDist, PxF32 elapsedTime const PxControllerFilters& filters, const PxObstacleContext* obstacles);
```

`disp` is the displacement vector for current frame. It is typically a combination of motion due to gravity and lateral motion when your character is moving, while users are responsible for applying gravity to characters here.

`minDist` is a minimal length used to stop the recursive displacement algorithm when the remaining distance to travel goes below this limit.

`elapsedTime` is the amount of time that passed since the last call to the

`filters` are filtering parameters similar to the ones used in the SDK. Use these to control what the character should collide with.

`obstacles` are optional additional obstacle objects with which the character should collide. Those objects are fully controlled by users and do not need to have counterparts in SDK objects. Note that touched obstacles are cached, meaning that the cache needs to be invalidated if the collection of obstacles changes.

`collisionFlags` is a bit mask returned to users to define collision events that happened during the move. This is a combination of PxControllerCollisionFlag flags to trigger various character animations. For example, your character might be playing a falling idle animation, and you might start the land animation as soon as PxControllerCollisionFlag::eCOLLISION_DOWN is returned.

It is important to understand the difference between `PxController::move` and `PxController::setPosition`. The `PxController::move` function is the core of the CCT module. This is where the aforementioned 'collide-and-slide' algorithm takes place, and it will start from the CCT's current position, and use sweep tests to attempt...
required direction. If obstacles are found, it may make the CCT slide against them. Or the CCT can get blocked against a wall: the result of the move depends on the surrounding geometry. On the contrary, `PxController::setPosition` is a simple 'teleport' function that will move the CCT to desired position no matter what, regardless of where the CCT starts from, regardless of surrounding geometry, and even if the required position is in the middle of another object.

Both `PxController::move` and `PxController::setPosition` are demonstrated in SampleBridges.
Graphics Update

Each frame, after `PxController::move` calls, graphics object must be kept in sync with the new CCT positions. Controllers' positions can be accessed using:

```cpp
const PxExtendedVec3& PxController::getPosition() const;
```

This function returns the position from the center of the collision shape, which is used internally both within the PhysX SDK and by usual graphics APIs. Retrieving this position and passing it to the renderer is illustrated in SampleBridge. Note that the position uses double-precision, to make the CCT module work well with large worlds. Also note that a controller never rotates so you can only access its position.

Alternative helper functions are provided to work using the character's bottom position, a.k.a. the foot position:

```cpp
const PxExtendedVec3& PxController::getFootPosition() const;
bool PxController::setFootPosition(const PxExtendedVec3&);```

Note that the foot position takes the contact offset into account.
Auto Stepping

Without auto-stepping it is easy for a box-controlled character to get stuck against elevations of the ground mesh. In the following picture the small step would stop the character completely. It feels unnatural because in the real world a character would just cross this small obstacle without thinking about it.

This is what auto-stepping enables us to do. Without any intervention from the player (i.e. without them thinking about it) the box correctly steps above the minor obstacle.
However, if the obstacle is too big, i.e. its height is greater than the stepOffset, the controller cannot climb automatically, and the character gets stuck ()
'Climbing' (over this bigger obstacle, for example) may also be implemented as an extension of auto-stepping. The step offset `PxControllerDesc::stepOffset` and later available through the `PxController` function.

Generally speaking, the step offset should be kept as small as possible.
Climbing Mode

The auto-stepping feature was originally intended for box controllers blocked by small obstacles on the ground. Capsule controllers, thanks to their rounded nature, do not necessarily need the feature.

Even with a step offset of 0.0, capsules are able to go over small obstacles on the ground. Their rounded bottom produces an upward motion after colliding with a small obstacle.

Capsules with a non-zero step-offset can go over obstacles higher than the step offset because of the combined effect of the auto-stepping feature and their rounded shape. In this case, the largest altitude a capsule can climb over is difficult to predict, depending on the auto-step value, the capsule's radius, and even the magnitude of the displacement vector.

This is why there are two different climbing modes for capsules:

- **PxCapsuleClimbingMode::eEASY**: in this mode, capsules are not constrained by the step offset value. They can potentially climb over obstacles higher than the step offset.
- **PxCapsuleClimbingMode::eCONSTRAINED**: in this mode, an attempt is made to make sure the capsule can not climb over obstacles higher than the step offset.
**Up Vector**

In order to implement the auto-stepping feature, the SDK needs to know about the 'up' vector. The up vector is defined in `PxControllerDesc::upDirection` and later available through the `PxController::getUpDirection()` function.

The up vector does not need to be axis-aligned. It can be arbitrary, modified each frame using the `PxController::setUpDirection()` function, allowing the character to navigate on spherical worlds. This is demonstrated in SampleCustomGravity.

Modifying the up vector changes the way the CCT library sees character volumes. For example, a capsule is defined by a `PxCapsuleControllerDesc::height`, which is the 'vertical height' along the up vector. Thus, changing the up vector effectively rotates the capsule from the point of view of the library. The modification happens immediately, without tests to validate that the character does not overlap nearby geometry. It is then possible for the character to be penetrating some geometry right after the call. Using the overlap recovery module is recommended to solve these issues.
In the above picture the capsule on the left uses a vertical up vector with the surrounding geometry. On the right the up vector has been set the capsule now penetrates the wall nearby. For most applications the constant, and the same for all characters. These issues will only appear navigating in spherical worlds (e.g. planetoids, etc).
Walkable Parts & Invisible Walls

By default the characters can move everywhere. This may not always be the case, particularly, it is often desired to prevent walking on polygons whose slope is too steep. The SDK can do this automatically thanks to a user-defined slope limit. All polygons whose slope is higher than the limit slope will be marked as non-walkable, and the SDK will prevent characters from going there.

Two modes are available to define what happens when touching a non-walkable part. The desired mode is selected with the `PxControllerDesc::nonWalkableMode`.

- `PxControllerNonWalkableMode::ePREVENT_CLIMBING` prevents moving up a slope, but does not move the character otherwise. The character will be able to walk laterally on these polygons, and to move down their slope.
- `PxControllerNonWalkableMode::ePREVENT_CLIMBING_AND_FORCE_SLIDING` not only prevents the character from moving up non-walkable slopes but also forces it to slide down those slopes.

The slope limit is defined in `PxControllerDesc::slopeLimit` and later available through the `PxController::getSlopeLimit()` function. The limit is expressed as the cosine of the desired limit angle. For example, this uses a slope limit of 45 degrees:

```cpp
slopLimit = cosf(PxMath::degToRad(45.0f));
```

Using `slopLimit = 0.0f` automatically disables the feature (i.e. characters can go everywhere).

This feature is not always needed. A common strategy is to disable it and place invisible walls in the level, to restrict player's movements. The character module creates those walls for you, if `PxControllerDesc::invisibleWallHeight` is non-zero. The library creates those extra triangles on the fly, and that parameter controls their height (extruded in the user-defined up direction). A common problem is that those walls are only created when non-walkable triangles are found. It is possible
character to go over them, if its bounding volume is too small and does non-walkable triangles below him. The \texttt{PxControllerDesc::maxJumpH} addresses this issue, by extending the size of the bounding volume down all potentially non-walkable triangles are properly returned by the collision queries, invisible walls are properly created - preventing the character from jumping.

A known limitation is that the slope limit mechanism is currently only enabled against static objects. It is not enabled against dynamic objects, and in particular against kinematic objects. It is also not supported for static spheres or static capsules.
Obstacle Objects

Sometimes it is convenient to create additional obstacles for the 
CCT to collide with, without creating an actual SDK object. This is useful in a number of situations. For example:

- the obstacles might only exist for a couple of frames, in which case deleting SDK objects is not always efficient.
- the obstacles might only exist for stopping the characters, not the objects. This would be for example invisible walls around geometry that characters should collide with. In this case it may not be very efficient to use invisible walls as SDK objects, since their interactions would then have to be filtered out for everything except the characters. It is probably more efficient to create additional invisible walls as external obstacles, that only characters can interact with.
- the obstacles might be dynamic and updated with a variable timestep while the SDK uses a fixed timestep. This could be for example a moving platform that characters can stand.

At the time of writing the character controller supports box and capsule objects, namely `PxBoxObstacle` and `PxCapsuleObstacle`. To create the `PxObstacleContext` object using the following function:

```cpp
PxObstacleContext* PxControllerManager::createObstacleContext()
```

Then manage obstacles with:

```cpp
ObstacleHandle PxObstacleContext::addObstacle(const PxObstacle& obstacle)
bool PxObstacleContext::removeObstacle(ObstacleHandle handle) = 0
bool PxObstacleContext::updateObstacle(ObstacleHandle handle, const PxObstacle&)
```

Typically `updateObstacle` is called right before the controllers' `move` call.

Using obstacles for moving platforms is illustrated in SampleBridges.
PLATFORMS_AS_OBSTACLES is defined in SampleBridgesSettings.h
Hit Callback

The *PxUserControllerHitReport* object is used to retrieve some controller's evolution. In particular, it is called when a character hits character, or a user-defined obstacle object.

When the character hits a shape, the *PxUserControllerHitReport::onShapeHit* callback is invoked - for both static and dynamic shapes. Various impact parameters are sent to the callback, and they can then be used to do various things like playing trails, applying forces, and so on. The use of *PxUserControllerHitReport::onShapeHit* is illustrated in SampleBridges. Note that this callback will only be called if a character moving against a shape. It will *not* be called if a (dynamic) shape collides against an otherwise non-moving character. In other words, this will only be called during a *PxController::move* call.

When the character hits another character, i.e. another object controlled by a character controller, the *PxUserControllerHitReport::onControllerHit* callback happens when the player collides with an NPC, for example.

Finally, when the character hits a user-defined *PxUserControllerHitReport::onObstacleHit* callback is invoked.
Behavior Callback

The `PxControllerBehaviorCallback` object is used to customize the character's behavior after touching a `PxShape`, a `PxController`, or a `PxObstacle`. This is done using the following functions:

```cpp
PxControllerBehaviorFlags PxControllerBehaviorCallback::getBehaviorFlags(const PxShape& shape, const PxActor& actor) = 0;
PxControllerBehaviorFlags PxControllerBehaviorCallback::getBehaviorFlags(const PxController& controller) = 0;
PxControllerBehaviorFlags PxControllerBehaviorCallback::getBehaviorFlags(const PxObstacle& obstacle) = 0;
```

At the time of writing the following returned flags are supported:

- `PxControllerBehaviorFlag::eCCT_CAN_RIDE_ON_OBJECT` defines if the character can effectively travel with the object it is standing on. For example a character standing on a dynamic bridge should follow the motion of the `PxShape` it is standing on (e.g. `SampleBridges`). But it should not be the case if the character stands on a bottle rolling on the ground (e.g. the snowballs in `SampleNorthPole`). Note that this flag only controls the horizontal displacement communicated from an object. The vertical motion is something slightly different, as many factors contribute: the `step offset` used to automatically walk over small bumps, the motion of underlying dynamic actors like e.g. the bridges in `SampleBridges`, and probably always been taken into account, etc.

- `PxControllerBehaviorFlag::eCCT_SLIDE` defines if the character should slide or not when standing on the object. This can be used as an alternative to the pre-slope limit feature, to define non-walk-able objects rather than non-walkable parts. It can also be used to make a capsule character fall off a platform's edge automatically when the center of the capsule crosses the platform's edge.

- `PxControllerBehaviorFlag::eCCT_USER_DEFINED_RIDE` simply disables all built-in code related to controllers riding on objects. This can be useful to get the legacy behavior back, which can sometimes be necessary when porting to PhysX 3.x and a piece of code built
around the PhysX 2.x character controller. The flag simply skips the
lets users deal with this particular problem in their own application, c
library.

The behavior callback is demonstrated in SampleBridges.
Character Interactions: CCT-vs-dynamic actors

It is tempting to let the physics engine push dynamic objects by applying forces at contact points. However it is often not a very convincing solution.

The bounding volumes around characters are artificial (boxes, capsules so the forces computed by the physics engine between a bounding volume and surrounding objects will not be realistic anyway. They will not properly model the interaction between an actual character and these objects. If the bound volume is large compared to the visible character, maybe to make sure that its limbs never penetrate the static geometry around, the dynamic objects will start moving (pushed by a bounding volume) before the actual character touches them - making it look like the character is surrounded by some kind of force field.

Additionally, the pushing effect should not change when switching from a capsule controller. It should ideally be independent from the bounding volume.

Pushing effects are usually dictated by gameplay, and sometimes require inverse kinematic solvers, which are outside of the scope of the CCT module. For simple use cases, it is for example difficult to push a dynamic box forward using a capsule controller: since the capsule never hits the box exactly in the middle, applied force tends to rotate the box - even if gameplay dictates that it should move in a straight line.

Thus, this is an area where the CCT module should best be coupled with specific code, to implement a specific solution for a specific game. This coupling can be done in many different ways. For simple use cases it is enough to use the PxUserControllerHitReport::onShapeHit callback to apply artificial forces to surrounding dynamic objects. Such an approach is illustrated in SampleBridges.

Note that the character controller does use overlap queries to determine which shapes are nearby. Thus, SDK shapes that should interact with the characters (e.g. the character should push) must have the PxShapeFlag::eSCENE_QUERY_SHAPE flag set to true, otherwise the CCT will not detect them and characters will move right through these shapes.
Character Interactions: CCT-vs-CCT

The interactions between CCTs (i.e. between two PxController objects) in this case both objects are effectively kinematic objects. In other words they should be fully controlled by users, and neither the PhysX SDK nor should be allowed to move them.

The PxControllerFilterCallback object is used to define basic interactions between characters. Its PxControllerFilterCallback::filter function can be used to determine if two PxController objects should collide at all with each other:

```cpp
bool PxControllerFilterCallback::filter(const PxController& a, const PxController& b) {
    // Implementation...
}
```

To make CCTs always collide-and-slide against each other, simply return true.

To make CCTs always move freely through each other, simply return false.

Otherwise, customized and maybe gameplay-driven filtering rules can be implemented in this callback. Sometimes the filtering changes at runtime, and two characters might be allowed to go through each other only for a limited amount of time. When that limited time expires, the characters may be left in an overlapping state until they separate and move again towards each other. To automatically separate overlapping characters, the following function can be used:

```cpp
void PxControllerManager::computeInteractions(PxF32 elapsedTime, PxControllerFilterCallback* cctFilterCb = NULL) = 0;
```

This function is an optional helper to properly resolve overlaps between CCTs and should be called once per frame, before the PxController::move calls. This function will not move the characters directly, but it will compute overlap information for characters that will be used in the next PxController::move call.
**Hidden Kinematic Actors**

The CCT library creates a kinematic actor under the hood, for each controlled character. When invoking the `PxController::move` function, the underlying hidden kinematic is also updated to reflect the CCT position in the physics scene.

Users should be aware of these hidden entities, since the total number of actors in the scene will be higher than the number they created themselves. Additionally, they might get back these potentially confusing unknown actors from scene-level collision queries.

One possible strategy is to retrieve the controllers' kinematic actors using the following function:

```cpp
PxRigidDynamic* PxController::getActor() const;
```

Then mark these actors with a special tag, using the `PxRigidDynamic::userData` way the CCT actors can easily be identified (and possibly ignored) in collision queries or contact reports.
Time Stepping

Actors used internally by the CCT library follow the same rules as objects. In particular, they are updated using fixed or variable times troublesome because the PxController objects are otherwise often upd time steps (typically using the elapsed time between two rendering fram

Thus the PxController objects (using variable time steps) may not alw sync with their kinematic actors (using fixed time steps). This phenor SampleBridges.
Invalidating Internal Geometry Caches

The CCT library caches the geometry around each character, in order to speed up collision queries. The temporal bounding box for a character is an AABB around the character's motion (it contains the character's volume at both its start and end position). The cached volume of space is determined by the size of the character's temporal bounding box, multiplied by a constant factor. This constant factor is defined for each character by `PxControllerDesc::volumeGrowth`. Each time a character moves, its temporal bounding box is tested against the cached volume of space. If the motion is fully contained within that volume of space, the contents of the cache are reused instead of being regenerated through PxScene-level queries.

In PhysX 3.3 and above, those caches should be automatically invalidated when a cached object gets updated or removed. However, it is also possible to manually flush those caches using the following function:
Prior to deciding if a character will travel with the motion of an object that the character is touching, a number of tests are automatically performed to decide if the object remains valid. These automatic validity tests mean that in the following cases it is not strictly necessary to invalidate the cache:

- If the shapes actor is released
- If the shape is released
- If the shape is removed from an actor
- If an actor is removed from scene or moved to another one
- If the shapes scene query flag changed
- If the filtering parameters of the shape or the scene have changed.

If a cached touched object is no longer actually touching the character, that the character no longer travels with the motion of that cached object, it is necessary to invalidate the cache. This holds true if the pair have separated as a consequence of an updated global pose or modified geometry.
Runtime Tessellation

The CCT library is quite robust, but sometimes suffers from FPU accuracy issues when a character collides against large triangles. This can lead to characters not smoothly sliding against those triangles, or even penetrating them. One way to effectively solve these problems is to tessellate the large triangles at runtime, replacing them on-the-fly with a collection of smaller triangles. The library supports a built-in tessellation feature with this function:

```c
void PxControllerManager::setTessellation(bool flag, float maxEdgeLength)
```

The first parameter enables or disables the feature. The second parameter defines the maximum allowed edge length for a triangle, before it gets tessellated. A smaller edge length leads to more triangles being created at runtime. The more triangles get generated, the slower it is to collide against them.

It is thus recommended to disable the feature at first, and only enable it if experiencing collision problems. When enabling the feature, it is recommended to use the largest possible `maxEdgeLength` that does fix encountered problems.
In the screenshot, the large magenta triangle on which the character is standing is replaced with the smaller green triangles by the tessellation module. The internal geometry cache is represented by the blue bounding box. Note that only the green triangles touching this volume of space are kept. Thus, the exact number of triangles produced by the tessellation code depends on both the `maxEdgeLen` parameter in `PxControllerDesc::volumeGrowth`.
Troubleshooting

This section introduces common solutions to common problems with the CCT library.

Character goes through walls in rare cases

1. Try increasing `PxControllerDesc::contactOffset`.
2. Try enabling runtime tessellation with `PxControllerManager::setTessellation` a small `maxEdgeLength` first, to see if it solves the problem. Then as much as possible.
3. Try enabling overlap recovery module with `PxControllerManager::setOverlapRecoveryModule`.

Tessellation performance issue

1. Try fine-tuning the `maxEdgeLength` parameter. Use the largest possible value that still prevents tunneling issues.
2. Try reducing `PxControllerDesc::volumeGrowth`.

The capsule controller manages to climb over obstacles higher than the step offset value

1. Try using `PxCapsuleClimbingMode::eCONSTRAINED`.
Particles (deprecated)
Introduction

The PhysX particle feature has been deprecated in PhysX 3. The standalone library PhysX FleX is an alternative with a richer feature set.

PhysX 3 offers two particle system types - a generic particle system and an SPH fluid particle system. The generic particle system provides basic particle motion with rigid actors. It can be used for objects that require collisions against the environment, but for which inter-particle interactions are not needed. Examples include small debris, sparks or leaves. The SPH fluid particle system can be used for fluid effects that require approximate incompressibility and flowing behavior, such as liquids or smoke filling up a volume.

PhysX 3 takes care of collision detection and particle dynamics, while facilities such as emitters, lifetime maintenance etc. need to be provided by the application.
Creating Particle Systems

Both particle system classes `PxParticleSystem` and `PxParticleFluid` inherit from `PxParticleBase`, which is the common interface providing particle manipulation and collision functionality. Particle systems inherit from `PxActor` and can be added to a scene.

Figure 1: PxParticleSystem inherits all properties from PxParticleBase, adds fluid specific properties

The following section shows how a particle system is created and added:

```cpp
// set immutable properties.
PxU32 maxParticles = 100;
bool perParticleRestOffset = false;

// create particle system in PhysX SDK
PxParticleSystem* ps = mPhysics->createParticleSystem(maxParticles);

// add particle system to scene, in case creation was successful
if (ps)
    mScene->addActor(*ps);
```
**Note:** The particle module has to be registered with `PxRegisterParticle` with static linking (non windows) before creating particle systems. `PxCreatePhysics` registers all modules by default as opposed to `PxCreateBasePhysics`. 
Particle Management

Particle systems reserve memory for a fixed number of particles. Each of these particles can be addressed by a fixed index throughout its lifetime. The given range of indices is [0, \text{PxParticleBase::getMaxParticles}]]. In order to support a dynamic amount of particles, particles are marked as being valid or invalid. This is achieved by two means:

1. The particle range indicates the range within which particles may be valid. All particles are defined as being invalid. Within that range valid particles are marked with the flag \text{PxParticleFlag::eVALID}. Alternatively, PhysX provides a bitmap corresponding to a valid particle within the valid particle range. The bitmap consists of an array of 32-bit unsigned integers with enough elements to cover the valid particle range.

![Diagram of particle management](image)

**Figure 2:** Scheme showing how valid particles are tracked.

Creating Particles

The application specifies an index for each new particle at particle creation time. If the application maintains its own representation of particles, and already tracks these indices, then these indices may be re-used by PhysX. If the application does not have indices at its disposal, it can use an index pool provided by the PhysX \text{PxParticleExt::IndexPool} as explained here: Index Pool Extension.

PhysX 3 itself has no built-in emitters. Instead, it simply provides an interface to create particles with initial properties. When creating particles, specifying indic
mandatory, while velocities and rest offsets may be specified optionally.

The PhysX particle API uses the PxStrideIterator template class to pass data between the SDK and the application. This allows the particle data layout to be more flexible by supporting interleaved arrays or padded data without forcing extra copies for reformatting. The stride iterator is configured by setting the type of the iterated data and specifying the pointer to the first element.

Example for creating a few particles:

```cpp
// declare particle descriptor for creating new particles
// based on numNewAppParticles count and newAppParticleIndices,
// newAppParticlePositions arrays and newAppParticleVelocity
PxParticleCreationData particleCreationData;
particleCreationData.numParticles = numNewAppParticles;
particleCreationData.indexBuffer = PxStrideIterator<const PxU32>(newAppParticleIndices);
particleCreationData.positionBuffer = PxStrideIterator<const PxVec3>(newAppParticlePositions);
particleCreationData.velocityBuffer = PxStrideIterator<const PxVec3>(newAppParticleVelocity);

// create particles in *PxParticleSystem* ps
bool success = ps->createParticles(particleCreationData);
```

The indices specified for particle creation need to be unique and within `PxParticleBase::getMaxParticles()`.

In this example the stride iterator is used to set the same velocity for all new particles. This is achieved by setting the stride to zero.

**Note:** For fluid particles it is necessary to spawn particles at distances close to `PxParticleFluid::getRestParticleDistance()` in order to achieve a regular emission, otherwise particles will spread immediately in all directions.

**Note:** In PhysX 3 all particle access such as creating, releasing, updating and reading particles can only be carried out while the simulation of the scene is not active.
Particles can be released by providing indices to the particle system. A versions of the PhysX SDK, particles get immediately released.

Example for releasing a few particles:

```cpp
// declare strided iterator for providing array of indices corresponding to particles that should be removed
PxStrideIterator<const PxU32> indexBuffer(appParticleIndices);

// release particles in *PxParticleSystem* ps
ps->releaseParticles(numAppParticleIndices, indexBuffer);
```

It is a requirement that the indices passed to the release method correspond to existing particles.

All particles can be released at once by calling:

```cpp
ps->releaseParticles();
```

Since only a limited number of particle slots (PxParticleBase::getMaxParticles()) available it might be appropriate to replace old particles with new ones achieved for instance by maintaining an application-side particle lifetime. Other reasons to release particles:

- Drains can be useful to remove particles that go to locations where they are needed anymore. See *Particle Drains*.
- The spatial data structure used for particles may overflow. Particles that cannot be covered are marked and should be released. See *Particle Grid*.

**Index Pool Extension**

Example for allocating particle indices using the PhysX extensions library:

```cpp
// create an index pool for a particle system with maximum particle count
PxParticleExt::IndexPool* indexPool = PxParticleExt::createIndexPool;

// use the indexPool for allocating numNewAppParticles indices that
```
Updating Particles

The following per-particle updates are carried out immediately:

- Position updates: Teleporting particles from one location to another.
- Velocity updates: Directly altering the velocities of particles.
- Rest offset updates: Changes particle rest offsets (only with `PxParticleBaseFlag::ePER_PARTICLE_REST_OFFSET`).

Particle updates that are carried out during the next scene simulation step:

- Force updates: Results in a velocity change update according to a vector unit specified by `PxForceMode`.

Example for force update:

```cpp
// specify strided iterator to provide update forces
PxStrideIterator<const PxVec3> forceBuffer(appParticleForces);

// specify strided iterator to provide indices of particles that
PxStrideIterator<const PxU32> indexBuffer(appParticleForceIndices);

// specify force update on PxParticleSystem ps choosing the "force"
ps->addForces(numAppParticleForces, indexBuffer, forceBuffer, PxForceMode);
```
Reading Particles

The PhysX SDK does not provide to the user all simulated per-particle properties of a particle system by default. The application can specify the data it needs by configuring `PxParticleBase::particleReadDataFlags`:

- `PxParticleReadDataFlag::ePOSITION_BUFFER`: On by default.
- `PxParticleReadDataFlag::eFLAGS_BUFFER`: On by default.
- `PxParticleReadDataFlag::eVELOCITY_BUFFER`: Off by default.
- `PxParticleReadDataFlag::eREST_OFFSET_BUFFER`: Off by default. May only be enabled if the particle system was created with per-particle rest offset support. See Creating Particle Systems.
- `PxParticleReadDataFlag::eCOLLISION_NORMAL_BUFFER`: Off by default.
- `PxParticleReadDataFlag::eDENSITY_BUFFER`: Only available for particle fluids and off by default.

Particle flags provide more information on individual particles:

- `PxParticleFlag::eVALID`: If set, the particle was created before released. If not set, the particle slot does not contain a valid particle. All other properties are invalid in this case and should be ignored.
- `PxParticleFlag::eCOLLISION_WITH_STATIC`: Shows whether a particle collided with a rigid static during the last simulation step.
- `PxParticleFlag::eCOLLISION_WITH_DYNAMIC`: Shows whether a particle collided with a dynamic rigid body during the last simulation step.
- `PxParticleFlag::eCOLLISION_WITH_DRAIN`: Shows whether a particle collided with a rigid actor shape that was marked as a drain (Particle Drains).
- `PxParticleFlag::eSPATIAL_DATA_STRUCTURE_OVERFLOW`: Shows whether a particle had to be omitted when building the SDK internal spatial data structure (Particle Grid).

