imstk-unity Documentation

Release 2.0.0

Kitware

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Introduction

iMSTK is a free & open source C++ toolkit for the prototyping of interactive multi-modal surgical simulations. The iMSTK-Unity asset gives you access to its capabilities through the Unity authoring interface. While this asset is still under development you can already exercise a variety of parts of iMSTK inside of Unity. This guide will help you get acquainted with the architecture and workings of the plugin.

The latest version of this documentation can be found on ReadTheDocs

iMSTK-Unity

User Documentation

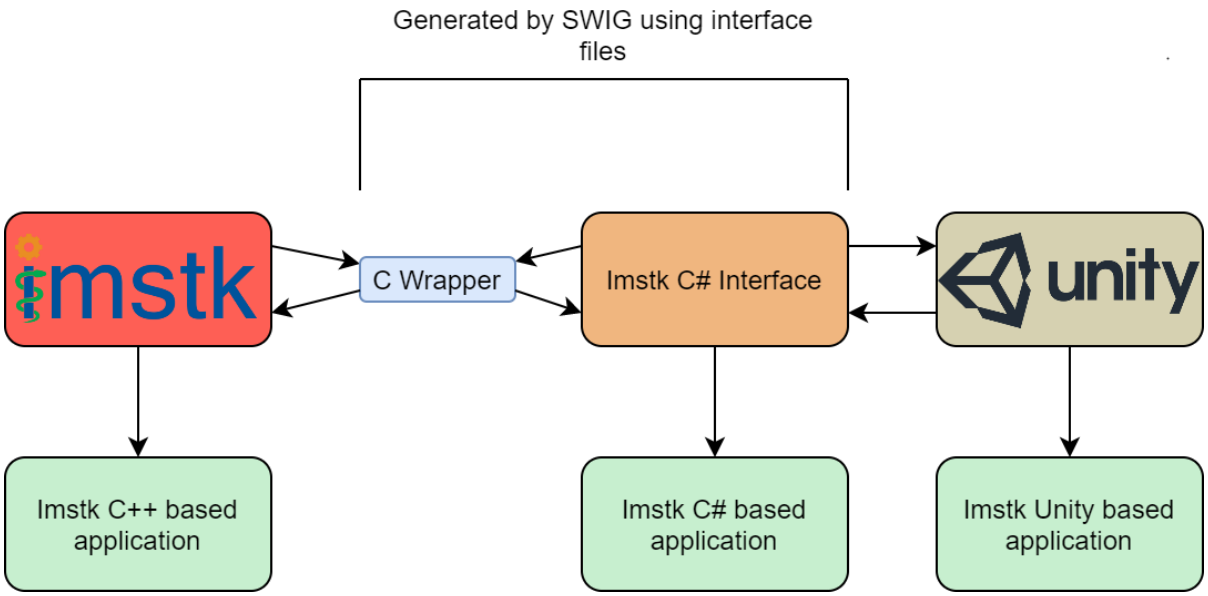
1 Introduction

This document describes the iMSTK-Unity interface as well as how to build and develop it.

1.1 Overview

iMSTK is a free & open source C++ toolkit for prototyping interactive multi-modal surgical simulations. The iMSTK-Unity asset provides classes that allow the use of iMSTK features inside of unity, those are amongst others various rigid and deformable models, collision detection and response, geometric importers and filters.

The iMSTK-Unity classes utilizes a C# interface of iMSTK that is generated by using the SWIG tool. This interface is wrapped around most C++ functions and forwards its calls to the original C++ code. This allows you to use iMSTK in C# almost the same way as you would in C++.



1.2 Limitations

Not all iMSTK classes are currently accessible through the Unity layer. Additionally there may be some combinations that have not been tested. Some errors *may* cause Unity to crash, save early and save often. Please report issues you encounter in the iMSTK-Unity issue tracker

While there is an OpenHaptics asset available on the Unity Asset Store. This is currently unsupported by the iMSTK Unity Asset. If you need support for the 3D-Touch series of devices you will have to build iMSTK with the appropriate settings.