Particle collision normals represent contact normals between particl
surfaces. A non-colliding particle has a zero collision normal. Collision
e.g. for orienting the particle visualization according to their contact with

Particle densities provided by particle fluids can be used for rendering
has a value of zero for a particle that is completely isolated. It has a
particle that has a particle neighborhood with a mean spacing

Particle data can only be read while the scene simulation is not execut
access to the SDK buffers a *PxParticleReadData* instance needs to be
SDK. It has the following properties:

- *numValidParticles*: Total number of valid particles for the corr
- *validParticleRange*: The index range of valid particles in the particle
- *validParticleBitmap*: Bitmap of valid particle locations.
- *positionBuffer, positionBuffer, velocityBuffer, restOffsetBu
collisionNormalBuffer*: Strided iterators for particle properties.

Additionally particle fluids provide *PxParticleFluidReadData* with

- *densityBuffer*: Strided iterator for particle densities.
Example of how to access particle data:

```c++
// lock SDK buffers of *PxParticleSystem* ps for reading
PxParticleReadData* rd = ps->lockParticleReadData();

// access particle data from PxParticleReadData
if (rd)
{
    PxStrideIterator<const PxParticleFlags> flagsIt(rd->flagsBuffer)
    PxStrideIterator<const PxVec3> positionIt(rd->positionBuffer)

    for (unsigned i = 0; i < rd->validParticleRange; ++i, ++flagsIt)
    {
        if (*flagsIt & PxParticleFlag::eVALID)
        {
            // access particle position
            const PxVec3& position = *positionIt;
        }
    }

    // return ownership of the buffers back to the SDK
    rd->unlock();
}
```
Example of how to use the valid particle bitmap to access particle data (without showing the locking and unlocking):

```cpp
if (rd->validParticleRange > 0)
{
    // iterate over valid particle bitmap
    for (PxU32 w = 0; w <= (rd->validParticleRange-1) >> 5; w++)
    {
        for (PxU32 b = rd->validParticleBitmap[w]; b; b &= b-1)
        {
            PxU32 index = (w << 5 | Ps::lowestSetBit(b));

            // access particle position
            const PxVec3& position = rd->positionBuffer[index];
        }
    }
}
```
Parameter Guide

There are three types of particle system parameter. Some need to be specified when the particle system is created and cannot be changed afterwards. Some are mutable while the particle system is not part of a scene and others can be changed at any time. The following description covers parameter that either cannot be set at any time, or may induce a performance overhead when changed.

\textit{maxParticles}:

The maximum number of particles that can be added to a particle system. The smaller the value, the smaller the memory footprint of the particle system is going to be. Can only be set on particle system creation.

\textit{PxParticleReadDataFlags}:

Specifies a subset of simulation properties which are returned to the application after simulation. See \textit{Reading Particles}. As few read data flags should be set as possible in order to save memory and improve performance by avoiding unnecessary particle data copying. Parameter can only be changed while particle system is not part of a scene.

\textit{gridSize}:

A hint for the PhysX SDK to choose the particle grouping granularity for proximity tests and parallelization. See \textit{Particle Grid}. Parameter can only be changed while particle system is not part of a scene.

\textit{PxParticleBaseFlag::eENABLED}:

Enables/disables particle simulation.

\textit{PxParticleBaseFlag::eGPU}:

Enable/disable GPU acceleration. Changing this parameter while the particle system is part of a scene induces a large performance overhead.
PxParticleBaseFlag::eCOLLISION_WITH_DYNAMIC_ACTORS:

Enable/disable collision with dynamic rigid bodies. Changing this parameter while the particle system is part of a scene induces a performance overhead.

PxParticleBaseFlag::eCOLLISION_TWOWAY:

Enable/disable twoway interaction between particles and rigid bodies. Changing this parameter while the particle system is part of a scene induces a performance overhead.

PxParticleBaseFlag::ePER_PARTICLE_COLLISION_CACHE_HINT:

Enable/disable internal collision caches. Changing this parameter while the particle system is part of a scene induces a performance overhead.

Particle Dynamics

externalAcceleration:

Acceleration applied to each particle at each time step. The scene gravity added to the external acceleration by default can be disabled using PxActorFlag::eDISABLE_GRAVITY.

maxMotionDistance:

The maximum distance a particle can travel during one simulation step. High values may hurt performance, while low values may restrict the particle velocity. In order to improve performance it's advisable to set this to a low value and increase it until particles can move fast enough to achieve the target effect. Parameter can only be changed while particle system is not part of a scene.

damping:

Velocity damping constant, which is globally applied to each particle. This is particularly useful when using particles for smoke to prevent ballistic behavior of individual particles which can look odd.
**particleMass:**

Mass used for two way interaction with rigid bodies \((\text{PxParticleBaseFlag::eCOLLISION_TWOWAY})\) and different force modes in the context of \text{PxParticleBase::addForces}. This mass property doesn't have any impact on the fluid dynamics simulation.

**PxParticleBaseFlag::ePROJECT_TO_PLANE, projectedPlaneNormal, projectedPlaneDistance:**

Parameter to configure the projection mode which confines particles to a plane. If projection is enabled particles can only move in a plane. This can be useful in the context of a 2D-Game.

## Collision with Rigid Actors

**restOffset:**

Defines the minimum distance between particles and the surface of rigid actors maintained by the collision system. Parameter can only be changed while the particle system is not part of a scene.

**PxParticleBaseFlag::ePER_PARTICLE_REST_OFFSET:**

Enables/disables per-particle rest offsets. Memory can be saved by turning per-particle rest offsets off. Per-particle rest offsets should only be enabled if the particles represent objects of significantly varying size, for example in the context of debris effects. See [Per-particle Rest Offsets](#). Can only be set on particle system creation.

**contactOffset:**

Defines the distance at which contacts between particles and rigid actors are created. The contacts are internally used to avoid jitter and sticking. It needs to be larger than \text{restOffset}. A good value to start with is about twice the size of the restOffset. Parameter can only be changed while particle system is not part of a scene.

**restitution:**
Restitution used for particle collision. This parameter defines how strongly particles bounce of rigid actors.

\textit{dynamicFriction:}

Dynamic friction used for particle collision. This parameter defines how easily particles slide over rigid actor surfaces. The lower the value is to 0, the easier particles slide. One is the maximal value supported.

\textit{staticFriction:}

Static friction used for particle collision. This parameter is similar to dynamic friction but defines how easily particles start to slide over a surface. Values larger than one are supported.

\textit{simulationFilterData:}

Filter data used to filter collisions between particles and rigid bodies. See \textit{Filtering}.

\textit{PxParticleBaseFlag::eCOLLISION_TWOWAY:}

The collision two-way flag allows enabling/disabling two-way interaction between rigid bodies and particles. The particle mass parameter defines the strength of the interaction. The flag can only be changed while the particle system is not part of a scene.

\textbf{Fluid (PxParticleFluid)}

The SPH simulation can be tricky to tweak for good results. As this simulation technique uses an explicit integration scheme it only provides stable results within a certain parameter sub-space. A good set of parameter values depend on the size of the simulation and the external forces applied (such as gravity). The suggested starting points for parameter values below assume a time step size of about 1/60 [s] and gravity around 10 [m/s^2]. Using a \textit{damping} value larger than zero allows a larger parameter sub-space, for example useful when implementing a smoke effect.
restParticleDistance:

Defines the resolution of the particle fluid. It defines the approximate distance neighboring particles will adopt within a fluid volume at rest. For the particle tweaking assumption mentioned above, the particle rest distance should not be smaller than 0.05 [m]. Parameter can only be changed while particle system is not part of a scene.

stiffness:

The stiffness (or gas constant) influences the calculation of the pressure force field. Low values of stiffness make the fluid more compressible (i.e., springy), while high values make it less compressible. The stiffness value has a significant impact on the numerical stability of the simulation; setting very high values will result in instability. Reasonable values are usually between 1 and 200.

viscosity:

Viscosity controls a fluid's thickness. For example, a fluid with a high viscosity will behave like treacle, while a fluid with low viscosity will be more like water. The viscosity value scales the force to reduce the relative velocity of particles in the fluid. Both, too high and too low values will typically result in instabilities. Reasonable values are usually between 5 and 300.
Collision Handling

By default, particles will collide with any shapes inside the PxScene that they belong to. They will attempt to maintain a fixed distance from these shapes using the function `PxParticleBase::setRestOffset()`.

Collision Filtering

Filtering particle versus rigid body collisions can be useful to avoid unnecessary performance overhead or simply to avoid undesired collisions.

For the following examples filtering is useful:

- Avoid particles colliding with trigger shapes (this is already the behavior of `PxDefaultSimulationFilterShader`)
- Configure a drain shape to exclusively collide with particles
- Have particles collide with a proxy shape as opposed to the shape used for rigid body collisions

Filter information for particles can be specified by calling `PxParticleBase::setSimulationFilterData()`. Instructions for how to setup filter shaders can be found here: Collision Filtering.

Per-particle Rest Offsets

It is also possible to set a rest offset per-particle, using `PxParticleBase::setRestOffsets()`. In order to provide per-particle rest offsets, `PxParticleBaseFlag::ePER_PARTICLE_REST_OFFSET` needs to be set and the rest offsets must be smaller than the per-system value given by `PxParticleBase.getRestOffset()`.

Particle Drains
Using drains is a good method for keeping the particle count and spread under control. Placing drains around the area of interest in which a particle system is used helps to maintain good performance of the particle simulation. The area of interest could, for example, also be moved with the player.

Example of how to flag a PxShape rbShape as a drain:

```cpp
rbShape->setFlag(PxShapeFlag::ePARTICLE_DRAIN, true);
```

Particles that collide with a drain are marked with `PxParticleFlag::eCOLLISION_WITH_DRAIN` and may be released.
Best Practices / Troubleshooting

Particle Grid and Spatial Data Structure Overflow

The PhysX SDK uses a grid to subdivide the particles of a particle system into groups. This is done to accelerate proximity queries and for parallelization purposes. The grid size parameter needs to be experimentally adjusted with `PxParticleBase::setGridSize()` for best performance. When doing this, it is helpful to visualize the grid using `PxVisualizationParameter::ePARTICLE_SYSTEM_GRID`.

Grid size values might result in spatial data structure overflow, since the number of grid cells is limited to about 1000. Large grid size values on the other hand might result in poor performance due to ineffective spatial queries or lack of parallelization opportunities.

In case of overflow, some particles will stop colliding with rigid actors in the scene. These particles are marked with `PxParticleFlag::eSPATIAL_DATA_STRUCTURE_OVERFLOW` and should be released.
GPU/CUDA Acceleration

PhysX 3 supports GPU acceleration. This allows for larger and more complex effects while retaining good performance levels. To achieve this gain, 

`physx::PxGpuDispatcher` for the scene we want to add the particle system

```cpp
#if PX_WINDOWS
    // create cuda context manager
    PxFoundation& foundation = ...
    physx::PxCudaContextManagerDesc cudaContextManagerDesc;
    physx::PxCudaContextManager* cudaContextManager = 
        PxCreateCudaContextManager(foundation, cudaContextManagerDesc);
#endif

    PxSceneDesc sceneDesc(mPhysics->getTolerancesScale());
    // ...
#if PX_WINDOWS
    if (cudaContextManager)
        sceneDesc.gpuDispatcher = cudaContextManager->getGpuDispatcher;
#endif
    // ...
    physicsSdk->createScene(sceneDesc);
```

A particle system can be configured for GPU simulation by setting `PxParticleBaseFlag::eGPU`. Toggling GPU acceleration while the particle system is part of a scene might have a bad impact on performance since its state needs to be copied to or from the GPU device memory. It is therefore better to set `PxParticleBase::setParticleBaseFlag()` before adding the particle system.

Particle data can be read directly from the GPU using `PxParticleBase::lockParticleReadData(PxDataAccessFlag::eDEVICE)` and `PxParticleFluid::lockParticleFluidReadData(PxDataAccessFlag::eDEVICE)` to render particles directly with CUDA Graphics Interop.

Convex, Triangle and Height field meshes are automatically mirrored in the GPU when the corresponding shapes are within the proximity of a GPU accelerated particle system. This may cause some undesired performance hiccups which can be prevented by mirroring the meshes explicitly, as shown in this example:
On Kepler and above GPUs, the triangle meshes can be cached to achieve better performance. The amount of memory to be allocated for caching can be set using:

```
PxParticleGpu::setTriangleMeshCacheSizeHint(const class PxScene& scene);
```

The triangle mesh cache will be shared among all the particle systems in the scene. The optimal size depends on the scene (i.e. triangle mesh density and particle distribution). The cache usage statistics can be queried and analyzed to fine-tune the cache size hint.
The SampleParticles shows both particle system types being used: \textit{PxParticleSystem} is used for small debris and smoke, while \textit{PxParticleFluid} is used for a waterfall. The sample provides example implementations of various aspects described in this guide:

- \textit{SampleParticles::createParticleSystem}, \textit{SampleParticles::createFluid} create particle systems.
- \textit{ParticleSystem::createParticles} creates particles within a particle system.
- \textit{ParticleSystem::update} shows how to read, update, release particles and deal with spatial data structure overflows.
- \textit{SampleParticlesFilterShader} is an example for setting up collision filtering.
- \textit{SampleParticles::createDrain} shows how to setup a rigid body shape as a particle drain.
- \textit{SampleBase::onInit} illustrates how to setup GPU/CUDA acceleration.

The sample makes use of various helper classes:

- \textit{ParticleSystem}: Encapsulates a \textit{PxParticleSystem} or \textit{PxParticleFluid} and manages application side data such as particle lifetimes and orientations. It facilitates creating and releasing particles and double buffers particle data for asynchronous rendering.
- \textit{RenderParticleSystemActor}: Owns a \textit{ParticleSystem} and provides rendering functionality.
- \textit{ParticleEmitterRate}: Emits particles at a specified rate (#particles per second).
- \textit{ParticleEmitterPressure}: Emits particles maintaining a certain distance between them.
- \textit{SampleParticles::Emitter}: Connects an emitter as described with \textit{RenderParticleSystemActor}.
- \textit{SampleParticles::Raygun}: Provides functionality for the ray force field, rigid body debris, particle debris and smoke emission.
In the sample, the smoke effect is achieved by using a `PxParticleSystem`. Each particle is rendered as a point sprite with a smoke texture. The smoke effect is achieved by using a `PxParticleSystem`. Each particle is rendered as a point sprite with a smoke texture. The smoke particles collide with the scene, which can be seen when roaming the smoke with the ray-gun. The realism of the smoke effect could be increased by using a particle fluid in order to get the smoke volume to expand. This is typically useful for indoor scenes or ground fog like effects where the particles get into pooling situations.

Two kinds of debris are shown in the sample. Larger chunks of debris are represented using convex-shaped rigid bodies. Smaller but more abundant chunks are represented by particles, which helps performance. The particle based debris is rendered using instanced meshes. It is spawned in the craters and at the ray-gun impact location.

In order to give the chunks the appearance of a tumbling motion a simple trick is used:

1. Assign an initial random rotation matrix to each particle.
2. Change this rotation matrix proportional to the linear velocity of particle.

The implementation of this approach can be found in `ParticleSystem::initializeParticlesOrientations` and `ParticleSystem::modifyRotationMatrix`.
References

*Particle-Based Fluid Simulation for Interactive Applications*
Matthias Muller, David Charypar and Markus Gross, Eurogrphics/Siggr
Breeen, M. Lin Editors
http://www.matthiasmueller.info/publications/sca03.pdf

*Fast GPU Fluid Simulation in PhysX*
Simon Schirm and Mark Harris, NVIDIA Corporation
Chapter 7.3 of Game Programming Gems 8, Adam Lake
Introduction

The PhysX clothing feature has been deprecated in PhysX version 3.4.1, and APEX clothing features are replaced by the standalone NvCloth.

Realistic movement of character clothing greatly improves the player experience. The PhysX 3 cloth feature is a complete and high-performance solution to simulating character clothing. It provides local space simulation for high accuracy and stability, new techniques to reduce stretching, collision against a variety of shapes, as well as particle self-collision and inter-collision to avoid the cloth penetrating itself or other cloth instances. The simulation can be offloaded to CUDA capable GPUs for better performance or to run assets at higher resolutions than the CPU is able to handle.

PhysX 3 cloth is a rewrite of the PhysX 2 deformables, tailored towards simulating character cloth. Softbodies, tearing, and two-way interaction have been removed, and behavior and performance for cloth simulation have been improved.
Simulation Algorithm

For one PhysX simulation frame, the cloth solver runs for multiple iterations. The number of iterations is determined by the solver frequency parameter and the simulation time. Each iteration integrates particle positions, solves constraints, character and self-collision. Cloth inter-collision is performed once per-frame after all cloth instances in the scene have been stepped forward. Local frame, motion constraints and collision shapes are interpolated per iteration from the per-frame values specified by the user.

Solver Frequency

The size of the iteration time step is inversely proportional to the number of iterations:

```c
cloth.setSolverFrequency(240.0f);
```

The solver frequency is specified as iterations per second. A solver frequency value of 240 corresponds to 4 iterations per frame at 60 frames per second. In general, the simulation will become more accurate if higher solver frequency value is used. However, the simulation time grows roughly linearly with solver frequency. Typically this value is between 120 and 300.

The number of iterations for each frame is derived using the simulation frequency and the simulation time-step. PhysX tries to handle variable time-steps carefully by taking variations of the time-step into account during position integration and when applying damping parameters like constraint stiffness. While this reduces the possible jittering artifacts due to varying time step sizes, use of variable time step sizes is generally not recommended.

Particle Integration

The first step in a cloth iteration predicts the new particle position based on the old position, velocity and external acceleration. While a particle state consists of the current position and the position before the last iteration, the particle velocity is
computed by dividing the position delta by the delta time of the previous iteration.

Local Space Simulation and Inertia Scale

Each PxCloth actor has a transformation that transforms particles from local space to world space positions. For example:

```cpp
cloth.setGlobalPose(PxTransform(PxVec3(1.0f, 0.0f, 0.0f)));
```

will change the cloth's world space position to (1,0,0). Now compare that to this function:

```cpp
cloth.setTargetPose(PxTransform(PxVec3(1.0f, 0.0f, 0.0f)));
```

, which also changes the cloth's position to the same place. So what's different?

`PxCloth::setGlobalPose()` only moves the cloth, but `PxCloth::setTargetPose()` generates acceleration (inertia) due to the position change. The amount of frame acceleration affects the cloth particles can be controlled using an example to impart half the local frame acceleration to the particles use:

```cpp
cloth.setInertiaScale(0.5f);
```

Scaling inertia effects individually per translation and rotation axis is also possible through the family of `PxCloth::set*InertiaScale()` methods. Limiting the amount of local frame accelerations affect particles can be especially useful for fast moving characters.

**Note:** Using `setGlobalPose()` is equivalent to using `setTargetPos()` when inertia scale is 0. In this case, the cloth does not receive any acceleration due to frame changes.

Constraints

After the particle positions have been integrated, a set of different constraints simulate stretch, shear and bending forces, as well as to confine the cloth within a certain region.
Distance Constraints

Figure 1. Typical configuration for vertical (left), and horizontal (right) stretching constraints.

One of the most important roles for the cloth solver is to maintain particles so that the cloth does not stretch. This is achieved by constraints between pairs of particles. The way particles are connected affects how the cloth stretches, compresses, shears, rotates, and bends. PhysX classifies distance constraints into 4 types (see PxClothFabricPhaseType), each of which can be configured with different stiffness parameters.

Below is an example of stiffness settings for each constraint type:
Sometimes it is desirable that distance constraints are not enforced rigorously. The stiffness parameter allows only correcting a portion of the edge length per iteration, for example to reduce the strength of bending constraints. A separate, lower stiffness can be used for edges that are only moderately stretched or compressed. For example, a dress can be made to stretch when the character is taking large steps, but still behave correctly during pirouettes.

The following code sets up the vertical constraints such that when edges are compressed more than 60% or stretched more than 120%, a stiffness of 0.8 will be used; otherwise a stiffness of 0.4 = 0.8 * 0.5 will be used:

```cpp
PxClothStretchConfig stretchConfig;
stretchConfig.stiffness = 0.8f;
stretchConfig.stiffnessMultiplier = 0.5f;
stretchConfig.compressionLimit = 0.6f;
stretchConfig.stretchLimit = 1.2f;
cloth.setStretchConfig(PxClothFabricPhaseType::eVERTICAL, stretchConfig);
```

**Note:** Stretch settings for horizontal and vertical directions are specified separately. This can be used to handle stretching along the gravity (vertical) direction.

**Tether Constraints**
Figure 4. Example tether constraint configuration

The distance constraints are solved only once per iteration without converging. The most visible artifact of this approximation is that the cloth becomes stretchy. Increasing solver frequency reduces the stretching, but results in increased simulation time.

PhysX 3.3 introduces tether constraints as a solution to avoid stretching under gravity or fast motion. Tether constraints prevent stretching by limiting the distance a particle can move away from their anchor particles. This constraint adds very little computation to the solver, so it is more effective than increasing the number of solver iterations.

The tether constraints are automatically generated by the cooker when some \textit{PxClothMeshDesc::invMasses} values are set to zero, telling the cooker that the corresponding particles are non-simulated anchor particles whose positions are provided solely from users. Changing inverse masses after the fabric has been created does not affect which anchor particles are used for the tether constraints.

**Motion Constraints**
One can fully constrain a point to user specified position with zero inverse mass. However, it is sometimes desirable to confine a point within a small region around (user specified) position. This allows small details to be generated by suppressing any excessive deviation from the desired position.

*Motion constraints* lock the movement of each particle inside a sphere. For example, an animation system can sketch the overall movement of a cloth while the fine scale details are handled by the cloth simulation.

*PxClothParticleMotionConstraint* structure holds the position and radius of each particle, and motion constraints can be specified as follows:

```cpp
PxClothParticleMotionConstraints motionConstraints[] = {
    PxClothParticleMotionConstraints(PxVec3(0.0f, 0.0f, 0.0f), 0.0f),
    PxClothParticleMotionConstraints(PxVec3(0.0f, 1.0f, 0.0f), 1.0f),
    PxClothParticleMotionConstraints(PxVec3(1.0f, 0.0f, 0.0f), 1.0f),
    PxClothParticleMotionConstraints(PxVec3(1.0f, 1.0f, 0.0f), FLT_MAX),
};
cloth.setMotionConstraints(motionConstraints);
```

If the sphere radius becomes zero or negative, the corresponding particle is locked at the sphere center and the inverse particle mass is set to zero for the next iteration. In the above example, the first particle will fully lock to the constraint position, and the second and third particles will remain within the sphere radius. The last particle will not be constrained.
The motion constraint sphere radius can be globally scaled and biased to transition between simulated and animated states. See `PxClothMotionConstraint` details.

**Separation Constraints**

![Figure 6. Example separation constraint](image)

Separation constraints work exactly the opposite way to the motion constraints, forcing a particle to stay outside of a sphere. When particle movement is moderately constrained by motion constraints (e.g. sleeves around an arm), separation constraints can represent the character’s collision shape more accurately than using capsules alone. For example, separation constraints can be placed slightly inside the character by setting the radius to be the distance from the sphere center to the surface of the character.

See `PxClothParticleSeparationConstraint` and `PxCloth::setSeparationConstraints()`.

**Collision Detection**

Each cloth object supports collision with spheres, capsules, planes, convexes (groups of planes) and triangles. By default these shapes are all treated separately from the main PhysX rigid body scene, however collision against other PxScene actors can be enabled using the `PxClothFlag::eSCENE_COLLISION` flag.

Collision shapes are specified in local coordinates for the next frame before simulating the scene. An independent and complete collision stage is performed as part of each iteration, using shape positions interpolated from the values at the beginning and the end.
of the frame. Sphere and capsule collision supports continuous collision an acceleration structure to cull far-away particles early in the collision and capsules are therefore the preferred choice to model the character. Convexes and triangles should only be used sparingly.

Spheres are defined as center and radius. Note that the radius is specifically allowed to change from frame to frame. The total number of spheres is limited to 32 per cloth.

Capsules are defined by a pair of indices into the spheres array and have a different radius thus forming a tapered capsule. Spheres can be shared between multiple capsules, which can be useful for modeling characters (upper and lower legs made up from capsules can share the sphere at the knee). Sharing of spheres also makes the simulation more efficient and robust, so is highly encouraged.

![Figure 7. A tapered capsule collision shape formed by two connected spheres](image)

![Figure 8. A leg shape formed by using two tapered capsules, each sharing a middle sphere](image)

Planes are defined by their normal and distance to origin. They will not be considered for collision unless they are referenced by a convex shape. Convexes reference planes using a mask, where each bit corresponds to an entry in the array of planes.
32 planes per cloth.

Triangle colliders are defined as vertex triplets in counter-clockwise winding order. The triangles should form a closed patch near the cloth for consistent collision handling; each particle collides against its closest triangle expanded to an infinite plane.

The order of planes and triangles should remain unchanged (apart from removing them through the `PxCloth::removeCollisionPlane/Triangle()` method) as their positions are interpolated between simulation frames.

### Continuous Collision Detection

Besides discrete collision which resolves particles inside shapes at the end of each iteration, continuous collision detection is supported and can be enabled with:

```cpp
// Enable continuous collision detection
cloth.setClothFlag(PxClothFlag::eSWEPT_CONTACT, true);
```

Continuous collision is around 2x more computationally expensive than discrete collision, but it is necessary to detect collision between fast moving objects. Continual collision analyzés the trajectory of particles and capsules to determine when a contact occurs. After the first time of contact, the particle is moved with the shape until the end of the iteration.

**Note:** The SIMD collision path handles sets of 4 particles in parallel. It is advantageous to spatially group cloth particles so that they are likely to collide with the same set of shapes.

### Virtual Particle Collision

Virtual particles provide a way of improving cloth collision without increasing resolution. They are called 'virtual' particles because they only exist during the collision processing stage and do not have their position, velocity or mass explicitly stored like regular particles, they can be thought of as providing additional samples on the collision surface.
During collision processing each virtual particle is created from three normal particles using barycentric interpolation. It is then tested for discrete collision like a regular particle and the collision impulse is redistributed back to the original particles using reverse interpolation.

Section *Adding Virtual Particles* explains the necessary steps to use this feature.

### Friction and Mass Scaling

Coulomb friction can be enabled and will be applied for particle and virtual particle collisions by setting a friction coefficient between 0 and 1:

```java
cloth.setFrictionCoefficient(0.5f);
```

Additionally, there is an option to artificially increase the mass of colliding particles. A temporary increase in mass can help reduce stretching along edges that are being pulled over a collision shape. The effect is determined by the relative velocity of the particle and collision shape and a user defined coefficient. A value of 20 is a reasonable starting point but users are encouraged to experiment with this value:

```java
cloth.setCollisionMassScale(20.0f);
```

### Self-Collision of a Single Cloth Actor

The particles of a cloth actor can collide among themselves. To enable this behavior, one should set both self-collision distance and self-collision stiffness to non-zero values:

```java
cloth.setSelfCollisionDistance(0.1f);
cloth.setSelfCollisionStiffness(1.0f);
```

Self-collision distance defines the diameter of a sphere around each particle, and the solver ensures that these spheres do not overlap during simulation. Self-collision stiffness defines how strong the separating impulse should be.
Self-collision distance should be smaller than the smallest distance between two particles in the rest configuration. If the distance is larger, self-collision may violate constraints and result in jittering.