Avoid calling `new Imstk.<ImstkClass>()` as variable initializers when declaring member variables, initialize in the constructor or later instead e.g.:

```
// PREFER
class Example {
        Imstk.LineMesh mesh;

        void Example () {
                mesh = new Imstk.LineMesh();
        }
}

// AVOID
class Example {
        Imstk.LineMesh mesh = new Imstk.LineMesh();
}
```

When initializing in the member declaration you may see unexpected crashes in the binary player under windows.

1.3 Project Structure

The files of the asset are split in the following directories:

- **Scripts**: This directory is for the runtime scripts of the plugin.
- **Scripts/Editor**: This directory is for the editor scripts of the plugin. These scripts implement custom editor functionality. Editor scripts may use runtime scripts but won't be included in the player, which means you should not use functions from these in your own scripts
- **Resources**: This directory contains resources required during runtime.
- **Editor/Resources**: This directory contains resources required in the editor (such as style sheets or UI markup).
- **Plugins**: This directory is for libraries (dlls/so) that Unity needs to load.

Directories needed for the project but not relevant to the plugin:

- **Models, Materials, & Textures**: These directories are for various assets used by the Demo. They are not part of the plugin.

The asset on the store may not contain the latest version of iMSTK-Unity, if you want to be up to date you can check out the sources from gitlab. As the binary files for iMSTK aren't included in the repository, you will also have to build iMSTK yourself when you go this route.

2 Setup for Development

When checking out iMSTK-Unity from gitlab you will first need to build iMSTK. iMSTK uses CMake for its build system. iMSTK is a superbuild meaning it builds, includes, and links to all of its dependencies. There is no need to go find them. The correct version of iMSTK is included in the repository under *iMSTKSource~* as a git submodule. To make sure it's up to date after an update of the repository run *git submodule update*. To build iMSTK you will need to use *cmake*. When building make sure that the build directory (where the binaries end up) is not inside the *iMSTKSource~* directory but close to the root of you drive, e.g. *C:imstk-build*, the iMSTK project structure is deep enough that there are issues with windows path length. Additionally turn on the `IMSTK_BUILD_FOR_UNITY` cmake switch, This will reduce the number of dependencies that are being built. It will also enable the generation of ".cs" files as well as ".dlls"/".so" files in your install directory that are needed by the ".cs" code. These will be used in Unity. Optionally enable `iMSTK_USE_VRPN` and/or `iMSTK_USE_OpenHaptics` for device support.

You can install the binaries two different ways, for both methods you need to know the directory in which iMSTK was installed. If you didn't change anything that directory will be called *install* and resides inside the directory that you defined in cmake to build imstk, e.g. `C:\Projects\imstk\build\install` :

- **Using `ImstkSource~\InstallImstk.bat` the format is** `ImstkSource~\InstallImstk.bat <path to imstk/install>`
- Alternatively you can enable *Developer Mode* for iMSTK inside of Unity. This option ca be found in "Edit->Project Settings->iMSTK Settings". When turned on, you will be prompted to install iMSTK whenever you start Unity. After turning on this option, you may need to restart Unity. When it prompts you, select yes and provide your iMSTK install directory, located in `<iMSTK build directory>/install`. All the necessary files will be copied. If you don't want to be asked to reinstall iMSTK toggle this option off again.

If you make changes in iMSTK you must reinstall it to Unity.

Note: There is a 'Force Install' button to install iMSTK into Unity at the instant it is clicked. This may not always work depending on if an iMSTK script (that utilizes a given dll) has run in the editor. In that case those dll's cannot be unloaded from Unity.

Note: Make sure Unity is not running, even though closed it may be running in the background and prevent any installation.

3 Devices

The asset available from the asset store does not have OpenHaptics or VRPN enabled. To use external devices you will have to build iMSTK. When building, enable `iMSTK_USE_VRPN` or `iMSTK_USE_OpenHaptics` respectively. This will create a version of iMSTK with device support enabled. When the build is done install iMSTK into the Unity Asset as described above.