When such a configuration cannot be avoided (e.g. due to irregular input meshes, etc.), one can assign additional rest positions:

```c++
cloth.setRestPositions(restPositions);
```

Collision between two particles is ignored if their rest-positions are closer than the collision distance. However, a large collision distance and use of rest-positions will significantly degrade performance of self-collision, so should be used sparingly.

Self-collision performance for high-resolution cloth instances can be improved by limiting self-collision to a subset of all particles (see `PxCloth::setSelfCollisionIndices()`).

### Inter-Collision between Multiple Cloth Actors

Different cloth actors can be made to interact with each other when inter-collision is enabled. The parameters for inter-collision are set for all cloth instances:

```c++
scene.setInterCollisionDistance(0.5f);
scene.setInterCollisionStiffness(1.0f);
```

The definition of distance and stiffness values are the same as self-collision, instances that specify a particle subset for self-collision use the same subset for inter-collision.
Best Practices / Troubleshooting

Performance Tips

The runtime of the cloth simulation scales approximately linearly with the number of particles and the solver frequency: Simulating a higher resolution mesh and increasing stretch stiffness and collision handling fidelity will increase the time it takes to simulate one frame. Additionally, there is a performance drop somewhere below 3000 particles for the GPU solver as explained in the next section. As a rough guideline, a dozen cloth instances with 2000 particles each and a solver frequency of 300Hz can be simulated in real-time as part of a game.

Convex collision and triangle collision do not use any mid phase acceleration structure, and are therefore slower than sphere and capsule collision.

Self-collision and inter-collision can take a significant amount of the time. Consider keeping the collision distance small and using self-collision indices to reduce the number of particles that collide with each other.

Using GPU Cloth

Cloth can be simulated on a CUDA or DirectCompute enabled GPU, by setting the corresponding flags:

```cpp
cloth.setClothFlag(PxClothFlag::eCUDA, true);
cloth.setClothFlag(PxClothFlag::eDIRECT_COMPUTE, true);
```

The entire cloth solver pipeline is run on the GPU, with the exception that no supported GPU is available PhysX will issue a warning and subsequent simulations will be run on CPU.

When the cloth is simulated using CUDA, the GPU simulation results can be requested by the graphics API by requesting CUDA device pointers to the particle data:
cloth.lockParticleData(PxDataAccessFlag::eDEVICE);

To take full advantage of the GPU hardware there should be at least as many cloth instances as streaming multiprocessors (SMs). This means it is generally better to simulate clothing as multiple instances (e.g. shirts and skirt) rather than grouped into one instance.

GPU PhysX performance is better when the particle data of a cloth fits into shared memory. The number of particles that fit into shared memory depends on the number of collision shapes, whether continuous collision or self-collisions are enabled, and the GPU version. For GPUs supporting SM 2.0 and above, about 2500-2900 particles fit into shared memory. If particles don't fit into shared memory they are automatically streamed through global memory, which incurs some performance cost.

Furthermore, the limited size of shared memory requires the number of collision triangles to be clamped to 500 when GPU simulation is enabled.

Fast-Moving Characters

Consistent collision handling for fast-moving characters can be difficult and rotations are best handled by tying the cloth local simulation frame to the character transformation. The inertia effects of the local frame transformations can be fine-tuned using the inertia scale settings.

If the cloth tunnels collision shapes during fast character animations, increasing the solver frequency or enabling swept contacts (see `PxClothFlag::eSWEP`)

Avoiding Stretching

Due to the iterative nature of the distance constraint solver, high resolution cloth can stretch undesirably under strong gravity even if the stretch stiffness is set to one. Increasing the solver frequency mitigates the stretching, but tether constraints are better suited to eliminate stretching efficiently.
Avoiding Jitter

Under certain configurations, different constraint types can violate each other and constrain the particle positions. For example, a motion constraint can cause a particle to move further from the anchor particle than the tether constraint permits, or particles can get pinched between two overlapping collision shapes. Over-constraining can result in jitter and should be avoided. In some situations jitter can be avoided by increasing the solver frequency or by reducing the corresponding constraint stiffness.

PVD Support

Cloth particle positions, distance constraints, and collision shapes are rendered as points, lines, and wireframes respectively in PVD. The SDK does not have access to the mesh used to create the fabric, and this mesh can't be displayed in PVD either. You can display individual sets of distance constraints instead of all at once. Set Mode to Single Phase in the Preferences dialog and use the Cloth Phase slider to display. The Particle Scale slider in the same dialog affects the rendering size of ordinary and virtual cloth particles as well. All properties of a selected cloth object can be viewed in the Inspector panel of PVD.
Snippets Discussion

The following paragraph describes code of the cloth snippet provided with the PhysX SDK.

The cloth constraint connectivity and rest values are stored in a fabric instance (PxClothFabric), separate from the cloth actor (PxCloth). The separation of constraints from particles allows the same fabric data to be reused for multiple cloth instances, reducing cooking time and storage requirements. PxClothFabricCreate library, creates a fabric from a triangle or quad mesh (see PxClothMeshDesc actor) itself is created through the physics instance (PxPhysics) and needs to be added to a scene (PxScene) in order to be simulated. Once the cloth actor is created, users can assign simulation settings such as collision data, constraint stiffness, solver frequency and self-collision. The createCloth function in the cloth snippet performs these steps.

The stepPhysics function advances the simulation by one frame. It first updates the local frame, which rotates around the y-axis. The collision shapes are not moving in scene coordinates, but their positions are specified in cloth local coordinates, and therefore need to be updated every frame. The following sections detail some of the available parameters and show how to configure them.

**Note:** The cloth module has to be registered with PxRegisterCloth on static linking (non windows) before creating cloth objects. PxCreatePhysics modules by default as opposed to PxCreateBasePhysics.

Filling in PxClothMeshDesc

The first task to create a cloth is to fill in the PxClothMeshDesc structure programmatically creates a regular grid of cloth particles connected. Below is a simpler example on how to create a cloth from a simple mesh, a single quad.

```plaintext
PxClothParticle vertices[] = {
    PxClothParticle(PxVec3(0.0f, 0.0f, 0.0f), 0.0f),
    PxClothParticle(PxVec3(0.0f, 1.0f, 0.0f), 1.0f),
```
PxClothParticle(PxVec3(1.0f, 0.0f, 0.0f), 1.0f),
PxClothParticle(PxVec3(1.0f, 1.0f, 0.0f), 1.0f)};

PxU32 primitives[] = { 0, 1, 3, 2 };

PxClothMeshDesc meshDesc;
meshDesc.points.data = vertices;
meshDesc.points.count = 4;
meshDesc.points.stride = sizeof(PxClothParticle);

meshDesc.invMasses.data = &vertices->invWeight;
meshDesc.invMasses.count = 4;
meshDesc.invMasses.stride = sizeof(PxClothParticle);

meshDesc.quads.data = primitives;
meshDesc.quads.count = 1;
meshDesc.quads.stride = sizeof(PxU32) * 4;

Each particle is defined by its position in local coordinates and its inverse mass. Setting the inverse mass to zero indicates that the particle is not simulated. Instead, the particle is fixed in local space or kinematically constrained to user specified positions. The inverse mass of simulated particles can normally be set to any fixed positive value.

The PxClothMeshDesc structure allows positions and inverse masses to be stored in separate arrays or interleaved like in the code above. The mesh can consist of quads or triangles, or both. The cooker prefers quad meshes over triangle meshes when creating constraints and classifying constraint types. The extensions library therefore provides the PxClothMeshQuadifier helper class to extract quads from a triangle mesh.

Creating Fabric

Given the mesh descriptor, a call to PxClothFabricCreate in the extensions library wraps the generation of constraints and the creation of the PxClothFabric structure:

PxClothFabric* fabric = PxClothFabricCreate(physics, meshDesc, Px);

The third parameter indicates the direction of gravity, which is used as the direction of 'horizontal' or 'vertical' constraints.
The *PxClothFabric* class describes internal solver data for a cloth. For constraints consisting of two particle indices and a rest-length are created and stored in the fabric data. Multiple cloth instances of the same mesh fabric instance.

### Creating Cloth

A *PxCloth* object is created using a fabric instance and the initial particle configuration.

Like all actors, the cloth instance is simulated as part of a scene:

```cpp
PxTransform pose = PxTransform(PxIdentity);
PxCloth* cloth = physics.createCloth(pose, fabric, vertices, PxClothFlags); scene.addActor(cloth);
```

The first parameter specifies the initial pose. The second input is the fabric instance created by the cooker. The third input provides initial particle positions and masses. Typically this array is the same as the one referenced by the mesh used to create the fabric. Note that the rest configuration (such as the rest length for a distance constraint) is computed from PxClothMeshDesc, so the initial particle positions do not affect rest configuration. The last parameter is a set of flags that allow GPU simulation and continuous collision detection to be enabled. The default is to turn off both options.

### Specifying Collision Shapes

The following code illustrates how to add two spheres of different radii and a tapered capsule between them:

```cpp
// Two spheres located on the x-axis
PxClothCollisionSphere spheres[2] =
{
    PxClothCollisionSphere( PxVec3(-1.0f, 0.0f, 0.0f), 0.5f ),
    PxClothCollisionSphere( PxVec3( 1.0f, 0.0f, 0.0f), 0.25f )
};

cloth.setCollisionSpheres(spheres, 2);
cloth.addCollisionCapsule(0, 1);
```
Planes can be added through `PxCloth::addCollisionPlane()` method but will not be considered for collision unless they are referenced by a convex shape. The following code shows how to setup a typical upward facing ground plane through the origin:

```cpp
cloth.addCollisionPlane(PxClothCollisionPlane(PxVec3(0.0f, 1.0f, 0.0f))); cloth.addCollisionConvex(1 << 0); // Convex references the first
```

Planes may be efficiently updated after construction using the `PxCloth::setCollisionPlanes()` function.

Finally, triangles are added using the `PxCloth::setCollisionTriangles()` function. For example, the following code adds a tetrahedron made of four triangles:

```cpp
PxClothCollisionTriangle triangles[4] = {
    PxClothCollisionTriangle(PxVec3(0.0f, 0.0f, 0.0f), PxVec3(1.0f, 0.0f, 0.0f), PxVec3(0.0f, 1.0f, 0.0f)),
    PxClothCollisionTriangle(PxVec3(1.0f, 0.0f, 0.0f), PxVec3(0.0f, 0.0f, 0.0f), PxVec3(0.0f, 1.0f, 0.0f)),
    PxClothCollisionTriangle(PxVec3(0.0f, 0.0f, 1.0f), PxVec3(0.0f, 1.0f, 0.0f), PxVec3(0.0f, 0.0f, 0.0f)),
    PxClothCollisionTriangle(PxVec3(0.0f, 0.0f, 0.0f), PxVec3(0.0f, 0.0f, 1.0f), PxVec3(1.0f, 0.0f, 0.0f))
};
```

**Note:** The snippet adds collision convex and capsule once in the `createCloth` function and then updates collision spheres, planes and triangles every frame in the `update()` function.

### Adding Virtual Particles
Figure 9. Four virtual particles (green) expressed as the weighted combination of a triangle's particles, virtual particles provide a better sampling of the cloth geometry that improves collision detection.

A virtual particle is defined by 3 particle indices and an index into a weights table defines the barycentric coordinates used to create a virtual from a linear combination of the referenced particles. The following is a table that can be used to create a distribution of 4 virtual particles on a triangle:

```cpp
static PxVec3 weights[] =
{
    PxVec3(1.0f / 3, 1.0f / 3, 1.0f / 3), // center point
    PxVec3(4.0f / 6, 1.0f / 6, 1.0f / 6), // off-center point
};
```

The code below shows an example of how to set up the virtual PxClothMeshDesc:

```cpp
PxU32 numFaces = meshDesc.triangles.count;
assert(meshDesc.flags & PxMeshFlag::e16_BIT_INDICES);
PxU8* triangles = (PxU8*)meshDesc.triangles.data;

PxU32 indices[] = new PxU32[4*4*numFaces];
for (PxU32 i = 0, *it = indices; i < numFaces; i++)
{
    PxU16* triangle = (PxU16*)triangles;
    PxU32 v0 = triangle[0];
    PxU32 v1 = triangle[1];
    PxU32 v2 = triangle[2];

    // center
    *it++ = v0; *it++ = v1; *it++ = v2; *it++ = 0;
```
// off centers
*it++ = v0; *it++ = v1; *it++ = v2; *it++ = 1;
*it++ = v1; *it++ = v2; *it++ = v0; *it++ = 1;
*it++ = v2; *it++ = v0; *it++ = v1; *it++ = 1;

triangles += meshDesc.triangles.stride;
}
cloth.setVirtualParticles(numFaces*4, indices, 2, weights);
delete[] indices;

**Accessing Particle Data**

The cloth snippet doesn't render the result of the simulation, and therefore doesn't read back any particle data. The `lockParticleData()` provides read and optionally write access to the particle positions of the current and previous iteration. As an example, the following code applies some external acceleration to each particle:

```cpp
PxClothParticleData* data = cloth.lockParticleData(PxDataAccessFlag::eREADWRITE);
float dt = cloth.getPreviousTimeStep();
for(PxU32 i = 0, n = cloth.getNbParticles(); i < n; ++i)
{
    data->previousParticles[i].pos -= particleAccelations[i] * dt;
}
data->unlock();
```
References


Introduction

With the PhysX Visual Debugger (see *PhysX Visual Debugger (PVD)* tool to record information about simulated PhysX scenes and visualize a remote viewer application. However, sometimes it is preferable to integrate information directly into the application's view. For that purpose, PhysX provides an interface to extract visual debug information as a set of basic rendering primitives: points, lines, triangles, and text. These primitives can then be rendered overlaid on the application render objects.
Usage

To enable debug visualization, the global visualization scale has to be set to a positive value first:

```cpp
PxScene* scene = ...
scene->setVisualizationParameter(PxVisualizationParameter::eSCALE, ...)
```

Then the individual properties that should be visualized can be enabled using a positive value:

```cpp
scene->setVisualizationParameter(PxVisualizationParameter::eACTOR_AXES, ...)
```

In the example, the actor world axes will be visualized. The scale used will be the product of the global scale (1.0 in this example) and the property scale (2.0 in this example). Please note that for some properties the scale factor does not apply, for example, shape geometry, will not be scaled since the size is defined by the user application. Furthermore, for some objects, visualization has to be enabled explicitly on the corresponding object instances too (see `PxActorFlag::eVISUALIZATION`, `PxShapeFlag::eVISUALIZATION`, ...).

After a simulation step, the visualization primitives can then be extracted as follows:

```cpp
const PxRenderBuffer& rb = scene->getRenderBuffer();
for(PxU32 i=0; i < rb.getNbLines(); i++)
{
    const PxDebugLine& line = rb.getLines()[i];
    // render the line
}
```

**Note:** Do not extract render primitives while the simulation is running.

The amount of debug visualization data might be too vast to create efficiently for large scenes. In cases where only a localized area is of interest, there is the option to use a culling box for debug visualization via `PxScene::setVisualizationCullingBox()`...
Note that simply enabling debug visualization (PxVisualizationParameter::eSCALE) can have a significant performance impact, even when all the other individual visualization flags are disabled. Thus, make sure debug visualization is disabled in your final/builds.
The PhysX Visual Debugger (PVD) provides a graphical view of the includes various tools to inspect and visualize variables of every. Additionally it can also record and visualize memory and timing data.

PVD can be downloaded from: http://supportcenteronline.com/ics/sideptID=1949

Questions regarding the usage of the GUI should all be answered by help.
Basic Setup (SDK Side)

PVD integration is enabled in the debug, checked and profiling configurations. In order to reduce memory footprint and code size, it is not enabled in the release configuration.

The SDK outputs the PVD debugging data in form of a stream. PVD supports reading the stream either from a TCP/IP network socket or from a file.

Network Setup

Streaming to TCP/IP is supported on almost all platforms, and is the convenient way to collect PVD data. In this mode the stream can be watched in real-time, depending on network speed and scene complexity. In network mode PVD acts as a TCP/IP server and must therefore be launched before the SDK tries to connect to it. The default listening port is 5425:

```cpp
use namespace physx;

PxPvd* pvd = PxCreatePvd(*foundation);
PxPvdTransport* transport = PxDefaultPvdSocketTransportCreate(PVD_HOST pvd->connect(*transport,PxPvdInstrumentationFlag::eALL));

PxPhysics* physics = PxCreatePhysics(PX_PHYSICS_VERSION, *gFoundation);

//After releasing PxPhysics, release the PVD
physics->release();
pvd->release();
transport->release();
```

File Setup

Streaming to file is an alternative to network streams. This is the recommended fallback in case your platform or system setup does not support a network connection. File streams are often faster than network sockets and therefore a good alternative if performance is more important than real-time viewing. Streams store...
loaded by drag&drop or over the File->Load menu in PVD:

```cpp
use namespace physx;

 PxPvd* pvd = PxCreatePvd(*foundation);
 PxPvdTransport* transport = PxDefaultPvdFileTransportCreate(filename);
 pvd->connect(*transport,PxPvdInstrumentationFlag::eALL);

 PxPhysics* physics = PxCreatePhysics(PX_PHYSICS_VERSION, *gFoundation);

 //After releasing PxPhysics, release the PVD
 physics->release();
 pvd->release();
 transport->release();
```
Advanced Setup

Connection Flags

To optimize the stream size we provide flags to enable specific features. This has both influence on PVD's and the SDK's performance:

- **PxPvdInstrumentationFlag::eDEBUG**: Transfer all debug data to inspect objects. This flag has usually the biggest impact on the stream size.
- **PxPvdInstrumentationFlag::ePROFILE**: Transfer timing information of various profiling zones in our SDK.
- **PxPvdInstrumentationFlag::eMEMORY**: Transfer memory usage data of our SDK.

Setup to transfer only profiling data over network:

```
pvd->connect(*transport, PxPvdInstrumentationFlag::ePROFILE);
```

Visualizing Externals and Extended Data

Joints are implemented as an extension to the SDK constraints and therefore need special handling to get transmitted to PVD. Both joint and contact data can increase the stream size significantly. Visualizing it in PVD is therefore disabled by default. To enable them use the following API calls:

```
mScene->getScenePvdClient()->setScenePvdFlags(PxPvdSceneFlag::eTRANSMIT_CONSTRAINTS);
```

or set the flags separately:

```
mScene->getScenePvdClient()->setScenePvdFlag(PxPvdSceneFlag::eTRANSMIT_CONSTRAINTS);
```

Visualizing SceneQuery
Visualizing SceneQuery in PVD is disabled by default since queries and hits data can increase the stream size significantly. To enable it use following API call:

```cpp
mScene->getScenePvdClient()->setScenePvdFlag(PxPvdSceneFlag::eTRANSMIT_SCENEQUERIES);
```

## Custom PvdClient

Implement the PvdClient interface if your application needs to react upon disconnection from PVD, or if you plan to send custom PVD events from your application. It is recommended to toggle the contact and constraint visualization in the `onPvdConnected/onPvdDisconnected` callbacks to avoid potential memory and compute overhead in the SDK:

```cpp
// derive from PvdClient
struct MyPvdClient : public physx::pvdsdk::PvdClient
{
    virtual void onPvdConnected()
    {
        // 1. create a PvdDataStream
        // 2. send your custom PVD class descriptions from here
        // this then allows PVD to correctly identify and represent
        // custom data that is sent from your application to a Px
        // example in JointConnectionHandler
        // 3. do something when successfully connected
        // e.g. enable contact and constraint visualization
    }
    virtual void onPvdDisconnected()
    {
        // handle disconnection, release PvdDataStream
        // e.g. disable contact and constraint visualization
    }
    // implement other methods
    ...
};

// register custom handler
MyPvdClient myPvdClient;
pvd->addClient(myPvdClient);
```
PVD Error Stream

PhysX SDK sends all its own error messages to PVD if PVD is connect can call Ps::Foundation::error() or Ps::Foundation::getErrorHandler report your error message. These functions will send error automatically.

The messages will be listed in ErrorStream view of PVD.

Custom profiling

When using PxPvdInstrumentationFlag::ePROFILE, PVD PxSetProfilerCallback() to set itself up as the current profiler. This happens PxPvd::connect() call, and it overrides the potentially already existing one. That is, if users call PxSetProfilerCallback() with their own user profiler initialize PVD with PxPvdInstrumentationFlag::ePROFILE, then the user's profiler callback is lost. Similarly, initializing PVD first then calling PxSetProfilerCallback() with their own user profiler callback will make PVD's profiling results vanish.

In case both PVD's internal profiling and a user's custom profiling are needed at the same time, it is recommended to initialize PVD first, then call PxSetProfilerCallback() with their own profiler. In your implementation, call the PVD profiling functions after performing your own profiling operations:

```cpp
struct UserProfilerCallback : public PxProfilerCallback
{
    PxPvd* mPvd;

    virtual void* zoneStart(const char* eventName, bool detached) {
        // Do custom profiling here

        // Then re-route to PVD implementation
        return mPvd->zoneStart(eventName, detached, contextId);
    }

    virtual void zoneEnd(void* profilerData, const char* eventName) {
        // Do custom profiling here
    }
};
```
// Then re-route to PVD implementation
mPvd->zoneEnd(profilerData, eventName, detached,
});

This is illustrated in SnippetCustomProfiler.
Interface

In this chapter we will have a quick look at the statistics information that PhysX collects every simulation step. Usually, this information can be explored in the PhysX Visual Debugger but we do offer a PhysX API method as well to allow applications to access the data directly. After a simulation step and a call to `PxScene::fetchResults()` statistics for the processed step can be retrieved through `PxScene::getSimulationStatistics()` interface. The method copies the data to a user provided `PxSimulationStatistics` structure. For details about the individual members please refer to the API documentation.

**Note:** Do not fetch the simulation statistics while the simulation is running.
Usage

The provided simulation statistics is mainly meant to help investigate performance issues. It provides a quantitative summary of the work done, i.e., the number of objects or combination of objects which have been processed in the current simulation step. For example, if you encounter performance spikes in certain frames, the simulation statistics might give some insight into possible causes. For instance:

- Has a large amount of volumes been added or removed from the scene in a single step? You could try to distribute the addition/removal of objects over multiple simulation steps or maybe there is a particle system in the scene with a very small grid size.
- Are there suddenly many more collision pairs processed than expected? This could be caused by a badly configured collision pair filter or maybe some threshold has been accidentally raised.
- etc.

Please keep in mind that the simulation statistics are currently less about what the scene contains but rather what got processed. So it is only partially helpful to detect whether objects have been configured and arranged properly.
Introduction

PhysX 3 features two approaches to serialization:

- API-level serialization to RepX (an XML format)
- Binary serialization

API-level serialization uses a human readable XML format - RepX - that corresponds to the PhysX API. It is therefore suitable for manual modification for debugging purposes. It offers platform independence and further supports loading data that was serialized with a previous PhysX SDK version. API-level serialization is not expected to be used in performance critical situations.

The binary serialization approach on the other hand supports instantiation of PhysX objects directly from memory without copying data. This in-place deserialization is well suited for performance critical real time situations. However, this approach is less flexible as the binary format is specific to a given platform and PhysX SDK version. It provides functionality to convert binary serialized data from authoring platforms to run-time platforms to ease the asset management.

Note: cooking also generates a binary output stream. The primary purpose, however, is to translate from a user format to a format suitable for the SDK, so it is not considered a serialization mechanism. Loading a cooked mesh involves allocation and endian conversion. As a consequence, it is much less efficient than PhysX' binary serialization mechanism. See *Shapes* for more details.

The following documentation will discuss how to use both serialization approaches to build collections of PhysX objects and how these collections are serialized and deserialized. Further it will show how dependencies to other PhysX or application side objects can be re-established when deserializing.

PhysX also supports extending serialization to custom types, such as specialized joints. This is described in more detail in Section *Extending Serialization*.
First Code

The following code creates and serializes a rigid dynamic using both formats:

```cpp
// Create a material, a shape and a rigid dynamic
PxSphereGeometry geometry(1.0f);
PxMaterial* material = PxGetPhysics().createMaterial(0.0f, 0.0f, 0.0f);
PxShape* shape = PxGetPhysics().createShape(geometry, *material);
PxTransform t = PxTransform(PxIdentity);
PxCollisionShape* collision = PxDefaultCylinder(1.0f, 2.0f);
PxCollisionShape* dynamics = PxDefaultSphere(0.5f);
PxRigidDynamic* dynamic = PxCreateDynamic(PxGetPhysics(), t, geometry, collision, dynamics);

// Create a collection and all objects for serialization
PxCollection* collection = PxCreateCollection();
collection->add(*dynamic);
PxSerializationRegistry* registry = PxSerialization::createSerializationRegistry();

// Write object to either binary or RepX
PxDefaultFileOutputStream outStream("serialized.dat");
outStream << (*dynamic);
outStream.close();

// Binary
PxSerialization::serializeCollectionToBinary(outStream, *collection);

// RepX
PxSerialization::serializeCollectionToXml(outStream, *collection);
```

Most operations related to serialization require an instance of `PxSerializationRegistry` which provides information on how to serialize PhysX types. In order to serialize an object, it needs to be added to a `PxCollection`. If an object has dependencies on other PhysX objects, they need to be serialized as well. `PxSerialization::complete` required objects to the collection.

The following code deserializes the rigid dynamic and adds it to a scene:

```cpp
PxSerializationRegistry* registry = PxSerialization::createSerializationRegistry();
```

// Deserialization
```cpp
PxSerializationRegistry::deserializeCollectionFromBinary(registry, collection, "serialized.dat");
```
When deserializing a binary serialized collection, the data first needs memory block that is aligned to 128 bytes. The memory block may before the objects have been released: it needs to persist for the entire lifetime of the objects. This does not apply to RepX deserialization, as the memory for PhysX objects is allocated within PhysX. Finally the objects of the resulting collection can be added to the scene with \textit{PxScene\:::addCollection}. 
In-depth Discussion

Collections

The serialization system makes use of a class *PxCollection*, which manages objects deriving from *PxBase*. Each collection represents a set of objects and maintains a mapping between IDs of type *PxSerialObjectId* and objects in the collection. IDs may be defined by the application. One caveat here is that the IDs must be unique within a collection, but do not have to be unique across different collections. If the latter is required by the application, it is the application's responsibility to ensure.

Here is an example of how to iterate over a collection, for instance to ensure that the objects intended for serialization have all been added to the collection. PhysX' dynamic typing mechanism can be used to classify the objects:

```cpp
PxCollection* collection;
PxU32 size = collection->getNbObjects();
for(PxU32 i=0; i<size; i++)
{
    PxBase* object = collection->getObject(i);
    if(!object->is<PxActor>())
        continue;

    switch((PxConcreteType)object->getConcreteType())
    {
        case PxConcreteType::eRIGID_DYNAMIC:
            ...
        break;
    }
}
```

**Note:** In order to simplify releasing object within a collection, PhysXExtensions contains a function to remove and release all objects from a collection: *PxCollectionExt::releaseObjects*.

**Note:** Releasing an object within a collection invalidates the mapping to objects.
A collection is said to be *complete* if no contained objects depend on an object outside the collection. For example, an actor, a shape with a box geometry, and the material of the shape would together form a complete collection. The same collection without the material would be incomplete.

![Diagram of a complete and incomplete collection]

Figure 1: Left: Complete Collection, Right: Incomplete Collection

For a formal definition please refer to *Complete*.

Both complete and incomplete collections can be serialized, but when deserializing an incomplete collection, references to objects which were not serialized will need to be resolved. The following two sections describe how PhysX collections can be serialized and deserialized using the binary format or RepX. The first section shows how to deal with complete collections, and the second section shows how to deal with incomplete collections.

### Serializing Complete Collections

This code snippet shows how to prepare a collection of PhysX objects (e.g. an actor, its shapes, and the materials and meshes they reference):

```cpp
PxPhysics* physics;               // The physics SDK object
PxRigidDynamic* dynamic = PxCreateDynamic(...);  // Create a rigid dynamic

// Create a serialization registry
PxSerializationRegistry* registry = PxSerialization::createSerializationRegistry();

PxCollection* collection = PxCreateCollection(); // Create the collection

collection->add(*dynamic);         // Add it to the collection
```
Instead of using `PxSerialization::complete` it is possible to manually add the objects required for serialization. All objects the `PxRigidDynamic` references would need to be added and then all objects referenced by the newly added objects would need to be added as well and so forth. See definitions: `Requires, Complete`.

By default `PxSerialization::complete` follows references from joints to their actors, but not from actors to their joints. The `followJoint` parameter can be used to change the behavior of `PxSerialization::complete` to add the joints attached to each actor. This will cause entire actor-joint chains to be added to the collection.

When all the necessary objects have been added to a collection, create an implementation of the `PxOutputStream` interface, then serialize the collection:

```cpp
PxCollection* collection; // Comp
PxSerializationRegistry* registry; // Reg
PxOutputStream& outStream = ...; // Impl

// Serialize

// Binary
    PxSerialization::serializeCollectionToBinary(outStream, *collection);
//~Binary

// RepX
    PxSerialization::serializeCollectionToXml(outStream, *collection);
//~RepX

// Collection and registry can be released if they are no longer needed.
// Note that releasing the collection will not release the contained objects!
    collection->release();
    registry->release();
```

**Note:** Serialization of objects in a scene that is simultaneously being simulated is not supported and leads to undefined behavior.
The following code shows how to deserialize a collection from a memory block or XML:

```cpp
PxSerializationRegistry* registry; // Registry for serializable types
PxCooking* cooking; // Cooking library needed for instantiating objects by RepX

// Deserialize

// Binary
void* memory128 = ...; // A 12-byte aligned buffer previously loaded from disk by the user
PxCollection* collection = PxSerialization::createCollectionFromBinary
//~Binary

// RepX
PxInputData& inputData = ...; // Impl
PxCollection* collection = PxSerialization::createCollectionFromXml
//~RepX
```

To add all the objects to the scene and release the collection and registry:

```cpp
PxScene* scene; // The scene object
scene->addCollection(*collection);
collection->release();
registry->release();
```

See `Serializable` for the exact set of conditions a collection must satisfy to be serialized. These conditions can be checked with ` PxSerialization::isSerializable(...)`

## Serializing Incomplete Collections

Another common use case is where a collection of actors and joints - say, a ragdoll - will be deserialized multiple times, with each instance sharing the same materials and meshes. To achieve this, serialize two collections:

- a collection A of the materials and meshes that will be deserialized
- a collection B of actors and joints which will be copied and deserialized

```cpp
```
Collection B is *incomplete*, since it contains references to objects in A. \(^1\) The serialized format will remember each reference to an object in A using each object's ID (if it doesn't have an ID, then serialization will fail.) As long as an object with a matching ID is supplied when deserializing collection B, the reference can be resolved. Although collection B is incomplete, it is also said to be complete relative to collection A. For a formal definition of complete please refer to *Complete*.

![Diagram showing relationships between MATERIAL, SHAPE, JOINT, CONVEX MESH, and ACTOR]

**Figure 2**: Left: Collection A with Sharable Objects, Right: Collection B

Concretely, to serialize and deserialize an incomplete collection:

- At serialization time, provide IDs for all objects in collection A that are referenced by objects in collection B.
- When deserializing, provide a collection with matching IDs for all the objects in A that were referenced by objects in B.

Here are examples of how the application can provide identities to express requirements of one collection to another. This can be done by adding the object with:

```
PxCollection* collection;
PxTriangleMesh* triMesh;
PxSerialObjectId triMeshId = 1;

collection->add(*triMesh, triMeshId);
```

Or set the ID after adding the object:
collection->add(*triMesh);
collection->addId(*triMesh, triMeshId);

There is a helper function to generate IDs for all objects in a collection that do not have IDs yet:

```cpp
PxSerialObjectId baseId = 1;
PxSerialization::createSerialObjectId(*collection, baseId);
```

Already used ID values will be skipped by `createSerialObjectId`, as we already have IDs.

After providing correct IDs, all required objects have been added to the collection, but without adding the objects that are intended to be referenced. The function in `PxSerialization` supports completing a collection relative to another collection:

```cpp
PxSerializationRegistry* registry;
PxCollection* collectionB;
PxCollection* collectionA;

PxSerialization::complete(*collectionB, *registry, collectionA);
```

Serialization example:

```cpp
PxConvexMesh** convexes;       // An array of mNbConvexes convexes
PxRigidDynamic** actors;       // An array of mNbConvexes actors
PxSerializationRegistry* registry;   // Registry for serializable types
PxOutputStream& convexStream;    // Output stream for the convex collection
PxOutputStream& actorStream;    // Output stream for the actors

PxCollection* convexCollection = PxCreateCollection();
PxCollection* actorCollection = PxCreateCollection();
```
// Add convexes to collection
for(PxU32 i=0;i<mNbConvexes;i++)
    convexCollection->add(*convexes[i]);

// Create IDs for the convexes, starting with 1
PxSerialization::createSerialObjectId(*convexCollection, PxSeria...

// Serialize the convexes along with their IDs
// Binary
PxSerialization::serializeCollectionToBinary(convexStream, *co...

// RepX
PxSerialization::serializeCollectionToXml(convexStream, *co...

// Add actors to other collection
for(PxU32 i=0;i<mNbActors;i++)
    actorCollection->add(*actors[i]);

// Add all required objects except the convexes
PxSerialization::complete(*actorCollection, *registry, convexColli...

// Serialize the actors with references to convexCollection
// Binary
PxSerialization::serializeCollectionToBinary(actorStream, *ac ...

// RepX
PxSerialization::serializeCollectionToXml(actorStream, *actor...

// Release collections and registry
convexCollection->release();
actorCollection->release();
registry->release();

Deserialization example:

PxPhysics* physics; // The physics SDK ob
PxSerializationRegistry* registry // Registry for seria
The next example shows how to deal with situations where the serialized objects require objects that are not serialized and deserialized but created by other means:
PxRigidDynamic** actors;       // An array of mNbConvexes actors
PxOutputStream& actorStream;    // Output stream for the actor collection

// Add materials with IDs to collection
PxCollection* materialCollection = PxCreateCollection();

for(PxU32 i=0;i<mNbMaterials;i++)
    materialCollection->add(*materials[i], PxSerialObjectId(i+1));

// Create actor collection, complete and serialize
PxCollection* actorCollection = PxCreateCollection();

for(PxU32 i=0;i<mNbActors;i++)
    actorCollection->add(*actors[i]);

PxSerialization::complete(*actorCollection, *registry, materialCollection,

    // Binary
    PxSerialization::serializeCollectionToBinary(actorStream, *actorCollection, materialCollection);

    // ~Binary

    // RepX
    PxSerialization::serializeCollectionToXml(actorStream, *actorCollection, materialCollection);

    // ~RepX

actorCollection->release();
materialCollection->release();   // Note that materialCollection was not serialized
registry->release();

Deserialization:

PxScene* scene;               // The scene into which the objects will be inserted
PxSerializationRegistry* registry;  // Registry for serializing
PxCooking* cooking;           // Cooking library needed
PxMaterial** materials;       // Created procedurally by application

// recreate material collection with consistent IDs, no deserialization
PxCollection* materialCollection = PxCreateCollection();

for(PxU32 i=0;i<mNbMaterials;i++)
    materialCollection->add(*materials[i], PxSerialObjectId(i+1));

// Deserialize actors with reference material collection
Reference Counting of Deserialized Objects

This section assumes the background in *Reference Counting*.

Objects that are created by deserialization are always created with a reference that the application needs to give up by explicitly calling `release()`. The information whether the application gave up a reference to an object is not preserved on serialization.

See *Shapes* for a discussion of the method `PxRigidActorExt::createExclusiveShape` which automatically releases the initial reference to the shape, leaving only the actor's reference. Again, the information that this reference has been released is not preserved by serialization.

Example for shapes:

```cpp
PxOutputStream& outStream;  // Output stream for the collection
PxSerializationRegistry* registry;  // Registry for serializable
PxRigidActor* actor;  // Any actor

// Creating shapes in different ways implies different rules for
```
// Shape is automatically released when actor gets released
PxShape* shapeA = PxRigidActorExt::createExclusiveShape(*actor, .

// Shape is either created as "shared" or "exclusive" and needs to be released
PxShape* shapeB = PxGetPhysics().createShape(...);
actor->attachShape(*shapeB);

// Create collection with actor and shapes and serialize
PxCollection* collection = PxCreateCollection();
collection->add(*actor);
collection->add(*shapeA);
collection->add(*shapeB);
PxSerialization::serializeCollectionToBinary(outStream, *collection);
collection->release();

// Releasing actors and shapes
actor->release(); // Releases actor and shapeA (automatically)
shapeB->release(); // Releases shapeB (necessary since shapeB was created through PxPhysics)

// Deserialze collection
...
void* memory128 = ...; // Aligned memory for serialized data
collection = PxSerialization::createCollectionFromBinary(memory128);

// Release actors and release ALL shapes (necessary since shape creation history is not preserved across serialization
for(PxU32 i = 0; i < collection->getNbObjects(); i++)
{
    switch (collection->getObject(i).getConcreteType())
    {
    case PxConcreteType::eRIGID_DYNAMIC:
    case PxConcreteType::eRIGID_STATIC:
        static_cast<PxActor&>(collection->getObject(i)).release();
        break;
    case PxConcreteType::eSHAPE:
        static_cast<PxShape&>(collection->getObject(i)).release();
        break;
    }
}

Note: There is a PhysXExtensions function to release all objects within a
PxCollectionExt::releaseObjects.
Reconnecting PhysX and Game-Objects

Here is an example of how to fix up references with gameplay objects of a collection:

```cpp
PxPhysics* physics; // The physics SDK object
PxCooking* cooking; // Cooking library needed
PxSerializationRegistry* registry; // Registry for serialization

// Deserialized objects along with IDs

// Binary
void* memory128; // Aligned memory contain
PxCollection* collection = PxSerialization::createCollectionFromBinary(memory128, *r
//~Binary

// RepX
PxInputData& inputData = ...; // Implemented by the ap
PxCollection* collection = PxSerialization::createCollectionFromXml(actorInputData,
materialCollecti
//~RepX

// Receive a list of all deserialized IDs
#define MAX_IDS 100
PxSerialObjectId idBuffer[MAX_IDS];
PxU32 numIds = collection->getIds(idBuffer, MAX_IDS);

// iterate over the list to patch up gameplay objects
for (PxU32 i = 0; i < numIds; i++)
{
    PxActor* actor = collection->find(idBuffer[i])->is<PxActor>();
    if (actor)
    {
        // this assumes that findGamePlayObjectFromId is able to
        // the corresponding game play object from a PxSerialObj
        actor->userData = findGamePlayObjectFromId(idBuffer[i]);
    }
}
```

Alternatively `PxCollection::getObjects(...) and PxCollection::getld(PxBa` used to achieve the same.
Serializing Everything

PhysX provides two utility functions for serializing the entirety of the PhysX runtime:

```
PxCollectionExt::createCollection(PxPhysics& sdk)
PxCollectionExt::createCollection(PxScene& scene)
```

```cpp
define PHYSX_Physics

PxPhysics* physics; // The physics SDK object
 PxScene* scene;    // The physics scene
 PxSerializationRegistry* registry; // Registry for serializable
 PxOutputStream& outStream;        // The user stream doing the

// 1) Create a collection from the set of all objects in the physics SDK that are shareable across
//    multiple scenes.
 PxCollection* everythingCollection = PxCollectionExt::createCollection(sdk);

// 2) Create a collection from all objects in the scene and add it to everythingCollection.
 PxCollection* collectionScene = PxCollectionExt::createCollection(scene);
 everythingCollection->add(collectionScene);
 collectionScene->release();

// 3) Complete collection
 PxSerialization::complete(*everythingCollection, *registry);

// 4) serialize collection and release it

// Binary
 PxSerialization::serializeCollectionToBinary(outStream, *everythingCollection);

// RepX
 PxSerialization::serializeCollectionToXml(outStream, *everythingCollection);

everythingCollection->release();
 registry->release();
```

Deserialization is as previously:

```cpp
define PHYSX_Physics

PxScene* scene; // The physics scene
 PxCooking* cooking; // Cooking library needed for...
 PxSerializationRegistry* registry; // Registry for serializable
```
Serializability

This section contains various definitions to describe serializability of a collection. Whether a collection can be successfully serialized and deserialized, optionally given an references collection, can be queried by calling `PxSerialization::isSerializable(...)`.

Requires

An object `A` requires another object `B` if `A` maintains a reference to `B` that needs to be re-established for successfully deserializing `A`. This implies that `B` needs to be deserialized before `A`.

Here is the table of the relationship `requires` of all PhysX objects:

<table>
<thead>
<tr>
<th></th>
<th>require their <strong>actors</strong> and <strong>constraint</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>joints</strong></td>
<td></td>
</tr>
<tr>
<td><strong>rigid actors</strong></td>
<td>require their <strong>shapes</strong></td>
</tr>
<tr>
<td><strong>shapes</strong></td>
<td>require their <strong>materials</strong> and <strong>mesh</strong> (triangle mesh, convex field), if any</td>
</tr>
<tr>
<td><strong>articulations</strong></td>
<td>require their <strong>links</strong> and <strong>joints</strong></td>
</tr>
<tr>
<td><strong>aggregates</strong></td>
<td>require their <strong>actors</strong></td>
</tr>
<tr>
<td><strong>cloth actors</strong></td>
<td>require their <strong>cloth fabric</strong></td>
</tr>
</tbody>
</table>
Subordinate

Subordinates are objects that cannot be instantiated without being owned by other objects. An articulation link, for example, can only be instantiated as part of its articulation.

The following three types are **subordinates**:  

| articulation links | articulation joint | constraints |

Complete

Definition of a complete set:

A set of objects \( C \) is **complete** if every object **required** by \( C \) is in \( C \).

Definition of a set that is complete relative to another set:

A set of objects \( C \) is **complete** relative to a set \( D \) if every object **require** \( D \). This means that \( C \) can be deserialized given \( D \).

Serializable

Here is the complete set of requirements on a collection \( C \) with deper that \( C \) can be serialized:

- \( C \) is complete relative to \( D \). ("no dangling references")
- Every object in \( D \) required by an object in \( C \) has a valid ID. ("no unnamed references")
- Every subordinate object in \( C \) is required by another object in \( C \). ("no orphans")

Binary Serialization Specifics

The following sections describe specific properties of the binary serialization
Memory Management

Management of memory blocks containing deserialized objects is left to the user's responsibility to:

- allocate the memory block. Note that it must be properly aligned to a \texttt{PX\_SERIAL\_FILE\_ALIGN} (128) bytes boundary.
- fill the block with serialized data, typically by loading it from disk.
- deallocate the memory block when the objects within have been released.

Although the user owns the memory block, the PhysX runtime owns the objects it contains. Concretely, calling \texttt{release()} on an object that was deserialized will cause its destructor to run, but will not deallocate the memory block is deallocated before the destructors have run for all the objects. The PhysX runtime will likely crash. For more information about how deserialized objects need to be released see \textit{Reference Counting of Deserialized Objects}.

Versioning

The binary serialized data is typically specific to the version of the SDK with. However, a SDK version can load the data of older SDK versions if the binary format didn't change. This is usually the case with bugfix releases. The compatible SDK versions are listed in the code documentation of \texttt{PX\_BINARY\_SERIAL\_VERSION} in \texttt{PxSerialization.h}.

Retargeting to other Platforms

Binary serialized data is platform-specific, and when serialized it targets the platform on which it was created. The binary converter in the extensions library retargets data from one platform to another. Typically assets are serialized on an authoring platform (Windows, Mac OS X and Linux). The serialized data can then be retargeted to a console or any other runtime platform.

The converter requires meta-data for the source and target platform.
information about the binary layout of objects for that platform. To obtain the function provided in the extensions library for each platform:

```cpp
void PxSerialization::dumpBinaryMetaData(PxOutputStream& stream,
```

On each target platform, run it once and keep generated data around. Of pre-built binary metadata is included with the PhysX SDK at [path to installed PhysX SDK]/Tools/BinaryMetaData.

![Diagram](Figure 3: Schema of Retargeting)

Assuming that the extensions library has been initialized, conversion follows:

```cpp
PxSerializationRegistry* registry; // Registry for serializable types
PxInputStream& srcMetadata; // metadata for the 'from' (e.g. PxDefaultFileInputData)
PxInputStream& dstMetadata; // metadata for the 'to'
PxInputStream& srcAsset; // stream containing source asset
PxU32 srcAssetSize; // size of the source asset
PxOutputStream& dstAsset; // output stream for retargeted data
PxBinaryConverter* converter = PxSerialization::createBinaryConverter;
converter->setMetaData(srcMetadata, dstMetadata);
converter->convert(srcAsset, srcAssetSize, dstAsset);
```
The Convert Tool

The convert tool is at [path to installed PhysX SDK]/Snippets/SnippetConvert. It illustrates how to convert PhysX 3 serialized binary files from one platform to another. It only compiles and runs on authoring platforms (Windows, MacOs and Linux).

SnippetConvert is a simple command-line tool supporting the following options:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--srcMetadata=&lt;filename&gt;</td>
<td>Defines source metadata file</td>
</tr>
<tr>
<td>--dstMetadata=&lt;filename&gt;</td>
<td>Defines target metadata file</td>
</tr>
<tr>
<td>--srcBinFile=&lt;filename&gt;</td>
<td>Source binary file to convert</td>
</tr>
<tr>
<td>--dstBinFile=&lt;filename&gt;</td>
<td>Outputs target binary file</td>
</tr>
<tr>
<td>--generateExampleFile=&lt;filename&gt;</td>
<td>Generates an example file</td>
</tr>
<tr>
<td>--verbose</td>
<td>Enables verbose mode</td>
</tr>
</tbody>
</table>

Object Names

Some SDK objects, such as shapes and actors, can be given names using the `PxShape::setName()` and `PxActor::setName()` functions. By default these names are not serialized. The 'exportNames' parameter of the `PxSerialization::serializeCollectionToBinary()` can be set to true in order to serialize the names along with the objects.

API-level Serialization (RepX) Specifics

RepX stands for Representation X and is the ASCII-XML serialization format for PhysX. As opposed to binary serialization, the RepX XML serialization is not intended to be used in performance critical or memory constrained situations. The following sections describe specifics of the RepX XML serialization system.

Upgrading RepX Data

Upgrading RepX data from an older PhysX version to a newer one is implicit when deserializing old RepX data with a newer PhysX SDK and re-serializing the resulting PxCollection.
Example for upgrading a RepX stream:

```cpp
PxPhysics* physics; // The
                    // Phxs
PxCooking* cooking; // Cook
                   // inst
PxSerializationRegistry* registry; // Regis

PxDefaultFileInputData inputData(pathTo30RepXFile); //load
PxCollection* collection = 
    PxSerialization::createCollectionFromXml(inputData, *cooking,
PxDefaultFileOutputStream outStream(pathToNewRepXFile);
PxSerialization::serializeCollectionToXml(outStream, *collection,
```

Object Names

As opposed to binary serialization, the object names that can be `PxShape::setName()` and `PxActor::setName()` functions, are always included in the serialized format. On deserialization with `PxSerialization::createCollectionFromXml(...)` the object names can be recovered by setting the `PxStringTable` parameter.

If `PxStringTable` parameter is set, the names will live within the memory which is allocated by the string table. The string table must not be released unless it cannot be guaranteed that the names will not be accessed any more.

Caching Cooked Geometry Data

In order to facilitate faster instantiation of XML data, it is possible to configure the XML serialization to store the cooked triangle and convex mesh data along with the plain data. The cooked data caching can be enabled by passing a `PxCooking` parameter to `PxSerialization::serializeCollectionToXml(...). The cached cooked data format is incompatible with the current SDK version.
Common Use Cases

API-level RepX serialization should be used whenever compatibility and human readability are important. The PhysX plug-ins for the DCC tools 3ds Max and Maya export PhysX objects. The resulting RepX files can then be deserialized into the PhysX runtime. This is useful for rapid prototyping or for generally loading PhysX assets if performance is not of a big concern. For quick loading of assets, convert RepX data into binary serialized data. RepX is also useful for situations with unwanted behavior without the need to provide the whole application. To do this, the application may be connected to the PhysX Visual Debugger (PVD) which records the scene of interest. A representative frame can then be saved from within PVD (see PVD).

Binary serialization should be used in performance and memory constrained situations. The main target use-case is streaming in chunks of a large game level that can’t be loaded into memory at once. Creating and loading save games is another application that could be optimized by using binary serialization. PhysX objects in binary format can also be sent over the network to enable efficient game state synchronization.
Snippet Discussion

The following snippets illustrate common operations such as managing collections, serialization, deserialization and re-targeting of binary data.

SnippetSerialization

SnippetSerialization shows binary and XML serialization of a scene with jointed rigid bodies representing a chain. This is done in a way that allows the instantiation of multiple chains while sharing the shape and the material across all of them. The snippet shows how to create and populate collections, specify IDs to resolve dependencies, serialize collections, deserialize collections and add actors to the scene for simulation.

The snippet also shows how to allocate a data block aligned to 128 bytes and demonstrates how to copy binary serialized data into it. It further demonstrates that data blocks containing the binary deserialized collections must be maintained until the corresponding objects are not needed anymore and have been released.
SnippetConvert

SnippetConvert illustrates how binary serialized data can be re-targeted from an authoring platform to a runtime platform such as a console. The snippet is a simple command line tool that can load a binary serialized data file along with metadata files for both source and destination platforms and then output a converted binary data file. See the source documentation for more details on usage.

SnippetLoadCollection

SnippetLoadCollection shows how to deserialize serialized collections or XML format. The snippet is a command line tool that can connect to a Debugger application and display the content of serialized collect. See the snippet's source documentation for more details.
Best practices / Troubleshooting

- Concurrent simulation and serialization is not supported and leads to undefined behavior.
- If releasing PhysX objects leads to crashes or errors it is possible the application is releasing some objects twice. The following two reasons should be considered:
  1. A potential source of error is to release PhysX objects without updating collections referencing these objects.
  2. Shapes that were created through an actor have their application reference automatically released on creation. If such a shape is serialized and deserialized, the creation history will be lost. It might be convenient to use the extension function `PxCollectionExt::releaseObjects` because it deals with the different cases as required. See Reference Counting of Deserialized Object.
- If accessing binary deserialized PhysX objects, including accesses during simulation, causes crashes it might be due to the premature release of the memory block that holds the deserialized objects.
- If binary files are too large and/or too slow to load it might be that they have been serialized multiple times. An example of a shared asset might be a mesh referenced by multiple shapes. The solution is to separate shared objects into a separate collection. See Serializing Incomplete Collections.
- If loading PhysX objects from RepX files is too slow two things should be considered:
  1. Could binary serialization be used instead? Even for debugging, it might make sense to convert RepX files into binary serialized data by re-serializing them with the binary approach.
  2. Meshes tend to load very slowly from text files. RepX serialization offers an option to cache cooked mesh data by in-lining the binary data into the RepX file. If such a cache is present and valid, the loading can become significantly faster. See Caching Cooked Geometry Data.
The PhysX Remote Debugger provides the functionality to export single scenes as RepX files. The resulting files can be used to playback a snapshot of the PhysX state. In many cases this is sufficient to isolate an issue. The option can be found in the menu of PVD: [Menu > File > Export Current Frame To RepX]

**Figure 5: RepX Functionality in PVD**
Introduction

The PhysX serialization system (*Serialization*) is extendable to custom types. If an application were to require a new joint type, for example, the serialization system could be extended to add support for serialization of that new joint type.

The following document contains some recipes and example code that show how serialization may be extended to custom types. It doesn't cover all extension mechanisms. It is therefore advisable to look into the following example for more details:

- PhysXVehicle library (PhysXVehicle/src)
Overview

Both binary and RepX serialization can be extended for custom type.
A custom type for serialization it must first inherit from PxBase. This allows a
custom type to be added to a PxCollection, which is a pre-requisite for
core serialization functionality needs to be provided by implementing
an interface. The template PxSerializerDefaultAdapter provides a default
implementation and can be specialized for the custom type as required. In order to support
RepX serialization an additional PxRepXSerializer interface needs to be implemented.
This relies on automatic code generation using clang. Scripts to run the code
examples can be found in (Tools/PhysXMetaDataGenerator).
Binary Serialization of Custom Classes

Serialization and deserialization of a custom class can be achieved with the following steps:

1. Define a `PxConcreteType` and type info for the custom class. Make sure its type value is unique.
2. The custom class needs to inherit from `PxBase` and implement its interface.
3. Instance `PxSerializerDefaultAdapter<T>` and implement specialized methods where necessary.
4. If retargeting to other platforms is needed, implement `getBinaryMetadata()`.
5. Register the adapter and metadata, see `PX_NEW_SERIALIZER_ADAPTER PxSerializationRegistry::registerSerializer` and `PxSerializationRegistry::registerBinaryMetaDataCallback`. Note that serializers also need to be unregistered before `PxSerializationRegistry::release`.