3.1 Debugging

Debugging may be done in visual studio, even on the native side. You must attach the debugger to Unity as you would to any external process. With iMSTK open in visual studio, click debug->attach to process. Select the Unity executable and make sure you're set on native debugging.

4 Tutorial

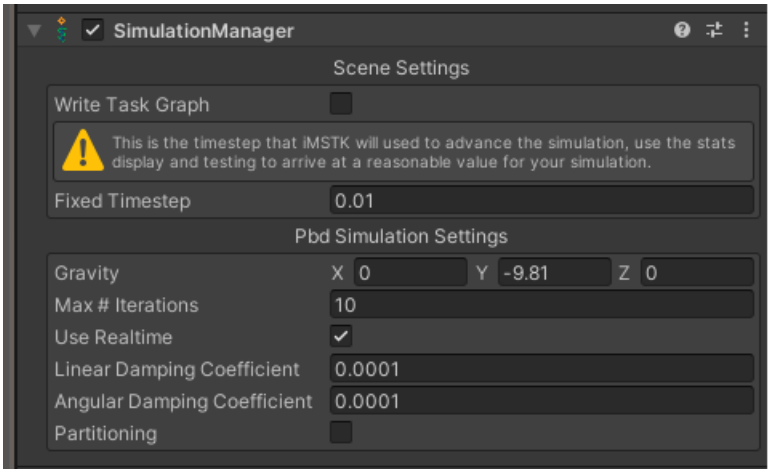
In this tutorial we are going to assemble a simple scene containing a deformable object colliding with static scenery. The completed tutorial is available as the *Tutorial* scene in the scene folder.

For the purpose of this guides component names will be written in a mono-spaced font e.g. `SimulationManager`, whereas the names of GameObjects or EditorFields will be in italics e.g. *HeartModel*

- Create a new scene in Unity
- Set the *Main Camera* transform to the values as seen in the image below

- Create a new gameobject and add a `SimulationManager` component to it

  The `SimulationManager` is a required component for all simulations using iMSTK-Unity, it controls initialization and updates and also lets you set a number of global variables.



- Create an empty GameObject, add a `Deformable` component and name it *HeartModel*.

`Deformable` is one of the classes that iMSTK-Unity offers, it implements the PBD[1] and XPBD[2] methods for simulating deformable objects.

We will add geometry separately but you can also use the items under the menu *iMSTK\GameObject* to add very simple objects with algorithmically generated meshes.

The `Deformable` has a large number of parameters but we will focus only on a few. This will eventually become a deformable object but there is still a lot of work to do. For more information look at the iMSTK Documentation

We will come back to this later.

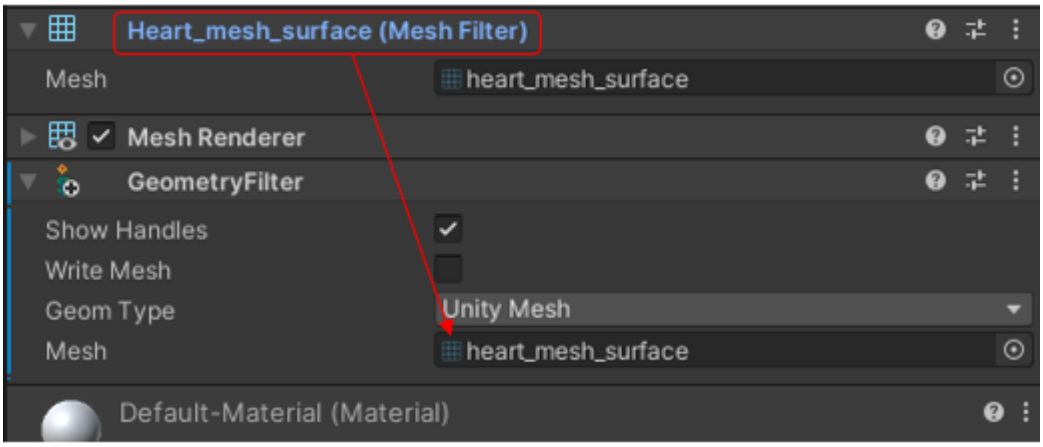
- From the *Models* folder add model named *heart* under the *HeartModel* GameObject

  This will serve as the visual representation of what the simulation is doing, to make it look better, get the *flesh* material from the *Materials* folder and assign it as well.