For pointer members the following needs to be done (Note that reference members are currently not supported):

6. Implement `PxSerializer::requires`. It should enumerate `PxBase` objects on which the object depends for deserialization. See `Requires`.
7. For a member pointer to another `PxBase` object, register the reference in the implementation of `PxSerializer::registerReferences`. The implementation of `PxSerializer::requires` may be used to help with this.
8. Resolve references in the implementation of `PxSerializer::createObject PxDeserializationContext::resolveReference`, `translatePxBase`.
9. Make sure that `PxSerializer::isSubordinate` returns whether the object is serialized along with its owner. See `Subordinate`.
10. Export non `PxBase` data by implementing `PxSerializer::exportExtraData`
11. Import non PxBase data in the implementation of PxSerializer::createObject

PxDeserializationContext::readExtraData, alignExtraData.

**Note:** In checked builds (PX_CHECKED defined as 1) metadata definitions are verified against serialized data. If metadata definitions are missing warnings are output on the error stream during re-targeting (PxBinaryConverter::convert). To avoid false warnings, all unused memory in custom serialized class instances should be marked with a 0xcd pattern. This can be done with Cm::markSerializedMem from CmUtils.

**Note:** The memory of a deserialized class instance should not be deallocated. The memory is embedded in the memory buffer containing the serialized data. PxBaseFlag::eOWNS_MEMORY can be used to decide whether the object needs to be deallocated or not.

Example for a custom class:

```cpp
#include "extensions/PxSerialization.h"
#include "common/PxTypeInfo.h"
#include "common/PxMetaData.h"
#include "common/PxSerializer.h"
#include "common/PxSerialFramework.h"

using namespace physx;

const PxType customClassType = PxConcreteType::eFIRST_USER EXTENSION;
Px_DEFINE_TYPEINFO(CustomClass, customClassType);

class CustomClass : public PxBase
{
    friend class PxSerializerDefaultAdapter<CustomClass>;

public:

    // constructor setting up PxBase object
    CustomClass() :
        PxBase(customClassType, PxBaseFlag::eOWNS_MEMORY | PxBaseFlag::eOWNED_MEMORY) {}

    // constructor called on deserialization
    CustomClass(PxBaseFlags baseFlags) : PxBase(baseFlags) {}
};
```
virtual ~CustomClass() {} 

//PxBase
virtual const char* getConcreteTypeName() const { return "CustomClass"; }  

virtual bool isKindOf(const char* name) const 
{
    return !strcmp("CustomClass", name) || PxBase::isKindOf(name);
}  
//~PxBase

//PxSerializationRegistry::registerBinaryMetaDataCallback
static void getBinaryMetaData(PxOutputStream& stream)
{
    PX_DEF_BIN_METADATA_VCLASS(stream, CustomClass)
    PX_DEF_BIN_METADATA_BASE_CLASS(stream, CustomClass, PxBase)
    PX_DEF_BIN_METADATA_ITEM(stream, CustomClass, PxRigidDynamic, PxMetaDataFlag::ePTR)
    PX_DEF_BIN_METADATA_ITEM(stream, CustomClass, char, mBuf,
    PX_DEF_BIN_METADATA_ITEM(stream, CustomClass, PxU32, mSize)
    PX_DEF_BIN_METADATA_EXTRA_ITEMS(stream, CustomClass, char

} //~PxSerializationRegistry::registerBinaryMetaDataCallback

private:
    PxRigidDynamic* mActor; //add in requires
    char* mBuf; //extra data
    PxU32 mSize; //size of mBuf
};

//PxSerializerDefaultAdapter
template<>
void PxSerializerDefaultAdapter<CustomClass>::requires(PxBase& obj
{
    CustomClass* custom = obj.is<CustomClass>();
    PX_ASSERT(custom);
    c.process(*custom->mActor);
}

template<>
void PxSerializerDefaultAdapter<CustomClass>::registerReferences(
```cpp
{   CustomClass* custom = obj.is<CustomClass>();
    PX_ASSERT(custom);

    s.registerReference(obj, PX_SERIAL_REF_KIND_PXBAS,
    size_t(&o
    s.registerReference(*custom->mActor, PX_SERIAL_REF_KIND_PXBAS
}

//template<>
void PxSerializerDefaultAdapter<CustomClass>::exportExtraData(PxBase
{
    CustomClass* custom = obj.is<CustomClass>();
    PX_ASSERT(custom);
    s.alignData(PX_SERIAL_ALIGN);
    s.writeData(custom->mBuf, custom->mSize);
}

//template<>
PxBase* PxSerializerDefaultAdapter<CustomClass>::createObject(PxU8
{
    CustomClass* custom = new (address) CustomClass(PxBaseFlag::eIS_RELEASABLE
    address += sizeof(CustomClass);

    // resolve references
    context.translatePtr(custom->mActor);

    // import extra data
    custom->mBuf = context.readExtraData<char*, PX_SERIAL_ALIGN>(

        // return deserialized object
        return custom;
    }
//~PxSerializerDefaultAdapter

void registerCustomClassBinarySerializer(PxSerializationRegistry&
{
    registry.registerSerializer(customClassType, PX_NEW_SERIALIZE
    registry.registerBinaryMetaDataCallback(CustomClass::getBinaryMetaData

void unregisterCustomClassBinarySerializer(PxSerializationRegistry
{
    PX_DELETE_SERIALIZER_ADAPTER(registry.unregisterSerializer(cu
```
RepX Serialization of Custom Classes

Serialization and deserialization of a custom class can be achieved steps:

1. Perform the first three steps from *Binary Serialization of Custom Classes* and *PxSerializer and PxSerializerDefaultAdapter<T>* required exclusive serialization may be left empty.
2. Create a custom RepX serializer that implements the *PxRepXSerializer*. *PxRepXSerializer* is used to create an object from the xml file and the xml file. The class *RepXSerializerImpl* can be used implementations of some methods.
3. Register the general serializer adapter and the RepX serializer. Note serializers also need to be unregistered and deallocated.
4. RepX supports automatic reading and writing of class properties. *clang* has to be used to generate corresponding metadata: *PhysX System*.

Example for a custom class:

```cpp
#include "SnRepXSerializerImpl.h"

const PxType customClassType = PxConcreteType::eFIRST_USER_EXTENSION
PX_DEFINE_TYPEINFO(CustomClass, customClassType);

struct CustomClassRepXSerializer : public RepXSerializerImpl<CustomClass>
{
    CustomClassRepXSerializer(PxAllocatorCallback& inCallback)
        : RepXSerializerImpl<CustomClass>(inCallback)
    {}

    virtual PxRepXObject fileToObject(XmlReader& inReader, XmlMemoryAllocator
        PxRepXInstantiationArgs& inArgs, PxCollection* inCollection
    {
        // factory for CustomClass instance provided by application
        CustomClass* object = createCustomClass();
    }
};
```
// when using the PhysX API metadata system readAllProperties(...) can be used to read all properties automatically
readAllProperties(inArgs, inReader, object, inAllocator,

    return PxCreateRepXObject(object);
}

virtual void objectToFileImpl(const CustomClass* obj, PxColle
XmlWriter& inWriter, MemoryBuff
PxRepXInstantiationArgs&)
{
    // when using the PhysX API metadata system writeAllProperties(...) can be used to save all properties automatically
writeAllProperties(obj, inWriter, inTempBuffer, *inCollection)

    // this can return NULL if fileToObject(...) is overwritten with a custom implementation.
virtual CustomClass* allocateObject(PxRepXInstantiationArgs&)
};

void registerCustomClassRepXSerializer(PxSerializationRegistry& reg
{
    registry.registerSerializer(customClassType,
        PX_NEW_SERIALIZER_ADAPTER(CustomC

        registry.registerRepXSerializer(customClassType,
            PX_NEW_REPX_SERIALIZER<Custom

    void unregisterCustomClassRepXSerializer(PxSerializationRegistry& reg
    {
        PX_DELETE_SERIALIZER_ADAPTER(registry.unregisterSerializer(cu
        PX_DELETE_REPX_SERIALIZER(registry.unregisterRepXSerializer(c

**Note:** Implementing a PxRepXSerializer is currently not practical without including the internal PhysXExtension header "SnRepXSerializerImpl.h".

**PhysX API Metadata System**

This system produces a set of objects that are analogues of the
descriptors in the PhysX system, all based on the public interface.

heuristically finds functions that start with get/set and, through a series combinerse those into several types of properties.

Currently the generator supports the following property types:

- Basic property
  - \{ptype\} get\{pname\}() const;
  - void set\{pname\}( const ptype& prop ); //plus variations
  - read-only, write-only variants of above.

- Range property
  - void get\{pname\}( \{ptype\}& lowEnd, \{ptype\}& highEnd );
  - void set\{pname\}( \{ptype\} lowEnd, \{ptype\} highEnd );

- Indexed property
  - \{ptype\} get\{pname\}( enumType idx );
  - void set\{pname\}( enumType idx, const \{ptype\}& prop );

- Dual indexed property (like above, but with two enumeration indexes).

- Collection
  - PxU32 getNb() const;
  - PxU32 get( \{ptype\}* buffer, PxU32 count );
  - void set(\{ptype\}* buffer, PxU32 count);

In order to make use of the generator the following files need to be created following recipe:

- CustomTypeExtensionAPI.h
  - Add all the types that should be exported to gUserPhysXTypes.
  - Add the unnecessary types to gAvoidedPhysXTypes. It metadata information for these types.
  - Be sure to append the included files for these types.
- runClang_[windows|osx|linux].[bat|sh] (e.g. runClang_windows.bat)
- Set definition folder for these autogenerated files and set the source file in there.
- Specify the filename of autogenerated files. Then it will generate files:

```
include/CustomTypeAutoGeneratedMetaDataObjectNames.h
include/CustomTypeAutoGeneratedMetaDataObjects.h
src/CustomTypeAutoGeneratedMetaDataObjects.cpp
```

- CustomTypeMetaDataObjects.h
  - `CustomTypePropertyInfoName` has to be defined and `CustomTypeAutoGeneratedMetaDataObjects.h` has to be included in this file. The file will then export the properties of the custom class and can be included for implementing the custom RepX serializer.

- CustomTypeMetaDataObjects.cpp
  - This file is optional. It is only required when custom properties are needed.

```
src/PhysXMetaData/include/PxVehicleMetaDataObjects.h
generateMetaData.py
```

Running the script will auto-generate the following files:

```
src/PhysXMetaData/include/PxVehicleAutoGeneratedMetaDataObjectNames.h
src/PhysXMetaData/include/PxVehicleAutoGeneratedMetaDataObjects.h
src/PhysXMetaData/src/PxVehicleAutoGeneratedMetaDataObjects.cpp
```

1. `PxVehicleExtensionAPI.h`: The type `DisabledPropertyEntry` is used which do not require export. `CustomProperty` is for properties customized and `gUserPhysXTypes` is for general properties that need
2. `runClang_[windows|osx|linux].[bat|sh]`: The target directory is set to `src/PhysXMetaData`, and the target name is ` PxVehicle`.
3. `PxVehicleMetaDataObjects.h`: It defines the custom properties.
   `PxVehicleAutoGeneratedMetaDataObjects.h`
4. `PxVehicleMetaDataObjects.cpp`: It implements the custom properties.

**Note:** The properties defined in `PxVehicleAutoGeneratedMetaDataObjects.h` are written to the `RepX` file automatically if `PxVehicleMetaDataObjects.h` is included for the custom `RepX` serializer.
Introduction

This chapter covers a number of best practices for the PhysX SDK to diagnose and fix frequently encountered issues.
Debugging

The PhysX SDK contains a few debugging helpers. They can be used to make sure scenes are properly set up.

Use checked builds and the error stream

The PhysX SDK has different build configurations: Debug, Checked, Profile. To make sure that the scene is properly set up without warnings or errors, use either Debug or Checked builds, and monitor the error callback. Please refer to the Reporting chapter for details. Note that some checks can be expensive and thus not performed in Release or Profile builds. If the SDK silently fails or crashes in a Release build, please switch to Debug or Checked builds to ensure this is not caused by an uncaught error.

Visualizing physics data

Use the PhysX Visual Debugger (PVD) to see what PhysX is seeing and make sure physics data is what you expect it to be. Please refer to the PhysX Visual Debugger chapter for details. Note that this is only available in Debug, Checked and Profile builds.

Visualizing physics data (2)

An alternative to PVD is the built-in debug visualization system. Please refer to the Visualization chapter for details. This option is available with all build configurations.

Limiting coordinates

Bugs in applications, or issues in content creation, can sometimes result in unexpected object placement. We recommend using PxSceneDesc::sanityBounds, to generate reports when objects are inserted at positions beyond what your application expects, or when application code moves objects to unexpected positions. Note that these bounds only apply to application updates, not to runtime operations.
coordinates, not updates by the simulation engine.
Performance Issues

The PhysX SDK has been optimized a lot in the past dot releases. However, there still exist various performance pitfalls that the user should be aware of.

Use profile builds to identify performance bottlenecks

The PhysX SDK has different build configurations: Debug, Checked, Release, Profile. To identify performance bottlenecks, please use Profile builds and use *PxPvdInstrumentationFlag::ePROFILE* only, since enabling the other connection flags might negatively affect performance. Please refer to the PhysX Visual Debugger chapter for details.

Use release builds for final performance tests

The PhysX SDK has different build configurations: Debug, Checked, Release. Release builds are the most optimal. If you encounter a performance issue while using other builds, please switch to Release builds and check if the problem is still there.

Disable debug visualization in final/release builds

Debug visualization is great for debugging but it can have a significant impact. Make sure it is disabled in your final/release builds. Please refer to the Visualization chapter for details.

Debug visualization is very slow

Debug visualization can be very slow, because both the code gathering and the code rendering it is usually not optimal. Use a culling box to limit the amount of data the SDK gathers and sends to the renderer. Please refer to the Debug Visualization chapter for details.

Consider using tight bounds for convex meshes
By default PhysX computes approximate (loose) bounds around convex objects. PxConvexMeshGeometryFlag::eTIGHT_BOUNDS enables smaller/tighter bounds, which are more expensive to compute but can result in improved simulation performance when a lot of convex objects are interacting with each other. Please refer to the Physics chapter for details.

**Use scratch buffers**

The PxScene::simulate function accepts optional scratch buffers that reduce temporary allocations and improve simulation performance. Please refer to the Simulation chapter for details.

**Use the proper mid-phase algorithm**

PxCookingParams::midphaseDesc can be used to select the desired mid-phase algorithm. It is a good idea to try the different options and see which one works best for you. Generally speaking, the new PxMeshMidPhase::eBVH34 introduced in PhysX 3.4 has better performance for scene queries against large triangle meshes. Please refer to the Geometry chapter for details.

**Use the proper narrow-phase algorithm**

PxSceneFlag::eENABLE_PCM enables an incremental "persistent contact manifold" algorithm, which is often faster than the previous implementation. It is a good idea to enable it in PhysX 3.4, but you can also try to enable it in previous versions like 3.3.

**Use the proper broad-phase algorithm**

PhysX also supports two different broad-phase implementations, PxSceneDesc::broadPhaseType. The different implementations have various performance characteristics, and it is a good idea to experiment with both and find the one that works best for you. Please refer to the Rigid Body Collision chapter for details.
Use the scene-query and simulation flags

If a shape is only used for scene-queries (raycasts, etc), disable its scene-query flag. If a shape is only used for simulation (e.g. it will never be raycasted again), disable its simulation flag. This is good for both memory usage and performance. Please refer to the Rigid Body Collision chapter for details.

Tweak the dynamic tree rebuild rate

If the PxScene::fetchResults call takes a significant amount of time in scenes containing a lot of dynamic objects, try to increase the PxSceneDesc::dynamicTreeRebuildRateHint parameter. Please refer to the Scene Queries chapter for details.

Use the insertion callback when cooking at runtime

Use PxPhysicsInsertionCallback for objects that are cooked at runtime. This is faster than first writing the data to a file or a memory buffer, and then passing the data to PhysX.

The "Well of Despair"

One common use-case for a physics engine is to simulate fixed-size time-steps independent of the frame rate that the application is rendered at. If the application is capable of being rendered at a higher frequency than the simulation frequency, it sometimes has the option to render the same simulation state, interpolate frames, or render the scene at a frequency higher than the simulation frequency. At this point, the options are to either run the physics with a larger time-step or to simulate multiple, smaller sub-steps. The latter is generally preferable because changing the size of time-steps in a physics engine significantly change perceived behavior. However, when using a sub-stepping approach, one must always be aware of the potential that this has to damage performance.

As an example, let's imagine a game that is running using v-sync at 60 FPS, simulating a large number of physics bodies and, as a result, the physics is very expensive. In order to meet the 60FPS requirement, the entire frame
within ~16ms. As already mentioned, the physics is reasonably expensive, scenario, takes 9ms to simulate 1/60th of a second. If the game was e.g. as a result of some OS activity, saving a check-point or loading a level, we may miss the deadline for 60FPS. If this happens, we must steps in the physics to catch up the missed time in the next frame. previous frame took 50ms instead of 16ms, we must now simulate 3 sub to simulate all the elapsed time. However, each sub-step takes ~9ms, we will take ~27ms to simulate 50ms. As a result, this frame also deadline for 60FPS, meaning that the frame including v-sync took 33ms must now simulate 2 sub-steps in the next frame, which takes ~18ms a 16ms deadline. As a result, we never manage to recover back to 60FP our decision to sub-step as a result of a spike has resulted in our application performance trough indefinitely. The application is capable of simulating at 60FPS but becomes stuck in the so-called "physics well of despair" substepping.

Problems like this can be alleviated in several ways:

- Decouple the physics simulation from the game's update/render loop. physics simulation becomes a scheduled event that occurs at a fixed rate, can make player interaction in the scene more difficult and may introduce latency so must be well-thought through. However, using multiple scenes (one synchronous for "important" objects, one asynchronous for "unimportant" objects) can help.
- Permit the game to "drop" time when faced with a short-term spike. This may introduce visible motion artifacts if spikes occur frequently.
- Introduce slight variations in time-step (e.g. instead of simulating a range between 1/50th and 1/60th). This can introduce non-determinism into the simulation so should be used with caution. If this is done, additional time that must be simulated can potentially be amortized over several frames using slightly larger time-steps.
- Consider simplifying the physics scene, e.g. reducing object count, adjusting iteration counts etc. Provided physics simulation is a s
total frame time, the application should find it easier to recover from

## Pruner Performance for Streamed Environments

PhysX provides multiple types of pruners, each of which aimed at specific applications. These are:

- Static AABB tree
- Dynamic AABB tree

By default, the static AABB tree is used for the static objects in the environment and the dynamics AABB tree is used for the dynamic objects in the environment. This approach works well but it must be noted that creating the static AABB tree can be very expensive. As a result, adding, removing or moving any static objects will result in the static AABB tree being fully recomputed, which can introduce significant performance cost. As a result, we recommend the use of dynamics AABB trees for both static and dynamic pruners in games which stream in the static environment. Scene query performance against newly added objects can be improved by using `PxPruningStructure`, which can precompute the AABB structure of inserted objects in offline.

## Performance Implications for Multi-Threading

The PhysX engine is designed from the ground-up to take advantage of multi-core architectures to accelerate physics simulation. However, this does not mean that more threads are always better. When simulating extremely simple scenes, additional worker threads can detrimentally affect performance. This is because, at its core, PhysX operates around a task queue. When a frame's simulation starts, it dispatches a chain of tasks that encapsulate that frame of physics simulation. At various stages of the physics pipeline, work can be performed in parallel on multiple worker threads. However, if there is insufficient work, there will be little or no parallel execution in this case, the use of additional worker threads may detrimentally affect performance because the various phases of the pipeline may be run by different worker threads, which may incur some additional overhead depending on the CPU architecture.
running on just a single worker thread. As a result, developers should measure the performance of the engine with their expected physics loads with different numbers of threads to maximize their performance and make sure that they are making the most of the available processing resources for their game.

**Memory allocation**

Minimizing dynamic allocation is an important aspect of performance tuning, and PhysX provides several mechanisms to control memory usage.

Reduce allocation used for tracking objects by presizing the capacities of scene data structures, using either `PxSceneDesc::limits` before creating the scene or `PxScene::setLimits()` afterwards. When resizing, the new capacities will be at least as large as required to deal with the objects currently in the scene. These values are for preallocation and do not represent hard limits, so if you add more objects than the capacity limits you have set, PhysX will allocate more space.

Much of the memory PhysX uses for simulation is held in a pool of blocks. You can control the current and maximum size of this pool with the `nbContactDataBlocks` and `maxNbContactDataBlocks` members of the `PxSceneDesc` type. PhysX will never allocate more than the maximum number of blocks specified; if insufficient memory is available, it will instead drop contacts or joint constraints. You can find out how many blocks are currently in use with the `getNbContactBlocksUsed()` method, and the maximum number that have ever been used with the `getMaxNbContactDataBlocksUsed()` method.

Use `PxScene::flushSimulation()` to reclaim unused blocks, and to shrink data structures to the size presently required.

To reduce temporary allocation performed during simulation, provide a memory block in the `simulate()` call. The block may be reused by the `fetchResults()` call, which marks the end of simulation. The size of the block must be a multiple of 16K, and it must be 16-byte aligned.
Character Controller Systems using Scene Queries and Penetration Computation

Implementing a Character Controller (CCT) is a common use case for a Scene Query (SQ) system. A popular approach is to use sweeps to implement movement logic, and to improve robustness by using Geometry Queries (GQ) to compute penetrations that occur due to object movement that does not account for the controller, or due to numerical precision issues.

Basic Algorithm:

1. Call a SQ-Sweep from the current position of the CCT shape to its goal position.
2. If no initial overlap is detected, move the CCT shape to the position of the first hit, and adjust the trajectory of the CCT by removing the motion relative to the contact normal of the hit.
3. Repeat Steps 1 and 2 until the goal is reached, or until an SQ-Sweep detects an initial overlap.
4. If an SQ-Sweep in Step 1 detects an initial overlap, use the GQ-Penetration Depth computation function to generate a direction for depenetration. Move out of penetration and begin again with Step 1.

Limitations and Problems

Step 4 of the algorithm above can sometimes run into trouble due to differences in SQ-Sweep, SQ-Overlap and GQ-Penetration Depth queries. In certain initial conditions it is possible that the SQ system will determine that a pair of objects is initially overlapping while the GQ-Penetration Depth computation considers them as disjoint (or vice-versa). Penetration depth calculations involve shrinking the convex hull and performing distance calculations between a shape and the shrunken convex hull. To understand the conditions under which this occurs and how to resolve the artefacts, please refer to the diagrams below. Each diagram represents the initial conditions of two shapes: a Character Controller shape (red boxes), a convex obstacle (black boxes), at the
the algorithm above is executed. In the diagrams, the outermost rectangular box represents the convex hull as seen by the SQ algorithms; the inner black box with a dashed line represents the shrunken convex shape and the black box with rounded corners is the shrunken convex shape inflated by the amount by which we shrunk. These three black boxes are used by the GQ-Penetration Depth computation. Although the example refers to convex hull obstacles, the issue is not exclusive to the convex hull shapes; it is similar for other shape types as well.

Diagram 1: CCT Shape Barely Touches an Obstacle

In Diagram 1, the red box of the CCT is barely touching the outermost convex obstacle. In this situation the SQ-Sweep will report an initial overlap, but the GQ-Penetration Depth function will report no hit, because the red box is not touching the black box with rounded corners.

To resolve this, inflate the CCT shape for the GQ-Penetration Depth calculation so that it detects an overlap and returns a valid normal. Note that after inflating the shape, the GQ-Penetration Depth function will report that the shapes are penetrated more deeply than they actually are, so take this additional penetration into account when depenetrating in Step 4. This may result in some clipping around the corners of convex objects but the CCT's motion should be acceptable. As the corners become more acute, the amount of clipping will increase.
Diagram 2: CCT Overlaps an Obstacle Slightly

Diagram 2 shows a case where the CCT initially overlaps the outer box seen by the SQ system, but does not overlap the shrunken shape seen by the GQ calculator. The GQ-Penetration Depth system will return the penetration from point b but not from point c to point a. Therefore the CCT may clip through the convex hull after depenetration. This can be corrected in Step 4.

Diagram 3: CCT Overlaps an Obstacle Significantly

As can be seen from Diagram 3, if the CCT penetrates sufficiently that it overlaps with the shrunken shape seen by GQ, the GQ-Penetration Depth calculator will return the penetration from point c to point a. In this case, the GQ-Penetration Depth value can be used without modification in Step 4. However, as this condition would be difficult to categorize without additional computational cost, it is best to inflate the shape as recommended in Step 4 and then subtract this inflation from the returned penetration depth.

Unified MTD Sweep

A recent addition to the scene query sweeps is the flag PxHitFlag::eMTD. This can be used in conjunction with default sweeps to generate the MTD (Minimum Translation Direction) when an initial overlap is detected by a sweep. This flag is guaranteed to generate an appropriate normal under all circumstances, including cases where the sweep may detect an initial overlap but calling a stand-alone MTD function may still suffer from accuracy issues with penetration depths but, in the cases outlined above around corners/edges, it will report a distance of 0 and the correct contact normal. This can be used to remove components of the sweep moving into the normal direction and then re-sweeping when attempting to implement a CCT. Th
compound MTDs for meshes/heightfields, which means that it reports penetrates the shape from the entire mesh rather than just an individual MTD exists.
Quantizing HeightField Samples

Heightfield samples are encoded using signed 16-bit integers for the y-height that are then converted to a float and multiplied by `PxHeightFieldGeometry::heightScale` to obtain local space scaled coordinates. Shape transform is then applied on top to obtain world space location. The transformation is performed as follows (in pseudo-code):

```cpp
localScaledVertex = PxVec3(row * desc.rowScale, PxF32(heightSample) * desc.columnScale)
worldVertex = shapeTransform( localScaledVertex )
```

The following code snippet shows one possible way to build quantized unscaled local space heightfield coordinates from world space grid heights stored in terrainData.verts:

```cpp
const PxU32 ts = ...; // user heightfield dimensions (ts = terrain samples)
// create the actor for heightfield
PxRigidStatic* actor = physics.createRigidStatic(PxTransform(PxIdentity))

// iterate over source data points and find minimum and maximum height
PxReal minHeight = PX_MAX_F32;
PxReal maxHeight = -PX_MAX_F32;
for(PxU32 s=0; s < ts * ts; s++)
{
    minHeight = PxMin(minHeight, terrainData.verts[s].y);
    maxHeight = PxMax(maxHeight, terrainData.verts[s].y);
}

// compute maximum height difference
PxReal deltaHeight = maxHeight - minHeight;

// maximum positive value that can be represented with signed 16 bit integer
PxReal quantization = (PxReal)0x7fff;

// compute heightScale such that the forward transform will generate a point
// to the source
// clamp to at least PX_MIN_HEIGHTFIELD_Y_SCALE to respect the PhysX API specs
PxReal heightScale = PxMax(deltaHeight / quantization, PX_MIN_HEIGHTFIELD_Y_SCALE);

 PxU32* hfSamples = new PxU32[ts * ts];
 PxU32 index = 0;
```
for(PxU32 col=0; col < ts; col++)
{
    for(PxU32 row=0; row < ts; row++)
    {
        PxI16 height;
        height = PxI16(quantization * ((terrainData.verts[(col*ts
deltaHeight]));

        PxHeightFieldSample& smp = (PxHeightFieldSample&)hfSamples;
        smp.height = height;
        smp.materialIndex0 = userValue0;
        smp.materialIndex1 = userValue1;
        if (userFlipEdge)
            smp.setTessFlag();
    }
}

// Build PxHeightFieldDesc from samples
PxHeightFieldDesc terrainDesc;
terrainDesc.format = PxHeightFieldFormat::eS16_TM;
terrainDesc.nbColumns = ts;
terrainDesc.nbRows = ts;
terrainDesc.samples.data = hfSamples;
terrainDesc.samples.stride = sizeof(PxU32); // 2x 8-bit material
terrainDesc.thickness = -10.0f; // user-specified heightfield
terrainDesc.flags = PxHeightFieldFlags();

PxHeightFieldGeometry hfGeom;
hfGeom.columnScale = terrainWidth / (ts-1); // compute column and
    // height grid
hfGeom.rowScale = terrainWidth / (ts-1);
hfGeom.heightScale = deltaHeight != 0.0f ? heightScale : 1.0f;
hfGeom.heightField = cooking.createHeightField(terrainDesc, physi
delete [] hfSamples;

PxTransform localPose;
localPose.p = PxVec3(-(terrainWidth * 0.5f), // make it so tha
    -(terrainWidth * 0.5f)); // heightfield is
localPose.q = PxQuat(PxIdentity);
PxShape* shape = PxRigidActorExt::createExclusiveShape(*actor, hf
shape->setLocalPose(localPose);
Reducing memory usage

The following strategies can be used to reduce PhysX's memory usage.

Consider using tight bounds for convex meshes

See the above chapter about Performance Issues for details. Using convex meshes is mainly useful for performance, but it can also reduce pairs coming out of the broad-phase, which decreases the amount of memory needed to manage these pairs.

Use scratch buffers

See the above chapter about Performance Issues for details. Scratch buffers can be shared between multiple sub-systems (e.g. physics and rendering), which can globally improve memory usage. PhysX will not use less memory per-se, but it will use it.

Flush simulation buffers

Call the PxScene::flushSimulation function to free internal buffers used for temporary computations. But be aware that these buffers are usually allocated once and reused in subsequent frames, so releasing the memory might trigger new re-allocations during the next simulate call, which can decrease performance. Please refer to the memory chapter for details.

Use preallocation

Use PxSceneDesc::limits to preallocate various internal arrays. Preallocating the exact necessary size for internal buffers may use less memory overall than the resizing strategy of dynamic arrays. Please refer to the Simulation memory chapter for details.
Tweak cooking parameters

Some cooking parameters have a direct impact on memory usage:
PxCookingParams::supressTriangleMeshRemapTable,
PxBVH33MidphaseDesc::meshCookingHint,
PxBVH33MidphaseDesc::meshSizePerformanceTradeOff,
PxBVH34MidphaseDesc::numTrisPerLeaf,
PxCookingParams::midphaseDesc,
PxCookingParams::gaussMapLimit and PxCookingParams::buildTriangleAdjacencies can be modified to choose between runtime performance, cooking performance, or memory usage.

Share shape and mesh data

Share the same PxConvexMesh and PxTriangleMesh objects between instances if possible. Use shared shapes if possible. Please refer to the "Collision" chapter for details about shape sharing.

Use the scene-query and simulation flags

If a shape is only used for scene-queries (raycasts, etc), disable its simulation flag. If a shape is only used for simulation (e.g. it will never be raycasted again), disable its scene-query flag. This is good for both memory usage and performance. Please refer to the "Rigid Body Collision" chapter for details.
**Behavior issues**

**Objects do not spin realistically**

For historical reasons the default maximum angular velocity is set to a low value (7.0). This can artificially prevent the objects from spinning quickly, which may look unrealistically wrong in some cases. Please use PxRigidDynamic::setMaxAngularVelocity to increase the maximum allowed angular velocity.

**Overlapping objects explode**

Rigid bodies created in an initially overlapping state may explode, because the SDK tries to resolve the penetrations in a single time-step, which can lead to large velocities. Please use PxRigidBody::setMaxDepenetrationVelocity to limit the de-penetration velocity to a reasonable value (e.g. 3.0).

**Rigid bodies are jittering on the ground**

Visualize the contacts with the visual debugger. If the jittering is caused by contacts that appear and disappear from one frame to another, try to increase PxShape::setContactOffset.

**Piles or stacks of objects are not going to sleep**

PxSceneFlag::eENABLE_STABILIZATION might help here. This is not recommended for jointed objects though, so use PxRigidDynamic::setStabilizationThreshold to enable/disable this feature on a per-object basis. It should be safe to enable for objects like debris.

**Jointed objects are unstable**

There are multiple things to try here:
- Increase the solver iteration counts, in particular the number of
  Please refer to the *Rigid Body Dynamics* chapter for details.
- Consider creating the same constraints multiple times. This is similar
  number of solver iterations, but the performance impact is local
  object rather than the simulation island it is a part of. So it can
  overall. Note that the order in which constraints are created is
  have 4 constraints named A, B, C, D, and you want to create ti
  Creating them in the AAAABBBBBCCCCDDDD order will not improve
  creating them in the ABCDABCDABCDABCD order will.
- Consider using joint projection. This might help for simple cases
  objects are connected. Please refer to the *Joints* chapter for details
- Use smaller time steps. This can be an effective way to improve
  although it can be an expensive solution. Instead of running 1 sir time-step dt and N solver iterations, consider trying N simulation calls at dt/N and 1 solver iteration.
- Consider tweaking inertia tensors. In particular, for ropes or chains
  the PxJoint::setInvMassScale and PxJoint::setInvInertiaScale function
  effective. An alternative is to compute the inertia tensor
  PxRigidbodyExt::setMassAndUpdateInertia) with an artificially increased mass, then set the proper mass directly afterwards (using PxRigidbody::setMass).
- Consider adding extra distance constraints. For example in a rope
  to create an extra distance constraint between the two ends of the
  stretching. Alternatively, one can create distance constraints between
  N+2 in the chain.
- Use spheres instead of capsules. A rope made of spheres will be
  rope made of capsules. The positions of pivots can also affect the
  pivots at the spheres’ centers is more stable than placing them on surfaces.
- Use articulations. Perhaps not surprisingly, articulations are much
  articulated objects. They can be used to model better ropes, br
ragdolls out-of-the-box, without the need for the above workaroun
de the *Articulations* chapter for details. They are more expensive
though.
GPU Rigid Bodies

Collision detection with PxSceneFlag::eENABLE_GPU_DYNAMICS will be executed on GPU for all convex-convex, convex-box, box-box, convex-mesh, box-mesh, and box-HF pairs. However, such pairs will not be processed if either the convex hull exceeds 64 vertices (convex PxConvexFlag::eGPU_COMPATIBLE can be used to create compatible hulls), the pair requests contact modification, the triangle mesh was not cooked with GPU (PxCookingParams::buildGrbData) or if the triangle mesh makes use of per-triangle materials.

Aggregates are used to lighten the load on broad phases. When running on the CPU, aggregates frequently improve performance by reducing the load on the broad phase algorithm. However, there is some cost when aggregates overlap these overlaps must be processed by a separate module. When using the use of aggregates generally result in performance regressions because of aggregate overlaps occurs on the CPU and, while using aggregates reduce the load on the GPU broad phase, the amount by which they improve performance is frequently smaller than the cost of processing the aggregate overlaps.
Determinism

The PhysX SDK can be described as offering limited determinism. Results can vary between platforms due to differences in hardware maths precision and the compiler reorders instructions during optimization. This means that different between different platforms, different compilers operating on the between optimized and unoptimized builds using the same compiler on. However, on a given platform, given the exact same sequence of even exact scene using a consistent time-stepping scheme, PhysX is expected to produce deterministic results. In order to achieve this determinism, the application must recreate the scene in the exact same order each time and insert the actors in PxScene. There are several other factors that can affect determinism such as the time-stepping scheme is used or if the application does not perform the same sequence of API calls on the same frames, the PhysX simulation can diverge.

In addition, the PhysX simulation can produce divergent behavior if any conditions in the simulation has varied. Even the addition of a single actor that is not interacting with the existing set of actors in the scene can produce divergent results.

PhysX provides a mechanism to overcome the issue of divergent behavior in existing configurations as a result of additional actors being added or actors being removed from the scene that do not interact with the other actors in the scene. This is enabled by raising PxSceneFlag::eENABLE_ENHANCED_DETERMINISM in PxSceneDesc::flags prior to creating the scene. Enabling this mode makes some performance concessions to be able to offer an improved level of determinism. The application must still follow all the requirements to achieve deterministic behavior described previously in order for this mechanism to produce consistent results.
This guide describes how to upgrade applications that have an integration using PhysX 3.x. As the changes are numerous and significant, the level in upgrading to PhysX 3 should be carefully assessed before assessing the application's integration code.
Removed Features

This section lists features of PhysX 2 that do not have a PhysX 3 equivalent. Features that rely on these features may need fundamental changes, or should switch to using PhysX 2.

Compartments

PhysX 2 scenes supported scene compartments. A separate compartment could be assigned to simulating rigid bodies, deformables or fluids. The compartments were simulated in parallel and the scene code contained some extra logic for interaction between compartments. Compartments were added as an afterthought and was not originally designed to support interaction between multiple simulation technologies. This design deficiency was addressed from the ground up in PhysX 3 and compartments are no longer needed.

One missing detail is that separate time steps are no longer directly supported. A possible workaround is to create multiple PxScenes and step them at different rates. In this scenario the force exchange implementation would be entirely up to the user. Another possible approach is to simulate the entire scene using the minimum time step required for any of the compartments.

Deformables

PhysX 2 supported a wide range of deformable mesh simulation features such as environmental cloth, soft bodies, inflatable balloons and plastic deformation of rigid metal. For performance and code quality reasons, 3.3 temporarily stopped supporting many of the 2.8 deformable features in favor of a much simpler and higher performance cloth simulation engine. In PhysX 3 dot releases, we will be incrementally adding back features such as environmental simulation. For the time being there is no substitute for many applications of PhysX 2 deformables.

NxUtilLib
The assorted utility functions that were in this library was either moved or deleted. Sweep, overlap and ray tests are available in PxGeometryQuery() and diagonalization is in PxDiagonalize(). Density computation from mass point unit manipulation routines are gone. Geometrical helpers are in general gone.

**Anisotropic Friction**

Friction on a surface in PhysX 2 could be configured to be stronger in one direction than another. This is no longer supported in PhysX 3, and there is no known workaround that will give comparable behavior.
Basics

SDK Header

In PhysX 2, the symbols of the SDK could be included in the user's relevant source files through the following header:

```cpp
#include "NxPhysics.h"
```

In PhysX 3, this should be replaced with:

```cpp
#include "PxPhysicsAPI.h"
```

SDK Redistribution

Unlike versions of PhysX prior to 2.8.4, PhysX 3 no longer needs a 'system software' installation on Windows.

API Conventions

The Nx prefix of API classes has changed to a Px prefix. Descriptors were removed and replaced with creation parameters inline in the creation function.

For example, a capsule was created with PhysX 2 like this:

```cpp
NxCapsuleShapeDesc capsuleDesc;
capsuleDesc.height = height;
capsuleDesc.radius = radius;
capsuleDesc.materialIndex = myMaterial->getMaterialIndex();
NxShape* aCapsuleShape = aCapsuleActor->createShape(capsuleDesc);
```

In PhysX 3 it is created more succinctly like this:

```cpp
PxShape* aCapsuleShape = PxRigidActorExt::createExclusiveShape(*aPxCapsuleGeometry(radius, halfHeight), myMaterial);
```
**Callback Classes**

PhysX 2 callback classes are listed below, followed by the corresponding PhysX 3 class, if there is one:

<table>
<thead>
<tr>
<th>PhysX 2 Class</th>
<th>PhysX 3 Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>NxUserAllocator</td>
<td>PxAllocatorCallback</td>
</tr>
<tr>
<td>NxUserOutputStream</td>
<td>PxErrorCallback</td>
</tr>
<tr>
<td>NxUserContactReport</td>
<td>PxSimulationEventCallback</td>
</tr>
<tr>
<td>NxUserNotify</td>
<td>PxSimulationEventCallback</td>
</tr>
<tr>
<td>NxUserTriggerReport</td>
<td>PxSimulationEventCallback</td>
</tr>
<tr>
<td><strong>NxUserRaycastReport</strong></td>
<td>Ray casting Results. Results are now passed to a PxHitBuffer object.</td>
</tr>
<tr>
<td><strong>NxUserEntityReport</strong></td>
<td>Sweep and Overlap results. Results are now passed to the user using a PxHitBuffer object.</td>
</tr>
<tr>
<td><strong>NxStream</strong></td>
<td>Data serialization. Serialized data is now written to binary buffers.</td>
</tr>
</tbody>
</table>

The following PhysX 2 callback classes have no PhysX 3 direct equivalent:

<table>
<thead>
<tr>
<th>PhysX 2 Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NxUserRaycastReport</strong></td>
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<tr>
<td><strong>NxStream</strong></td>
<td>Data serialization. Serialized data is now written to binary buffers.</td>
</tr>
</tbody>
</table>

Below is a list of new callback classes that offer functionality that did not exist in PhysX 2 yet:

<table>
<thead>
<tr>
<th>PhysX 3 Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PxBroadPhaseCallback</strong></td>
<td>Broad-phase related events.</td>
</tr>
<tr>
<td><strong>PxSimulationFilterCallback</strong></td>
<td>Contact filtering.</td>
</tr>
<tr>
<td><strong>PxUserControllerHitReport</strong></td>
<td>Reports character controller events.</td>
</tr>
<tr>
<td><strong>PxControllerBehaviorCallback</strong></td>
<td>Customizes behavior of character controllers.</td>
</tr>
<tr>
<td><strong>PxContactModifyCallback</strong></td>
<td>Modification of contact constraints.</td>
</tr>
<tr>
<td><strong>PxCCDContactModifyCallback</strong></td>
<td>Modification of CCD contact constraints.</td>
</tr>
<tr>
<td><strong>PxConstraintConnector</strong></td>
<td>Custom constraints.</td>
</tr>
<tr>
<td><strong>PxProcessPxBaseCallback</strong></td>
<td>Serialization.</td>
</tr>
<tr>
<td><strong>PxQueryFilterCallback</strong></td>
<td>Scene query filtering.</td>
</tr>
<tr>
<td><strong>PxSpatialLocationCallback</strong></td>
<td>Scene Queries against PxSpatialIndex</td>
</tr>
<tr>
<td><strong>PxSpatialOverlapCallback</strong></td>
<td>Scene Queries against PxSpatialIndex</td>
</tr>
</tbody>
</table>
Memory Management

NxUserAllocator is renamed to PxAllocatorCallback. An important change since PhysX 2:
The SDK now requires that the memory that is returned be 16-byte aligned. On many platforms malloc() returns memory that is 16-byte aligned, but on Windows the system function _aligned_malloc() provides this capability.

Debug Rendering

Debug visualization formerly provided by NxScene::getDebugRenderable is now handled by PxScene::getRenderBuffer() and related functions.

Error Reporting

NxUserOutputStream is now called PxErrorCallback, but works the same way. A separate reportAssertViolation() function. Asserts are only contained which only ships with the source release and go directly to platform hooks.

Type Casting

PhysX 2 style downcasting:

```cpp
NxSphereShape * sphere = shape->isSphere();
```

is replaced by the following template syntax:

```cpp
const PxRigidDynamic* myActor = actor->is<PxRigidDynamic>();
```

Multithreading

Compared to PhysX 2, there are now more situations where it is legal to call the SDK from multiple threads. See the section on Multithreading for details.

While PhysX 2 simulation threads were managed internally by the SDK,
could simply specify the number to use, PhysX 3 allows the application to take over the simulation's thread scheduling. It is also possible for the application to define its own tasks and submit them to the SDK's default scheduler. See TaskManagement for details.

**Startup and Shutdown**

PxCreatePhysicsSDK() has been renamed PxCreatePhysics(), and the parameters have slightly changed. A foundation instance must first be created using PxCreateFoundation().

**Extensions**

A lot of non-essential utility code has been moved to the extensions library. NxActor::addForceAtPos() is now exposed as PxRigidBodyExt::addForceAtPos(). The former function appears to be missing, look there. It is available after calling PxInitExtensions().

**Heightfields**

Heightfields now need to be pre-cooked like convexes and meshes. PhysX 3 heightfields can be set to use the same internal collision logic as meshes so they have uniform behavior.

**Cooking**

The PhysX 2 cooking library was created by calling:

```c
NxCookingInterface *gCooking = NxGetCookingLib(NX_PHYSICS_SDK_VERSION);
gCooking->NxInitCooking();
```

It can now be accessed through a single PxCreateCooking() call. Cooking function names are slightly changed, e.g. NxCookTriangleMesh() is now cooking.cookTriangleMesh().
PhysX 3 has two serialization systems: 'RepX' based on XML, and a separate system for fast binary data. Neither approach is similar to PhysX 2's save-to-desc and load-from-desc based serialization code, though the PhysX 3 'RepX' serialization is similar to NxEStream.
API Design Changes

Changed Actor Hierarchy

PhysX 2 only had a single actor class, and it was possible to call any instance of this class even if it wasn't applicable to the kind of actor object in question. For example, `isSleeping()` could be called on static actors which did not have sleep logic.

In PhysX 3, we decoupled actor into a hierarchy of specialized sub-classes. `PxCloth` and `PxParticleSystem` are now subclasses of `PxActor`.

Actor Creation

In PhysX 2, the objects inside each scene were created by the scene class itself. In PhysX 3, objects are created by `PxPhysics`, and need to be added to a scene in a subsequent step by calling:

```cpp
mScene->addActor(actor);
```
Material Indexes

PhysX 2 uses so-called material indexes for stored materials. Material indexes are supported in PhysX 3 only to specify per-triangle materials in meshes. In other cases the material object is referenced directly.
Continuous Collision Detection

PhysX 2 uses CCD skeleton meshes for CCD. PhysX 3 no longer needs skeleton related code can simply be removed.
Pose Description

In PhysX 2 pose is specified using a matrix. In PhysX 3, pose is PxTransform type that consists of a PxVec3 for translation and a PxQuat for rotation. Constructors are provided to convert 4x4 matrices to PxTransform matrices from quaternions, as well as conversely.
Shape Description

PhysX 2 has multiple subclasses of NxShape, one for each type corresponding NxShapeDesc classes. PhysX 3 has only a single PxShape class, to which a PxGeometry object is passed on creation. To determine the geometrical type, call PxShape::getGeometryType(). To extract a PxGeometry object of unknown type, use PxShape::getGeometry().

Skin Width

PhysX 2's NX_SKIN_WIDTH and NxShapeDesc::skinWidth were replaced with PxShape::setContactOffset() and setRestOffset(). See Tuning Shape Collision Behavior.
The D6 driveType in PhysX 2 no longer exists in PhysX 3. Now drive spring-like: if you want position drive you set the 'spring' value non-zero, velocity drive you set the damping field non-zero, and if you set both you get a damped spring. Some specialized joints like NxJointDriveDesc, NxJointLimitDesc (PhysX 2 names) now were moved to Extensions (see the extensions folder inside the include directory).

If you have used the deleted NxSpringAndDamperEffector, you should use a joint with a spring property.

All special axes for a joint (rotation axis for revolute, translation axis for prismatic, twist axis for D6) now use the x-axis.

Joint limits now require a contact offset, which determines the distance at which it becomes active. It functions similarly to the contactOffset parameter for collision detection.
**Time Stepping**

PhysX 2 had two different time stepping modes: `NX_TIMESTEP_FIXED` (SDK subdivided into fixes steps) and `NX_TIMESTEP_VARIABLE` (user specified steps) to the `setTiming()` function. This controlled SDK-internal substepping to compute the proper size of the next time step, and called an internal simulate function with the elapsed time.

PhysX 3 discards with the substepping code altogether, and exposes simulate function directly:

```c
mScene->simulate(mStepSize);
```

In PhysX 2 it was legal to call `simulate` with a timestep of zero to force various side-effects of simulation. PhysX 3 neither requires nor supports this.

The `fetchResults` function stayed the same, however there is no more flag to specify which simulation to fetch, as there is now only a single simulation.

**Simulation Parameters**

The global speeds below which objects go to sleep, `NX_DEFAULT_SLEEP_LIN_VEL_SQUARED` and `NX_DEFAULT_SLEEP_ANG_VEL_SQUARED` are gone. PhysX 3 instead features per-body function `PxRigidDynamic::setSleepThreshold()` which is an energy based setting, more similar to the PhysX 2 `NX_DEFAULT_SLEEP_ENERGY`.

The global `NX_BOUNCE_THRESHOLD` is replaced by `PxSceneDesc::bounceThresholdVelocity`.

The `NX_DYN_FRICT_SCALING`, `NX_STA_FRICT_SCALING` scaling factors have been removed. These values should now be pre-baked into friction coefficients.

The `NX_MAX_ANGULAR_VELOCITY` value has been removed.
NX_ADAPTIVE_FORCE has been renamed PxScenFlag.ADAPTIVE_F
Collision Filtering

PhysX 2 supported multiple fixed function mechanisms for filtering collisions such as collision groups. In PhysX 2 multiple group tags specified as collidable with each other and assigned to shapes.

PhysX 3, supports user callbacks for collision filtering with a restriction that memory cannot be accessed by filtering code so that it can be executed on GPUs with optimal performance. If performance is not a priority, similar functionality can be achieved via conventional callbacks (PxSimulationFilterCallback).

When migrating PhysX 2 code, note that we provide PxDefaultSimulationFilterShader in PhysX 3, which emulates a portion of behavior. Start by checking if this class is sufficient. As this is an extension class, the source code is available and may be extended or customized.

To migrate your fixed function PhysX 2 filtering code on your own, you need to be aware of its exact behavior and implement it as a callback or shader. Let us look at the precise mechanisms and make some recommendations for porting:

```cpp
virtual void NxScene::setShapePairFlags(NxShape& shapeA,
                                        NxShape& shapeB,
                                        NxU32 nxContactPairFlag  //0 or NX_IGNORE_PAIR
                                    )

virtual void NxScene::setActorPairFlags(NxActor& actorA,
                                         NxActor& actorB,
                                         NxU32 nxContactPairFlag
                                    )
```

The first function stored explicit shape pairs in a hash, and a lookup indicating to filter or not. The second did the same for actor pairs. Because of the arbitrary size of the pair hash, implementing this mechanism as a shader with fixed memory is difficult in practice, but implementing as a callback should be trivial using a data structure such as the STL hash_map where Key is a struct holding the two pointers and Data is the bit flag.
Another scheme provided by PhysX 2 were collision groups:

```cpp
class NxShape {
public:
    virtual void setGroup(NxCollisionGroup collisionGroup) = 0;
    virtual void setGroupCollisionFlag(NxCollisionGroup group1, NxCollisionGroup group2, bool enable) {
    }
};//
class NxScene {
public:
    virtual void setGroup(NxCollisionGroup collisionGroup) = 0;
    virtual void setGroupCollisionFlag(NxCollisionGroup group1, NxCollisionGroup group2, bool enable) {
    }
};//
```

This approach let the user assign shapes to one of 32 collision groups. Each pair of groups be assigned a boolean pair flag. This approach lends itself better to a shader based implementation. To do this, you should reserve a word in each shape's filterData (say word0) to hold the group index, and assign this as before. Next, define a matrix to hold the group pair bits, and a function to set it:

```cpp
NxU32 groupCollisionFlags[32];

//init all group pairs to true:
for (unsigned i = 0; i < 32; i++)
    groupCollisionFlags[i] = 0xffffffff;

void setU32CollisionFlag(NxU32 groups1, NxU32 groups2, bool enable) {
    NX_ASSERT(groups1 < 32 && groups2 < 32);
    if (enable)
        {
            //be symmetric:
            groupCollisionFlags[groups1] |= (1 << groups2);
            groupCollisionFlags[groups2] |= (1 << groups1);
        }
    else
        {
            groupCollisionFlags[groups1] &= ~(1 << groups2);
            groupCollisionFlags[groups2] &= ~(1 << groups1);
        }
}
```

Unfortunately it is not possible to change this state after the scene is created. This is because if the matrix could change during simulation, it would force an arbitrary amount of existing contact pairs to be refiltered. In a large simulation, this could be an unacceptable amount of computation. Therefore the matrix must be initialized to its final state before the
scene is created, like this:

```cpp
PxSceneDesc desc;
...
desc.filterShaderData = groupCollisionFlags;
desc.filterShaderDataSize = 32 * sizeof(PxU32);
scene = sdk.createScene(desc);
```

Finally, you need to code the filter shader to access this data:

```cpp
PxFilterFlags FilterShader(
    PxFilterObjectAttributes attributes0, PxFilterData filterData0,
    PxFilterObjectAttributes attributes1, PxFilterData filterData1,
    PxPairFlags& pairFlags, const void* constantBlock, PxU32 cons
) {
    // let triggers through, and do any other prefiltering you need
    if (PxFilterObjectIsTrigger(attributes0) || PxFilterObjectIsTrigger(attributes1)) {
        pairFlags = PxPairFlag::eTRIGGER_DEFAULT;
        return PxFilterFlag::eDEFAULT;
    }
    // generate contacts for all that were not filtered above
    pairFlags = PxPairFlag::eCONTACT_DEFAULT;

    PxU32 ShapeGroup0 = filterData0.word0 & 31;
    PxU32 ShapeGroup1 = filterData1.word0 & 31;
    PxU32* groupCollisionFlags = (PxU32*)constantBlock;

    if (((groupCollisionFlags[ShapeGroup0] & (1 << ShapeGroup1)) ==
    return PxFilterFlag::eSUPPRESS;
    else
        return PxFilterFlag::eDEFAULT;
}
```
Scene Queries

The API for scene query functions that return multiple intersections (e.g. PxScene::raycast(...)) has changed. In PhysX 3, raycast/overlap/sweep functions expect a pre-allocated buffer or a callback class as a parameter in order to return multiple intersections. If you do not know the maximum number of intersections in advance, you can inherit from PxHitCallback and override processTouches virtual function to receive an arbitrary number of intersections via multiple callbacks using only a fixed size buffer. Please refer to the Scene Query section of the guide for more details and examples.

Raycasts

The interface for making raycasts was changed in PhysX 3. Now you should pass an origin (PxVec3) and a direction (PxVec3) instead of a NxRay that combined these fields in PhysX 2.