  With the *heart* GameObject selected add a `GeometryFilter` component to it and drag the *Mesh-Filter* component, the name will be *Heart_mesh_surface (Mesh Filter)* into the *Mesh* field of the `GeometryFilter`. The drop down menu should say *Unity Mesh*. This makes this mesh available to iMSTK-Unity.

  For every kind of geometry you want to use in the PBD model, iMSTK-Unity needs a `GeometryFilter`. This maps the Unity type to something that iMSTK can understand. It can also be used to define fixed shapes like Plane or Capsule. For meshes the source of a Geometry filter can either be a Unity mesh in the scene, a mesh asset, or (especially for tetrahedral meshes) an asset imported by the geometry importer of iMSTK-Unity.

  You can use the check box named *Show Handles* to verify that the mesh is in the correct location. If you don't see the mesh, make sure the Gizmos are turned on for the scene view.



- Set up the parameters for our `Deformable`

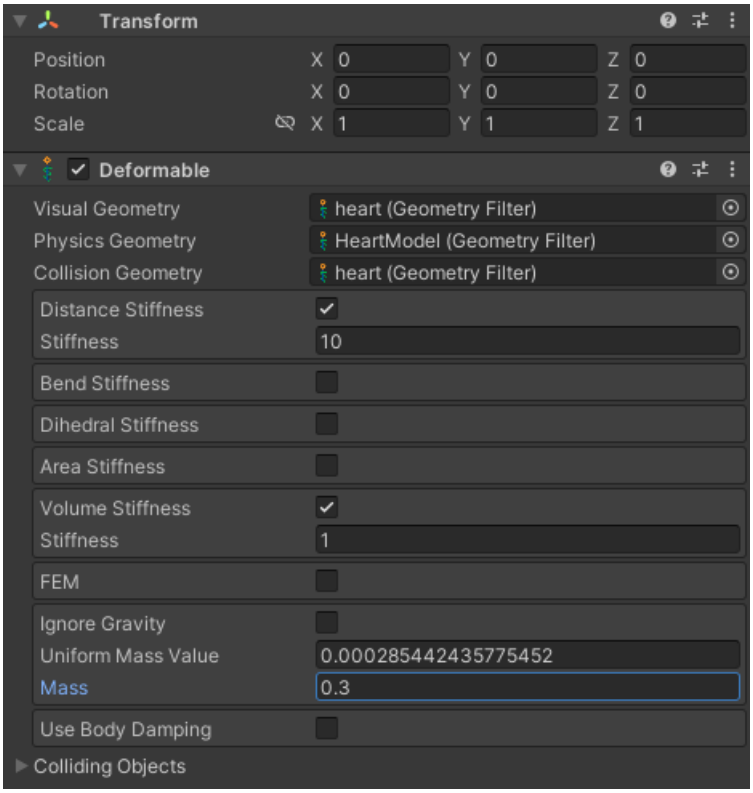
  First check the *Distance Stiffness*, *Volume Stiffness* and fill in the properties as you see in the image below. This sets the material properties of this object. Uncheck all other stiffness options.

  The `Mass` and `Uniform Mass Value` fields are dependent on each other. The `Uniform Mass Value` is a per node/vertex value.

[1] M. Müller, B. Heidelberger, M. Hennix, and J. Ratcliff, "Position based dynamics," Journal of Visual Communication and Image Representation, vol. 18, no. 2, pp. 109–118, Apr. 2007, doi: 10.1016/j.jvcir.2007.01.005.