Overlaps

Routines like overlapSphereShapes, overlapAABBShapes, or overlapCapsuleShapes are now all covered with PxScene::overlap, passing in a PxSphereGeometry, PxBoxGeometry or PxCapsuleGeometry as a first parameter.

Sweep Tests

PhysX 2 provides a linearCapsuleSweep that takes two points to define the capsule's two spherical ends. In PhysX 3 we have a general sweep() routine that takes a PxGeom and an initial PxTransform position. Capsules were defined in PhysX 2 as two points that should be converted to an initial transformation (PxTransform) that contains an initial position and PxQuat for rotation. PxCapsuleGeometry's length is along the x-axis in local space.
This guide highlights all significant parts of the API that have changed release. An application with a working integration of the older version will be able to easily migrate to the newer version by following these points.
Math Classes

The static createIdentity() and createZero() methods are now deprecated, and will be removed in a future release. The preferred method is to use PxMat33(PxIdentity), PxMat44(PxIdentity), PxQuat(PxIdentity), PxTr for identity transforms, and PxMat33(PxZero) and PxMat44(PxZero) for
Scene Query API

- The Scene Query API underwent significant changes. The highlights are:
  - Former raycastAny, raycastMultiple, raycastSingle API calls are now folded into a single PxScene::raycast call
    - Same for overlaps and sweeps
    - Same for PxBatchQuery and PxVolumeCache
  - For PxScene queries a deprecated backwards compatibility mapping was added to aid the transition
    - This mapping will be removed in the next dot release.
  - There are now dedicated callback and buffer classes for receiving query results, replacing PxRaycastHit array and count parameters.
    - Same for sweeps and overlaps
    - See PxRaycastBuffer, PxSweepBuffer, PxRaycastCallback, PxSweepCallback, PxOverlapCallback
  - The way results are returned is now more robust and transparently handle unbounded number of results without dynamic allocations.
  - Header PxSceneQueryFiltering.h was renamed to PxQueryFiltering.h
  - PxHitFlag::eIMPACT changed to PxHitFlag::ePOSITION
  - PxRaycastHit.impact renamed to PxRaycastHit.pos
  - PxQueryFlag::eNO_BLOCK and PxQueryFlag::eANY_HIT
The following classes were renamed

- PxSceneQueryHit -> PxQueryHit
- PxSceneQueryFlags -> PxHitFlags
- PxSceneQueryHitType -> PxQueryHitType
- PxSceneQueryFilterData -> PxQueryFilterData
- PxSceneQueryFilterCallback -> PxQueryFilterCallb
- PxSceneQueryFilterFlags -> PxQueryFlags
- PxSceneQueryCache -> PxQueryCache
- PxCCTNonWalkableMode -> PxControllerNonWalk
- PxControllerFlags -> PxControllerCollisionFlags
- PxCCTHit -> PxControllerHit
- PxConstraintDominance -> PxDominanceGroupPa
- PxActorTypeSelectionFlags -> PxActorTypeFlags
- PxFindOverlapTriangleMeshUtil -> PxMeshOverlap
- Old versions are #defined to new versions to simpli
  #defines are deprecated and will be phased out.

queryClient parameter was removed from raycast/sweep
list and added to PxQueryFilterData

- The fix is to simply pass the s:
PxQueryFilterData::clientId

PxBatchQueryDesc now requires 3 parameters at constr
maxRaycastsPerExecute, PxU32 maxSweepsPerE
maxOverlapsPerExecute

- Each of these numbers is an upper bound c
PxBatchQuery::raycast(), sweep() and overlap() c:
execute()
- Previously there was no way to check for results
batch query code since sizes of these buffers were
The fix is to specify the batch query result (different sizes at construction).

- PxBatchQueryDesc no longer directly holds pointers to memory; these are moved to PxBatchQueryMemory.
  - It is now possible to set a new batch query memory before each execute
  - userRaycastHitBuffer has been renamed to userRaycastHitBuffer
  - raycastHitBufferSize has been renamed to raycastHitBufferSize
  - same for overlaps and sweeps (userSweepHitBuffer, sweepHitBufferSize, userOverlapHitBuffer, overlapHitBufferSize)

- A code snippet below illustrates the migration for these code changes

- PxQueryFilterData constructors are now explicit. This means it was possible to write
  - scene->raycast(..., PxQueryFlag::eDYNAMIC | PxQueryFlag::eSTATIC, ...), causing PxQueryFilterData implicitly constructed by the compiler
  - now it is required to explicitly write
    - scene->raycast(..., PxQueryFilterData(PxQueryFlag::eDYNAMIC, PxQueryFlag::eSTATIC), ...)
  - This change was made to improve type safety and while reading the code employing implicit constructors

- PxRaycastBufferN, PxOverlapBufferN and PxSweepBufferN were added for convenience
  - A buffer object with space for 10 touching hits and one blocking hit can now be conveniently declared as PxRaycastBufferN<10>

- PxRaycastHit and PxSweepHit now inherit from PxLocationHit (formerly from PxSceneQueryImpactHit)
- bool PxLocationHit::hadInitialOverlap() function was added to determine if a swept shape was overlapping at sweep distance=0 or if a raycast hit at distance=0.

- Functionality of PxSceneQueryFlag::eINITIAL_COLLISION and PxSceneQueryFlag::eINITIAL_OVERLAP_KEEP was replaced with PxHitFlag::eASSUME_NO_INITIAL_OVERLAP and PxLocationHit::hadInitialOverlap().

- Overlap scene queries with preFilter or postFilter returning eBLOCK hits would previously return multiple results as touching hits.
  - eBLOCK should not be returned from user filters for overlap(). Doing so will result in undefined behavior, and a warning will be issued.
  - If the PxQueryFlag::eNO_BLOCK flag is set, the eBLOCK will instead be automatically converted to an eTOUCH and the warning suppressed.

- Sweeps in 3.3 execute using a new faster code path, in some cases with reduced precision. If you encounter precision issues not previously experienced in earlier versions of PhysX, use ePRECISE_SWEEP flag to enable the backwards compatible more accurate sweep code.

- Snippets demonstrating API migration:

  Former raycastSingle call:

  ```cpp
  PxRaycastHit hit;
  bool hadHit = scene->raycastSingle(..., hit, ...);
  if (hadHit) doStuff(hit);
  ```

  Is now:

  ```cpp
  PxRaycastBuffer buf;
  Bool hadHit = scene->raycast(..., buf, ...);
  if (hadHit) doStuff(buf.block);
  ```
Former raycastAny call:

```cpp
PxSceneQueryHit hit;
bool hadHit = scene->raycastAny(hit);
if (hadHit) doStuff(hit);
```

Is now:

```cpp
PxRaycastBuffer buf; // declare a hit buffer with room for a single hit
PxFilterData fdAny; fdAny.flags |= PxQueryFlag::eANY_HIT;
bool hadHit = scene->raycast(buf, PxHitFlags(), fdAny);
if (hadHit) doStuff(buf.block);
```

Former Multiple call:

```cpp
PxRaycastHit buffer[N];
bool hasBlock;
PxI32 result = Scene->raycastMultiple(buffer, N, hasBlock);
if (result == -1)
   handleOverflow();
else
{
   if (hasBlock)
   {
      doBlocking(buffer[result-1]);
      doTouches(buffer, result-1);
   }
   else
   {
      doTouches(buffer, result);
   }
}
```

Is now:

```cpp
PxRaycastBufferN<N> buf;
scene->raycast(buf);
if (buf.hasBlock)
   doBlocking(buf.block);
doTouches(buf.touches, buf.nbTouches);
```

or:
for (PxU32 i = 0; i < buf.getNbAnyHits(); i++) // "any" in this context refers to blocking or touching hits
    doAnyHit(buf.getAnyHit(i));

Former batch query memory setup code in 3.2:

const PxU32 maxRaycastHits = 16, maxRaycastQueries = 8;
PxRaycastQueryResult* resultBuffer = new PxRaycastQueryResult[maxRaycastHits];
PxRaycastHitBuffer* hitBuffer = new PxRaycastHit[maxRaycastHits];
PxBatchQueryDesc desc; // required no arguments, there was no safety check for maximum number of queries per batch (not hits per query)
desc.userRaycastResultBuffer = resultBuffer;
desc.userRaycastHitBuffer = hitBuffer;
desc.raycastHitBufferSize = maxRaycastHits;
PxBatchQuery* bq = PxCreateBatchQuery(desc);
for (PxU32 iQuery = 0; iQuery < maxRaycastQueries; iQuery++)
    bq->raycastSingle(...); // up to 8 raycast queries are allowed but there was no overflow check
bq->execute();

for (PxU32 iResult = 0; iResult < nQueries; iResult++)
{
    for (PxU32 iHit = 0; iHit < resultBuffer[i].nbHits; iHit++)
    {
        bool isBlocking = (iHit == resultBuffer[i].nbHits &&
            (resultBuffer[iResult].hits[iHit].flags & PxSceneQueryFlag.processHit) || isBlocking);
    }
}

Batch query setup code in 3.3:

const PxU32 maxRaycastHits = 16, maxRaycastQueries = 8;
PxBatchQueryDesc desc(maxQueries, 0, 0); // note the new required argument
PxBatchQuery* bq = scene->createBatchQuery(desc);
PxRaycastQueryResult* resultBuffer = new PxRaycastQueryResult[maxRaycastQueries];
PxRaycastHitBuffer* hitBuffer = new PxRaycastHit[maxRaycastHits];
PxBatchQueryMemory mem(maxQueries, 0, 0); // maximum number of queries for each type
mem.userRaycastResultBuffer = resultBuffer;
mem.userRaycastTouchBuffer = hitBuffer;
mem.raycastTouchBufferSize = maxHits;

PxBatchQuery* bq = PxCreateBatchQuery(desc);
bq->setUserMemory(mem);

for (PxU32 iQuery = 0; iQuery < maxRaycastQueries; iQuery++)
    bq->raycastSingle(...); // up to 8 raycast queries are allowe
    // with query count overflow check as
bq->execute();

for (PxU32 iResult = 0; iResult < nQueries; iResult++)
{
    // note that the blocking hit is now reported in resultBuffer
    // resultBuffer[i].touches
    for (PxU32 iHit = 0; iHit < resultBuffer[i].nbTouches; iHit++)
        processTouchingHit(resultBuffer[iResult].touches[iHit]);

    processBlockingHit(resultBuffer[iResult].block);
}
**SPU batch queries**

In 3.2 the number of SPUs to be used per batch query was controlled via setSceneParamInt call:

```
PxPS3Config::setSceneParamInt(getScene(), PxPS3ConfigParam::eSPU_...
```

In 3.3 PxBatchQuery no longer automatically executes on multiple SPUs, but requires a separate PPU thread, this design allows higher flexibility, such as executing multiple SPU and PPU threads simultaneously, better control of parallel execution, and allows the user to fine tune thread load balancing. Here's one possible way to run batch queries on multiple SPUs in 3.3:

```c++
struct BQThread : shdfnd::Thread
{
    Ps::Sync mBatchReady;
    Ps::Sync mBatchCompleted;
    PxBatchQuery* mBatch;

    PX_FORCE_INLINE BQThread() { mBatch = NULL; }
    PX_FORCE_INLINE void submitBatch(PxBatchQuery* batch) { mBatch = batch; }

    virtual void execute()
    {
        // execute submitted batches until quit is signalled
        for(;;)
        {
            mBatchReady.wait();
            mBatchReady.reset();

            if (quitIsSignalled())
                break;

            mBatch->execute();

            mBatch = NULL;
            mBatchCompleted.set();
        } // for (;;)

        quit(); // shutdown thread
    }
};
```
};

// main thread code:
// pre-create and launch batch execute threads
for (PxU32 iThread = 0; iThread < nThreads; iThread++)
{
    BQThread* t = PX_NEW(BQThread);
    t->start();
    mThreads.pushBack(t);
}

// submit batches
for (PxU32 iThread = 0; iThread < nThreads; iThread++)
{
    // create batches
    PxBatchQuery* threadBatch = createBatch(...);
    threadBatch->setRunOnSpu(true);

    mThreads[iThread]->submitBatch(threadBatch);
    mThreads[iThread]->mBatchReady.set();
}

// execute another batch on PPU in the meantime.
PxBatchQuery* threadBatch = createBatch(...);
threadBatch->setRunOnSpu(false);
threadBatch->execute();

// do other PPU work...

// wait for SPU batches to complete:
for (PxU32 i=0; i<mThreads.size(); ++i)
{
    mThreads[i]->mBatchCompleted.wait();
    mThreads[i]->mBatchCompleted.reset();
    releaseBatch(mThreads[i]->mBatch);
}

// terminate batch threads
for (PxU32 i=0; i<mThreads.size(); ++i)
{
    mThreads[i]->signalQuit();
    mThreads[i]->mBatchReady.set();
    mThreads[i]->waitForQuit();
    PX_DELETE(mThreads[i]);
}
Whether the batch is executed on SPU or PPU is determined by
PxBatchQueryDesc::runOnSpu or PxBatchQuery::setRunOnSpu(bool)
query is executed on SPU:

```cpp
PxBatchQueryDesc desc;
...
desc.runOnSpu = true;
...
```
The following methods require that the corresponding objects have been added to a scene. Calling these methods for objects which are not in a scene will result in undefined behavior. In the CHECKED build configuration an error message will get sent.

- addForce/addTorque/clearForce/clearTorque() on a PxRigidBody
- isSleeping/wakeUp/putToSleep() on a PxRigidDynamic, PxArticulation or PxCloth
- PxScene::resetFiltering() and the deprecated counterparts on PxParticleBase

The sleep behavior of dynamic rigid bodies has changed significantly. Among the changes are:

- The wakeUp() method of PxRigidDynamic and PxArticulation has lost the wake counter parameter. Use the newly introduced setWakeCounter() instead to set a specific value.
- Putting a dynamic rigid actor to sleep will clear any pending force updates.
- Switching a dynamic actor to kinematic will put the actor to sleep immediately.
- Switching a kinematic actor back to dynamic will not affect the sleep state (previously the actor was woken up).
- Calling wakeUp/putToSleep() on a kinematically controlled actor is not valid any longer. The sleep state of a kinematic actor is solely defined based on whether a target pose has been set (see API documentation of isSleeping() for details).
- A call to PxRigidBody::setCMassLocalPose() does not wake up the actor anymore. Add a call to PxRigidBody::wakeUp() to get the old behavior back.
Note: this also affects related methods in PhysX PxRigidBodyExt::updateMassAndInertia() etc.

- Adding or removing a PxConstraint to/from the scene does not wake connected actors up automatically anymore (note: this applies to PxJoint in PhysX Extensions as well).
- If a non-zero velocity or force is set through PxRigidBody::setLinearVelocity(), ::setAngularVelocity(), ::addForce(), ::addTorque(), the actor will get woken up automatically even if the autowake parameter is false.
- PxRigidBody::clearForce() and ::clearTorque() do not have the autowake parameter, to optionally wake the actor up, anymore. These change the sleep state any longer. Call ::wakeUp() subsequently to get the old default behavior.

- Shapes may now be shared between actors. This change has several ramifications:
  - PxShape::getActor() now returns a pointer rather than a reference. If the shape is shareable, the pointer is NULL.
  - The following methods of PxShape have been removed: raycast(), sweep(), overlap(), getWorldBounds(). Replacements can be found in PxShapeExt.
  - PxShape now has the same reference counting semantics as meshes and materials, so that release() releases the user reference, and when the last reference is released, the shape is destroyed.
  - Shapes created through PxRigidActor::createShape() are destroyed automatically when the actor is released. However, after deserializing such a shape, the regular reference counting semantics apply.
  - return results from scene queries which previously specified a shape now specify an actor also.

- Shape local transforms cannot be specified on shape creation any
the local transform after creation with PxShape::setLocalPose().

- The PxObserver/PxObservable system has been replaced by the API. The supported object types have been extended from PxActor inheriting from PxBase. Furthermore, two kinds of deletion distinguished: user release and memory release. The following pseudocode for the transition from the previous to the new API:

old API:

```cpp
class MyObserver : public PxObserver
{
public:
    virtual void onRelease(const PxObservable& observable);
};

MyObserver myObs;
PxRigidDynamic* d = create...;
d->registerObserver(myObs);
```

new API:

```cpp
class MyDelListener : public PxDeletionListener
{
public:
    virtual void onRelease(const PxBase* observable, void* userData,
                        PxDeletionEventFlag::Enum deletionEvent);
};

MyDelListener myDelListener;
PxPhysics* physics = create...;
PxRigidDynamic* d = create...;
physics->registerDeletionListener(myDelListener, PxDeletionEventFlag::Enum::DELETION_USER);
PxBase* b = d;
physics->registerDeletionListenerObjects(myDelListener, &b, 1);
```

- The contactStream in PxContactPair is now stored in a variable-size compressed contact stream. This is used to save memory. As such, you can **not** access it to a PxContactPoint* and access the data. Instead, you can use PxContactPair::extractContacts or a PxContactStreamReader to...
Please see the callbacks section of the user guide for further information.

- The friction API and behavior for dynamic rigid bodies has changed:
  - Friction mode flags `eENABLE_ONE_DIRECTIONAL_FRICTION` and `eENABLE_TWO_DIRECTIONAL_FRICTION` have been replaced by `PxFrictionType::Enum PxSceneDesc::frictionType`.
  - `PxSceneDesc::contactCorrelationDistance` has been deprecated, and it no longer has an influence on how many friction anchors are created in a single frame, only when they are removed in later frames. This may cause a very minor change in friction behavior.

- `PxShape::resetFiltering()` and `PxParticleBase::resetFiltering()` have been deprecated. Please use one of the new overloaded methods `PxScene::resetFiltering()` instead.

- `PxClientBehaviorBit` and `PxActorClientBehaviorBit` have been renamed to `PxClientBehaviorFlag` and `PxActorClientBehaviorFlag` respectively.

- `PxActorTypeSelectionFlag` and `PxActorTypeSelectionFlags` have been renamed to `PxActorTypeFlag` and `PxActorTypeFlags` respectively.

- `PxConstraintDominance` has been renamed to `PxDominanceGroup`.

- The parameter 'spring' on articulation joints has been renamed 'stiffness'.

- The parameter 'tangentialSpring' on articulation joints has been renamed 'tangentialStiffness'.

- `PxConstraintFlag::Type` has been renamed to `PxConstraintFlag::Enum`.

- Discrete contact reports are no longer produced for `PxPairFlag::eDETECT_DISCRETE_CONTACT` raised in the filter shader. Previously, discrete contact generation would always have been performed regardless of the presence of the `PxPairFlag::eDETECT_DISCRETE_CONTACT` flag.
potentially improves performance when using specific shapes for CCD-only collision, which would have previously generated discrete contacts and then ignored them in the solver.

- Trigger reports are no longer produced for PxPairFlag::eDETECT_DISCRETE_CONTACT raised in the filter shader. PxPairFlag::eTRIGGER_DEFAULT has been modified to include the PxPairFlag::eDETECT_DISCRETE_CONTACT flag.
PhysX Extensions

- Joint limits have been more carefully separated into PxJointAngularLimitPair, PxJointLinearLimitPair.
- PxJoint::getType() is deprecated. Joints now inherit from PxBase, and getConcreteType() replaces getType(). Alternatively, to dynamically cast to a particular joint type, use e.g. joint->is<PxD6Joint>() which will return a pointer to a D6 joint if the type matches, otherwise NULL.
- The parameter 'spring' in joint limits and drives has been renamed 'stiffness'.
- Dominance settings no longer apply to joints. To achieve this effect, use setInvMassScale. For example if actor0 in the joint is to affect actor1 but not conversely, use setInvMassScale0(0.0f), setInverseInertiaScale0(0.0f).
PhysX Character Controller

- When creating a PxControllerManager, a reference to a PxScene is required. As a consequence, creating a controller from a PxControllerManager now only requires the controller descriptor as an argument.
- On PxControllerManager::release(), all associated PxObstacleContext instances will get deleted automatically. Make sure to not access PxObstacleContext the corresponding manager has been released.
PhysX Vehicles

- A new struct has been introduced to hold the enumerated list PxVehicleDrive4W::eFRONT_LEFT_WHEEL. The changes are
  - PxVehicleDrive4W::eFRONT_LEFT_WHEEL
    - PxVehicleDrive4WWheelOrder::eFRONT_LEFT
  - PxVehicleDrive4W::eFRONT_RIGHT_WHEEL
    - PxVehicleDrive4WWheelOrder::eFRONT_RIGHT
  - PxVehicleDrive4W::eREAR_LEFT_WHEEL
    - PxVehicleDrive4WWheelOrder::eREAR_LEFT
  - PxVehicleDrive4W::eREAR_RIGHT_WHEEL
    - PxVehicleDrive4WWheelOrder::eREAR_RIGHT

- A new struct has been introduced to hold the enumerated list PxVehicleDrive4WControl::eANALOG_INPUT_ACCEL. The changes are
  - PxVehicleDrive4W::eANALOG_INPUT_ACCEL
    - PxVehicleDrive4WControl::eANALOG_INPUT_ACCEL
  - PxVehicleDrive4W::eANALOG_INPUT_BRAKE
    - PxVehicleDrive4WControl::eANALOG_INPUT_BRAKE
  - PxVehicleDrive4W::eANALOG_INPUT_HANDBRAKE
    - PxVehicleDrive4WControl::eANALOG_INPUT_HANDBRAKE
  - PxVehicleDrive4W::eANALOG_INPUT_STEER_LEFT
    - PxVehicleDrive4WControl::eANALOG_INPUT_STEER_LEFT
  - PxVehicleDrive4W::eANALOG_INPUT_STEER_RIGHT
    - PxVehicleDrive4WControl::eANALOG_INPUT_STEER_RIGHT
  - PxVehicleDrive4W::eMAX_NUM_DRIVE4W_ANALOG_INPUTS
    - PxVehicleDrive4WControl::eMAX_NB_DRIVE4W_ANALOG_INPUTS
A new struct has been introduced to hold the enumerated list PxVehicleDrive4W::eFRONT_LEFT_WHEEL. The changes are

- PxVehicleDriveTank::eTANK_WHEEL_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::eFRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::eFRONT_RIGHT,
- PxVehicleDriveTank::eTANK_WHEEL_1ST_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e1ST_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_1ST_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e1ST_FROM_FRONT_RIGHT
- PxVehicleDriveTank::eTANK_WHEEL_2ND_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e2ND_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_2ND_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e2ND_FROM_FRONT_RIGHT
- PxVehicleDriveTank::eTANK_WHEEL_3RD_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e3RD_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_3RD_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e3RD_FROM_FRONT_RIGHT
- PxVehicleDriveTank::eTANK_WHEEL_4TH_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e4TH_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_4TH_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e4TH_FROM_FRONT_RIGHT
- PxVehicleDriveTank::eTANK_WHEEL_5TH_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e5TH_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_5TH_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e5TH_FROM_FRONT_RIGHT
- PxVehicleDriveTank::eTANK_WHEEL_6TH_FROM_FRONT_LEFT
  PxVehicleDriveTankWheelOrder::e6TH_FROM_FRONT_LEFT
- PxVehicleDriveTank::eTANK_WHEEL_6TH_FROM_FRONT_RIGHT
  PxVehicleDriveTankWheelOrder::e6TH_FROM_FRONT_LEFT
A new struct has been introduced to hold the enumerated list that began with PxVehicleDriveTank::eANALOG_INPUT_ACCEL. The changes are

- PxVehicleDriveTank::eANALOG_INPUT_ACCEL
  PxVehicleDriveTankControl::eANALOG_INPUT_ACCEL
- PxVehicleDriveTank::eANALOG_INPUT_BRAKE_LEFT
  PxVehicleDriveTankControl::eANALOG_INPUT_BRAKE_LEFT
- PxVehicleDriveTank::eANALOG_INPUT_BRAKE_RIGHT
  PxVehicleDriveTankControl::eANALOG_INPUT_BRAKE_RIGHT
- PxVehicleDriveTank::eANALOG_INPUT_THRUST_LEFT
  PxVehicleDriveTankControl::eANALOG_INPUT_THRUST_LEFT
- PxVehicleDriveTank::eANALOG_INPUT_THRUST_RIGHT
  PxVehicleDriveTankControl::eANALOG_INPUT_THRUST_RIGHT
- PxVehicleDriveTank::eMAX_NUM_DRIVETANK_ANALOG_INPUTS
A new struct has been introduced to hold the enumerated list 
PxVehicleDriveTank::eDRIVE_MODEL_STANDARD. The changes are
- PxVehicleDriveTank::eDRIVE_MODEL_STANDARD
  PxVehicleDriveTankControlModel::eSTANDARD
- PxVehicleDriveTank::eDRIVE_MODEL_SPECIAL
  PxVehicleDriveTankControlModel::eSPECIAL

A new struct has been introduced to hold the enumerated list 
eVEHICLE_TYPE_DRIVE4W. The changes are
- eVEHICLE_TYPE_DRIVE4W -> PxVehicleTypes::eDRIVE4
- eVEHICLE_TYPE_DRIVETANK -> PxVehicleTypes::eDRIVETANK
- eVEHICLE_TYPE_NODRIVE -> PxVehicleTypes::eNODRIVE
- eMAX_NUM_VEHICLE_TYPES
  PxVehicleTypes::eMAX_NB_VEHICLE_TYPES

A new struct has been introduced to hold the enumerated list 
PxVehicleGraph::eCHANNEL_JOUNCE. The changes are
- PxVehicleGraph::eCHANNEL_JOUNCE
  PxVehicleWheelGraphChannel::eJOUNCE
- PxVehicleGraph::eCHANNEL_SUSPFORCE
  PxVehicleWheelGraphChannel::eSUSPFORCE
- PxVehicleGraph::eCHANNEL_TIRELOAD
  PxVehicleWheelGraphChannel::eTIRELOAD
- PxVehicleGraph::eCHANNEL_NORMALIZED_TIRELOAD
  PxVehicleWheelGraphChannel::eNORMALIZED_TIRELOAD
- PxVehicleGraph::eCHANNEL_WHEEL_OMEGA
  PxVehicleWheelGraphChannel::eWHEEL_OMEGA
- PxVehicleGraph::eCHANNEL_TIRE_FRICTION
  PxVehicleWheelGraphChannel::eTIRE_FRICTION
- PxVehicleGraph::eCHANNEL_TIRE_LONG_SLIP
  PxVehicleWheelGraphChannel::eTIRE_LONG_SLIP
- PxVehicleGraph::eCHANNEL_NORM_TIRE_LONG_FORCE
  PxVehicleWheelGraphChannel::eNORM_TIRE_LONG_FORCE
- PxVehicleGraph::eCHANNEL_TIRE_LAT_SLIP
  PxVehicleWheelGraphChannel::eTIRE_LAT_SLIP
- PxVehicleGraph::eCHANNEL_NORM_TIRE_LAT_FORCE
  PxVehicleWheelGraphChannel::eNORM_TIRE_LAT_FORCE
- PxVehicleGraph::eCHANNEL_NORM_TIRE_ALIGNING_MOMENT
  PxVehicleWheelGraphChannel::eNORM_TIRE_ALIGNING_MOMENT
- PxVehicleGraph::eMAX_NUM_WHEEL_CHANNELS
  PxVehicleWheelGraphChannel::eMAX_NB_WHEEL_CHANNELS