[2] M. Macklin, M. Müller, and N. Chentanez, "XPBD: position-based simulation of compliant constrained dynamics," in Proceedings of the 9th International Conference on Motion in Games, Burlingame California, Oct. 2016, pp. 49–54. doi: 10.1145/2994258.2994272.

Note: While iMSTK is inherently unitless, the default value in the simulation manager for gravity is 9.81 m/s^2. And the unmodified output of the haptic device in Newtons. If you want to use the default values, you should use meters and kilograms for your objects. Otherwise you need to modify the gravity and the `forceScaling` parameter in the `OpenHapticsDevice`. To match the units you want to use.



- Add a `GeometryFilter` to use in the simulation

  We will need a mesh to use as the geometry for calculating the physical behavior of our object. Add a `GeometryFilter` to the *HeartModel* object. As we will use a tetrahedral mesh, the method to assign the mesh is slightly different than what we used before. First Select *Tetrahedral Mesh* in the drop down menu. Then click on the *o* icon to the right of the *Mesh* input field. This will bring up an input dialog. Select the "Assets" tab, and double click the item name *heart_mesh*.

  As you can see the `GeometryFilter` component can be used for meshes in the scene or just assets of the project.

- Now we will set the shapes that are being used for simulation and visualization.

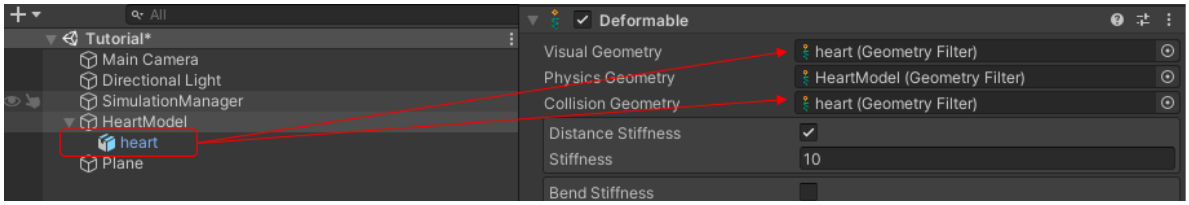
  The `Deformable` uses three different geometries

  – *Visual Geometry* is the geometry that is being shown on the screen, this is usually some textured mesh

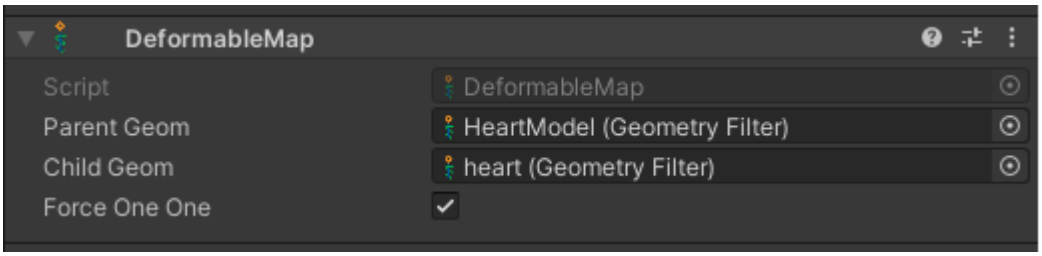
- *Physics Geometry* is the geometry that is being used in the simulation
- *Collision Geometry* is the geometry that is being used to determine collisions with other objects.

The tetrahedral mesh that was set up in the previous step will be used for the *Physics Geometry*; the other mesh from earlier will be used for the two other geometries.

First Drag the `Geometry Filter` that you just created into the *Physics Geometry* of the `Deformable` component. Then drag the *heart* GameObject from the hierarchy view to both the *Visual Geometry* and the *Collision Geometry* fields.



As we used different geometries for visualization and simulation we need a way to keep those in the same state, this is the responsibility of the `GeometryMap` component. Add one and drag the *HeartModel* Gameobject into the *Parent Geom* slot. Then drag the *heart* GameObject into the *Child Geom* slot. Additionally make sure the *Force One One* is checked.