- A new struct has been introduced to hold the enumerated list
  PxVehicleGraph::eCHANNEL_ENGINE_REVS. The changes are
  - PxVehicleGraph::eCHANNEL_ENGINE_REVS
    PxVehicleDriveGraphChannel::eENGINE_REVS
  - PxVehicleGraph::eCHANNEL_ENGINE_DRIVE_TORQUE
    PxVehicleDriveGraphChannel::eENGINE_DRIVE_TORQUE
  - PxVehicleGraph::eCHANNEL_CLUTCH_SLIP
    PxVehicleDriveGraphChannel::eCLUTCH_SLIP
  - PxVehicleGraph::eCHANNEL_ACCEL_CONTROL
    PxVehicleDriveGraphChannel::eACCEL_CONTROL
  - PxVehicleGraph::eCHANNEL_BRAKE_CONTROL
    PxVehicleDriveGraphChannel::eBRAKE_CONTROL
  - PxVehicleGraph::eCHANNEL_HANDBRAKE_CONTROL
    PxVehicleDriveGraphChannel::eHANDBRAKE_CONTROL
- PxVehicleGraph::eCHANNEL_STEER_LEFT_CONTROL
  PxVehicleDriveGraphChannel::eSTEER_LEFT_CONTROL
- PxVehicleGraph::eCHANNEL_STEER_RIGHT_CONTROL
  PxVehicleDriveGraphChannel::eSTEER_RIGHT_CONTROL
- PxVehicleGraph::eCHANNEL_GEAR_RATIO
  PxVehicleDriveGraphChannel::eGEAR_RATIO
- PxVehicleGraph::eMAX_NUM_ENGINE_CHANNELS
  PxVehicleDriveGraphChannel::eMAX_NB_DRIVE_CHANNELS

- A new struct has been introduced to hold the enumerated list
  PxVehicleGraph::eGRAPH_TYPE_WHEEL. The changes are
    - PxVehicleGraph::eGRAPH_TYPE_WHEEL
      PxVehicleGraphType::eWHEEL
    - PxVehicleGraph::eGRAPH_TYPE_ENGINE
      PxVehicleGraphType::eDRIVE

- Non-persistent data is no longer stored in the vehicle. Instead of
  each vehicle it is stored in an array and passed to PxVehicleUp:
  function argument. A simple example of how to construct, use, ar
  given below. This example code updates an array of vehicles and
  the air. If the vehicles are not in the air then the actor under each
  and stored in an array:

```c++
void updateVehicles(const Px32 timestep, const PxVec3& gravity
const PxVehicleDrivableSurfaceToTireFrictionPairs& fricPa
PxVehicleWheels** vehicles, PxU32 numVehicles, std::vector
{
    // Count the total number of wheels.
    unsigned int numWheels = 0;
    for(unsigned int i = 0; i < numVehicles; i++)
    {
        numWheels += vehicles[i]->mWheelsSimData.getNbWheels(
    }

    // Allocate buffers to store results for each vehicle and
```
The following accessors to non-persistent data associated with each wheel have been replaced as follows:

- `PxVehicleWheelsDynData::getSuspLineStart` becomes `PxWheelQueryResult::suspLineStart`
- `PxVehicleWheelsDynData::getSuspLineDir` becomes `PxWheelQueryResult::suspLineDir`
- PxVehicleWheels::getSuspRaycast -> PxWheelQueryResult::suspLineStart, PxWheelQueryResult::suspLineDir, PxWheelQueryResult::suspLineLength
- PxVehicleWheelsDynData::getTireDrivableSurfaceShape -> PxWheelQueryResult::tireContactShape
- PxVehicleWheelsDynData::getTireDrivableSurfaceMaterial -> PxWheelQueryResult::tireSurfaceMaterial
- PxVehicleWheelsDynData::getTireDrivableSurfaceType -> PxWheelQueryResult::tireSurfaceType
- PxVehicleWheelsDynData::getTireDrivableSurfaceContactPoint -> PxWheelQueryResult::tireContactPoint
- PxVehicleWheelsDynData::getTireDrivableSurfaceContactNormal -> PxWheelQueryResult::tireContactNormal
- PxVehicleWheelsDynData::getTireFriction -> PxWheelQueryResult::tireFriction
- PxVehicleWheelsDynData::getSuspJounce -> PxWheelQueryResult::suspJounce
- PxVehicleWheelsDynData::getSuspensionForce -> PxWheelQueryResult::suspSpringForce
- PxVehicleWheelsDynData::getTireLongitudinalDir -> PxWheelQueryResult::tireLongitudinalDir
- PxVehicleWheelsDynData::getTireLateralDir -> PxWheelQueryResult::tireLateralDir
- PxVehicleWheelsDynData::getTireLongSlip -> PxWheelQueryResult::longitudinalSlip
- PxVehicleWheelsDynData::getTireLatSlip -> PxWheelQueryResult::lateralSlip
- PxVehicleWheelsDynData::getSteer -> PxWheelQueryResult::steerAngle
- PxVehicleWheels::isInAir -> PxWheelQueryResult::isInAir

- PxVehicleWheels::setWheelShapeMapping
  PxVehicleWheels::getWheelShapeMapping have been
PxVehicleWheelsSimData::setWheelShapeMapping
PxVehicleWheelsSimData::getWheelShapeMapping

- PxVehicleWheels::setSceneQueryFilterData
  PxVehicleWheels::getSceneQueryFilterData have been moved
PxVehicleWheelsSimData::setSceneQueryFilterData
PxVehicleWheelsSimData::getSceneQueryFilterData

- PxVehicle4WEnable3WTadpoleMode and PxVehicle4WEnable3WDeltaMode now take an extra function argument: a non-const reference to a PxVehicleWheelsDynData

- PxVehicleWheels::isInAir() has been replaced with Px\VehicleWheelQueryResult& vehWheelQueryResults

- PxVehicleDrive4WSmoothAnalogRawInputsAndSetAnalogInputs now takes an extra function argument "const bool isVehicleInAir". This can be calculated using the function PxVehicleIsInAir

- To improve api consistency PxVehicleTelemetryData::getNumWheelGraphs is now PxVehicleTelemetryData::getNbWheelGraphs

- To improve api consistency PX_MAX_NUM_WHEELS is now PX_MAX_NB_WHEELS

- To improve api consistency PxVehicleGraph::eMAX_NUM_TITLE_CHARS is now PxVehicleGraph::eMAX_NB_TITLE_CHARS

- PxVehicleTireData::mCamberStiffness has been replaced with PxVehicleTireData::mCamberStiffnessPerUnitGravity. PxVehicleTireData::mCamberStiffnessPerUnitGravity should be set so that it is equivalent to the old value of PxVehicleTireData::mCamberStiffness divided by the magnitude of gravitational acceleration (PxScene::getGravity().getMag()). The advantage of using PxVehicleTireData::mCamberStiffnessPerUnitGravity is that it is independent of length scale.
• PxVehicleComputeTireForceDefault has been removed from the public vehicle API. Custom tire shaders that call PxVehicleComputeTireForceDefault implemented by taking a copy of PxVehicleComputeTireForceDefault instead.
CCD

- The mechanism to activate CCD per shape has changed. PxShapeFlag::eUSE_SWEPT_BOUNDS that was used in 3.2 to activate swept bounds per shape has been removed. In its place is PxRigidBodyFlag::eENABLE_CCD that is set per rigid actor. Setting this flag for an actor in 3.3 has approximately the same effect as PxShapeFlag::eUSE_SWEPT_BOUNDS on all the actor's shapes in 3.2.

- PxPairFlag::eSWEPT_INTEGRATION_LINEAR has been replaced with PxPairFlag::eCCD_LINEAR in PhysX 3.3.

- PxSceneFlag::eENABLE_SWEPT_INTEGRATION flag in 3.2 has been replaced with PxSceneFlag::eENABLE_CCD in PhysX 3.3.

- A simple example of how to enable CCD on a specific shape is given below. This demonstrates creating a body consisting of a large box and a small sphere, where the box is only used in discrete collision detection and the sphere is only used in CCD. The simulation filter shader shown here requires that the shapes be flagged with eCCD_RESPONSE to generate a collision response (PxPairFlag::eCCD_LINEAR). Likewise, the filter shader shown here requires that the filter data of both shapes need to be flagged with eDISCRETE_RESPONSE in order to generate a collision response (PxPairFlag::eRESOLVE_CONTACTS).

  
  struct CCDFilterTest
  {
    enum FilterFlags
    {
      eDISCRETE_RESPONSE = 1 << 0,
      eCCD_RESPONSE = 1 << 1,
    };
  }
static PxFilterFlags filterShader(
PxFilterObjectAttributes attributes0,
PxFilterData filterData0,
PxFilterObjectAttributes attributes1,
PxFilterData filterData1,
PxPairFlags& pairFlags,
const void* constantBlock,
PxU32 constantBlockSize)
{
    pairFlags = PxPairFlags(0);

    PxU32 combo = filterData0.word0 & filterData1.word0;
    if(combo & eDISCRETE_RESPONSE)
    {
        pairFlags |= PxPairFlag::eRESOLVE_CONTACTS;
    }
    if(combo & eCCD_RESPONSE)
    {
        pairFlags |= PxPairFlag::eCCD_LINEAR;
    }
    return PxFilterFlags();
}

PxRigidDynamic* dyn = getPhysics().createRigidDynamic(PxTransform
PxBoxGeometry box;
box.halfExtents = PxVec3(1.f, 1.f, 1.f);
PxSphereGeometry sphere;
sphere.radius = 0.75f;
PxShape* boxShape = dyn->createShape(box, getDefaultMaterial();
PxShape* sphereShape = dyn->createShape(sphere, getDefaultMaterial;

PxFilterData data = boxShape->getSimulationFilterData();
data.word0 |= CCDFilterTest::eDISCRETE_RESPONSE;
boxShape->setSimulationFilterData(data);

data = sphereShape->getSimulationFilterData();
data.word0 |= CCDFilterTest::eCCD_RESPONSE;
sphereShape->setSimulationFilterData(data);

dyn->setRigidBodyFlag(PxRigidBodyFlag::eENABLE_CCD, true);
getActiveScene().addActor(*dyn);
PhysX Visual Debugger

- A new flag has been introduced to configure the visualizing of constraints:
  PxVisualDebuggerFlag::eTRANSMIT_CONSTRAINTS;

- A new function has been introduced to configure PxVisualDebugger:
  PxVisualDebugger::setVisualDebuggerFlags(PxVisualDebuggerFlag);

- A new function has been introduced to send error stream to PVD:
  PxVisualDebugger::sendErrorMessage(( PxErrorCode::Enum code, const char* message, const char* file, PxU32 line));

- The following functions were renamed:
  PxVisualDebugger::getPvdConnectionFactory() -> PxVisualDebugger::getPvdConnection();
  PxVisualDebugger::getPvdConnection(); PxVisualDebugger::getPvdDataStream();

- The PVD connect function changed to the same method as previous:
  PxVisualDebuggerExt::connect -> PxVisualDebuggerExt::createConnection;

- The constraint, contacts and scene queries visualizing can all be configured with PxVisualDebuggerFlag in 3.3. Here is an example for how to enable the contacts:

```cpp
mPhysics->getVisualDebugger() ->setVisualDebuggerFlags(PxVisualDebuggerFlag::eTRANSMIT_CONSTRAINTS);
```
PhysX Cloth

There have been substantial changes to the PhysX 3.3 cloth solver that improve performance and behavior. This has resulted in a reorganization of how constraints are stored and processed in the cloth fabric. Prior to PhysX 3.3 the cloth solver used fibers to organize edge constraints into independent groups. In PhysX 3.3 it is no longer necessary to decompose constraints into fibers, instead edge constraints now exist individually and are solved in larger, independent sets. Interface changes are detailed below:

- Previously there were multiple solver types to choose from for each group of constraints such as eFAST, eSTIFF, eBENDING, PxClothPhaseSolverConfig::SolverType). There is now one type of constraints, this is a flexible distance constraint with controls to adjust stiffness within certain ranges of compression and stretch (see PxClothStretchConfig). Behaviors such as bending are now achieved by the way distance constraints are arranged geometrically, rather than through a specialized bending solver.

- To reduce stretching a new constraint type has been added called 'tether'. These constraints do not act along edges of the mesh, but as attachments between particles that enforce a maximum distance between them. See PxClothFabric::getTetherAnchors().

- Cloth cooking which was previously part of the PxCooking library has been moved to the extension library, see PxClothFabricCooker:

```cpp
// PhysX 3.2.x
cooking->cookClothFabric(meshDesc, gravity, outputStream);

// PhysX 3.3
PxClothFabricCooker cooker(meshDesc, gravity, useGeodesicTethers); cooker.save(outputStream, false);
```

- The PxClothCollisionData parameter has been removed from PxPhysx::createCloth(). The collision shapes can now be added after cloth creation using PxCloth::addCollisionSphere and PxCloth::addCollisionCapsule.
- PxCloth::wakeUp() does not have a parameter anymore. Use the method setWakeCounter() instead to set a specific value.

- PxCloth::setDampingCoefficient now takes a PxVec3 instead of a the damping per axis.

- PxCloth::setPhaseSolverConfig() has been renamed to PxCloth::setStretchConfig()

- PxCloth::lockClothReadData() has been renamed to PxCloth::lockParticleData()

- PxClothFabricTypes.h has been removed, this header has been merged with PxClothFabric.h
RepX Serialization

Substantial changes were made to the PhysX 3.3 serialization interface. Collections and references between collections have been unified for serialization.

- The RepX and RepXUpgrader libraries have been removed. RepX functionality is now provided through PhysXExtensions.

- RepXCollection has been replaced with PxCollection, which is the class for both RepX and binary serialization in 3.3. Collections are instantiated with PxSerialization::createCollectionFromXml(). Empty collections can be created with PxCreateCollection(). Serialization into RepX format is achieved through PxSerialization::serializeCollectionToXml().

- TRepXId has been replaced with PxSerialObjectId.

- RepXIdToRepXObjectMap and RepXObject have been replaced with functionality in PxCollection, which now maps between serializable objects and PxSerialObjectId values.

- RepXExtension was removed. Serialization and deserialization of objects is achieved through the PxRepXSerializer interface.

- RepXUtility and PxToolkit functionality has been replaced with various functions in PxSerialization, PxCollection and PxScene.
  - A PxCollection with all PxPhysics-level objects such as shapes, meshes or materials (formally referred to as buffers) can be created with PxCollectionExt::createCollection(PxPhysics&).
  - Similarly PxCollectionExt::createCollection(PxScene&) can be used to create a collection of PxScene-level objects.
  - Dependencies between objects and collections can
PxSerialization::complete().
- The objects of a collection can be added to PxScene::addCollection().
- Operations on files are generally handled with abstract interfaces: PxOutputStream and PxInputData. Default implementations are PxDefaultFileOutputStream and PxDefaultFileInputData.

- RepXUpgrader::upgradeCollection was removed. RepX data can be converted to newer PhysX versions by deserializing and re-serializing:
  PxSerialization::createCollectionFromXml(),
  PxSerialization::serializeCollectionToXml().

- Serialization functionality requires a PxSerializationRegistry instance created with PxSerialization::createSerializationRegistry().

- XML serialization can be configured to store the cooked triangle data along with the plain data for faster loading.

- PhysXVehicles supports RepX serialization. PxSerializationReg provided to PxInitVehicleSDK() for vehicle serialization, PxCloseVehicleSDK() for cleanup.

- Custom class RepX serialization is supported in 3.3, more information please read Serialization.
Binary Serialization

The binary serialization interface has been refactored and unified.

- Most serialization functionality requires an instance of PxSerializationRegistry. It is application managed and can be created with PxSerialization::createSerializationRegistry() and released with PxSerializationRegistry::release().

- The base class for serializable types has been renamed from PxBase. Most of the serialization functionality moved to a separate PxSerializer instance per serializable type is registered in PxSerializationRegistry. All PhysX and PhysXExtension serializables are registered by default.

- PxCollection has been reworked.
  - PxCollection::serialize() and PxCollection::deserialize() were replaced with PxSerialization::createCollectionFromBinary()
  - PxCollection::serializeCollectionToBinary() in PhysXExtensions.

- PxSerializable::collectForExport() has been replaced with PxSerializable::collectForExport().
  - PxSerializable::collectForExport() helps to add required objects and dependencies. PxSerializable::isSerializable() should be used to check if a collection can be successfully serialized.

- PxUserReferences was removed: PxCollection instances can now resolve dependencies between collections on deserialization.

- PxSerializable::complete() helps to add required objects and dependencies. PxSerializable::complete() supports creating collections with external dependencies.

- PxSerialObjectRef has been replaced with PxSerialObjectId.

- PxCollectForExportSDK() and PxCollectForExportScene() functions were replaced.
with `PxCollectionExt::createCollection(PxPhysics& physics)` and `PxCollectionExt::createCollection(PxScene& scene)`.

- `PxDumpMetaData()` was replaced with `PxSerialization::dumpBinaryMetaData()`.
- The `PxBinaryConverter` moved from `PhysXCooking` to `PxCooking::createBinaryConverter()` was replaced with `PxSerialization::createBinaryConverter()`.
- `PhysXVehicles` supports binary serialization. `PxSerializationRegistry` needs to be provided to `PxInitVehicleSDK()` for vehicle serialization, `PxCloseVehicleSDK()` for cleanup.
- Custom class binary serialization is supported in 3.3, more information please read `Serialization`.
PhysX TaskManager

- The pxtask namespace has been removed and all its types are relocated to the physx namespace with a Px prefix, for example pxtask::LightCpuTask becomes physx::PxLightCpuTask.
• This guide highlights all significant parts of the API that have changed in the last release. An application with a working integration of the older version should be able to easily migrate to the newer version by following these pointers.

• Functionality shared with the APEX SDK was moved into a separate directory outside of the "PhysX" directory. Since the PxFoundation PxShared library, it is versioned separately. PxCreateFoundation takes PX_FOUNDATION_VERSION as an argument.
Deprecated APIs

**PxRigidActor::createShape**

PxRigidActor::createShape() is deprecated, and will be removed. PxRigidActorExt::createExclusiveShape() replaces this method.

**PxSceneFlag::eDEPRECATED_TRIGGER_TRIGGER_REPORTS**

PxSceneFlag::eDEPRECATED_TRIGGER_TRIGGER_REPORTS is deprecated, and will be removed in PhysX 3.5. More details are mentioned under Core Phys

**PhysX particles**

The PhysX particle feature has been deprecated in PhysX version 3. The standalone library PhysX FleX is an alternative with a richer feature set.

**PhysX cloth**

The PhysX clothing feature has been deprecated in PhysX version 3.4. APEX clothing features are replaced by the standalone NvCloth library.
Core PhysX

- PxCreatePhysics now requires a PxFoundation object to be passed.
  It receives a pointer to a PxPvd object, used for connecting Phydebugger.

- PxActor::isRigidStatic, isRigidDynamic, isParticleSystem, isArticulationLink, isCloth, isRigidActor, isRigidBody, isParticle removed. Use corresponding PxBase::is() with class template pcasting.

- PxContactPairFlag::eINTERNAL_HAS_FACE_INDICES is obsolete and has been removed.

- Trigger shapes will no longer send notification events for interactors. For PhysX 3.4 there is the option to re-enable the PxSceneFlag::eDEPRECATED_TRIGGER_TRIGGER_REPORTS no longer be available in PhysX 3.5. It is recommended to eDEPRECATED_TRIGGER_TRIGGER_REPORTS and instead use a non-trigger shape, both with the same geometry and local pose, notifications for overlaps between trigger shapes.

- Implementations of PxSimulationEventCallback will have to provide implementation of the newly added method onAdvance() to avoid compilation errors.

- The deprecated method PxPhysics::createHeightField(const Px has been removed. Please use PxCooking::createPxHeightFieldDesc&, PxPhysicsInsertionCallback&) instead. The can be obtained through PxPhysics::getPhysicsInsertionCallback().

- The deprecated flag PxActorTypeSelectionFlag/PxActorTypeSelectionFlags removed. Please use PxActorTypeFlag/PxActorTypeFlags instead.
- The deprecated class PxFindOverlapTriangleMeshUtil has been removed. Please use PxMeshOverlapUtil instead.

- The deprecated flag PxConstraintFlag::eREPORTING has been removed. Force reports are now always generated.

- The deprecated flag PxConstraintFlag::eDEPRECATED_32_CC has been removed.

- PxRegisterHeightFields() now registers unified heightfields. To register legacy heightfields, call PxRegisterLegacyHeightFields(). Legacy heightfield collision is deprecated and will be removed in a future PhysX release.

- The following deprecated simulation event flags have been removed:
  - PxContactPairHeaderFlag::eDELETED_ACTOR_0, ::eDELETED_ACTOR_1 (use PxContactPairHeaderFlag::eREMOVED_ACTOR_0, ::eREMOVED_ACTOR_1 instead)
  - PxContactPairFlag::eDELETED_SHAPE_0, ::eDELETED_SHAPE_1 (use PxContactPairFlag::eREMOVED_SHAPE_0, ::eREMOVED_SHAPE_1 instead)
  - PxTriggerPairFlag::eDELETED_SHAPE_TRIGGER, ::eDELETED_SHAPE_OTHER (use PxTriggerPairFlag::eREMOVED_SHAPE_TRIGGER, ::REMOVED_SHAPE_TRIGGER, ::REMOVED_SHAPE_OTHER instead)

- PxContactPair now reports separate pointers for contactPatches, contactImpulses rather than reporting a single pointer that the PxContactStreamIterator parses. The interface for PxContactStreamIterator has been modified accordingly. See the PxContactPair::extractContacts implementation
further guidance on how to iterate over this contact data if required.
Contact Generation

- PCM contact generation is now used by default. Legacy SAT-based contact generation can be re-enabled by clearing the PxSceneFlag::eENABLE_PCM from PxSceneDesc::flags.
- Unified heightfields are now the default heightfield collision approach. This mirrors the way in which mesh contact gen functions so permits meshes and heightfields to be used interchangeably with negligible behavioral difference. The legacy heightfield collision approach can be used by calling PxRegisterLegacyHeightFields().
- When unified heightfields are in use, the bounds of heightfield shapes will not be extruded by "thickness". If legacy heightfield collision is used, the bounds will still be extruded by thickness.
**PhysX Cooking**

- The deprecated `PxMeshPreprocessingFlag::eREMOVE_UNREFERENCED_VERT` and `::eREMOVE_DUPLICATED_TRIANGLES` have been removed. Meshes get cleaned up by default unless `PxMeshPreprocessingFlag::eDISABLE_CLEAN_MESH` is set.
- `PxCookingParams::meshSizePerformanceTradeOff` and `PxCookingParams::meshCookingHint` have been moved to `PxBVH` since they only affect the BVH33.
- The `PxGaussMapLimit.h` file has been removed. The `PxGetGaussMapVertexLimitForPlatform` function has been moved but the function is now deprecated, along with the `PxPlatform` enum. Now an explicit `PxCookingParams::gaussMapLimit` parameter. As far as transition to PhysX 3.4 is concerned there is nothing to do other than removing `PxGaussMapLimit.h`, and perhaps including `PxCooking.h` instead if needed.
- Legacy convex hull (`PxConvexMeshCookingType::eINFLATION_INCREMENTAL_HULL`) uses inflation in all cases. To cook a convex mesh without inflation the `PxConvexMeshCookingType::eQUICKHULL` algorithm must be used; it does not support inflation.
Reference Counting

- In previous releases, isReleasable() for shareable objects (shapes, convex meshes, cloth fabrics, materials and heightfields) would return false on once release() had been called on the object, which was only allowed once. In 3.4, reference counts can be manually incremented with acquireReference() and decremented with release(), and so the fact that release() has called once is not a reliable indicator of whether it can be called again.
- As a consequence of the above, applications must ensure they own counted reference to each shareable object in a collection PxCollectionExt::releaseObjects. The main case in which this might be different is when using PxRigidActor::createShape(), since in that case only the actor has a counted reference to the shape. In this specific case, the releaseExclusiveShapes to PxCollectionExt::releaseObjects may be helpful.
- Since there is no unique user release for shareable objects, they do not generate USER_RELEASE events when release() is called.
PhysX Visual Debugger

- PxVisualDebugger is deprecated, and new PxPvd has been introduced. More details are mentioned in *PhysX Visual Debugger (PVD)*.
Scene queries

- PxPruningStructure enum has been renamed to PxPruningStructureType.
- Deprecated type PxSceneQueryHit has been removed. Please use PxQueryHit instead.
- Deprecated type PxSceneQueryFilterData has been removed. Please use PxQueryFilterData instead.
- Deprecated type PxSceneQueryFilterCallback has been removed. Please use PxQueryFilterCallback instead.
- Deprecated type PxSceneQueryCache has been removed. Please use PxQueryCache instead.
- Deprecated types PxSceneQueryFlag(s) has been removed. Please use PxHitFlag(s) instead.
- Deprecated scene query functions have been removed (e.g. PxScene::raycastAny(), etc). To make the transition easier they are still available in PxSceneQueryExt.h, as part of PhysXExtensions. A previous PxScene::raycastAny(...) call should now use PxSceneQueryExt::raycastAny(PxScene, ...), or PxScene::raycast(...).
- PxHitFlag::eFACE_INDEX was introduced. In order to receive the face index in sweeps against convex geometry, the flag needs to be set.
- PxHitFlag::eDISTANCE has been deprecated, since the distance and its computation cannot be skipped. Please simply avoid using it on. The flag has no effect and it will be removed in the next version.
- The "anyHit" parameter of the PxGeometryQuery::raycast() and PxShapeExt::raycast() functions has been removed. Please use PxHitFlag::eMESH_ANY instead.
- PxMeshQuery::sweep() now respects PxHitFlag::eMESH_BOTH. If you previously used that flag when calling that function, it was ignored, and the upgrade to 3.4 might start generating different results compared to 3.3. If keeping the previous behaviour is important, please disable PxHitFlag::eMESH_BOT
PxMeshQuery::sweep() calls.

- Batched scene queries are marked as deprecated and will be system in future releases.
- Volume cache feature is marked as deprecated, it will be removed in
- Spatial index feature is marked as deprecated, it will be removed in
The signatures for the PxComputeMeshPenetration and PxComputeHeightFieldPenetration functions have changed. The old functions are still available but they are now deprecated. It is recommended to transition to the new functions (with the same names but a different signature).
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