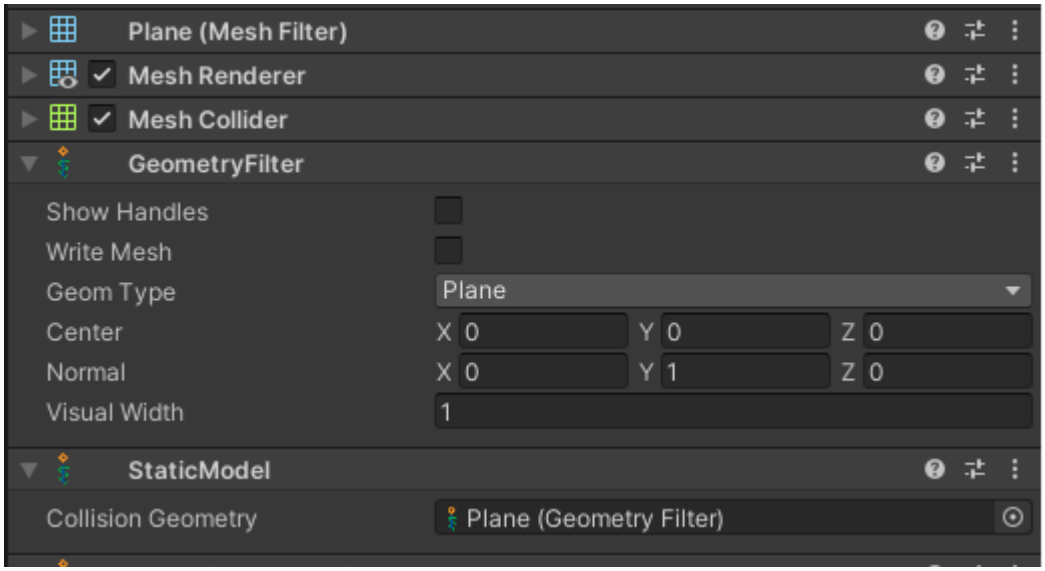
This concludes the setup for the `Deformable` object.

You should be able to run the scene now but as there are no other objects to interact with the heart will just succumb to gravity and drop on the ground.

- Let's add a plane for collisions

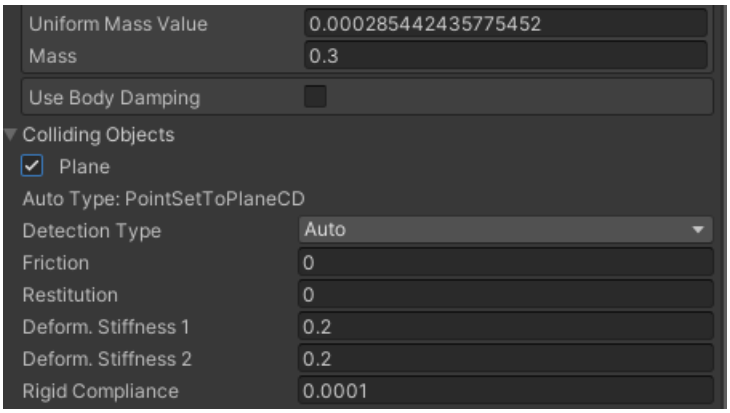
  Instead of meshes we will use a fixed shape for the other side of the collision. In the hierarchy view add a Plane and move it to a position of 0.0, -2.5, and 0.0. Add a `Geometry Filter` to the plane object and select *Plane* in the drop down menu. The default settings for the plane will work, its position and normal will be calculated from the transform. Even though the visual mesh of the plan is finite in the editor, with regards to iMSTK this plane is infinite.

  To enable the plane to interact with other iMSTK objects we need to set up a model for it as well. Add a `StaticModel` component to the *Plane* object and drag the `GeometryFilter` component into the *Collision Geometry* field. A `StaticModel` represents an object that participates in collision but doesn't react.

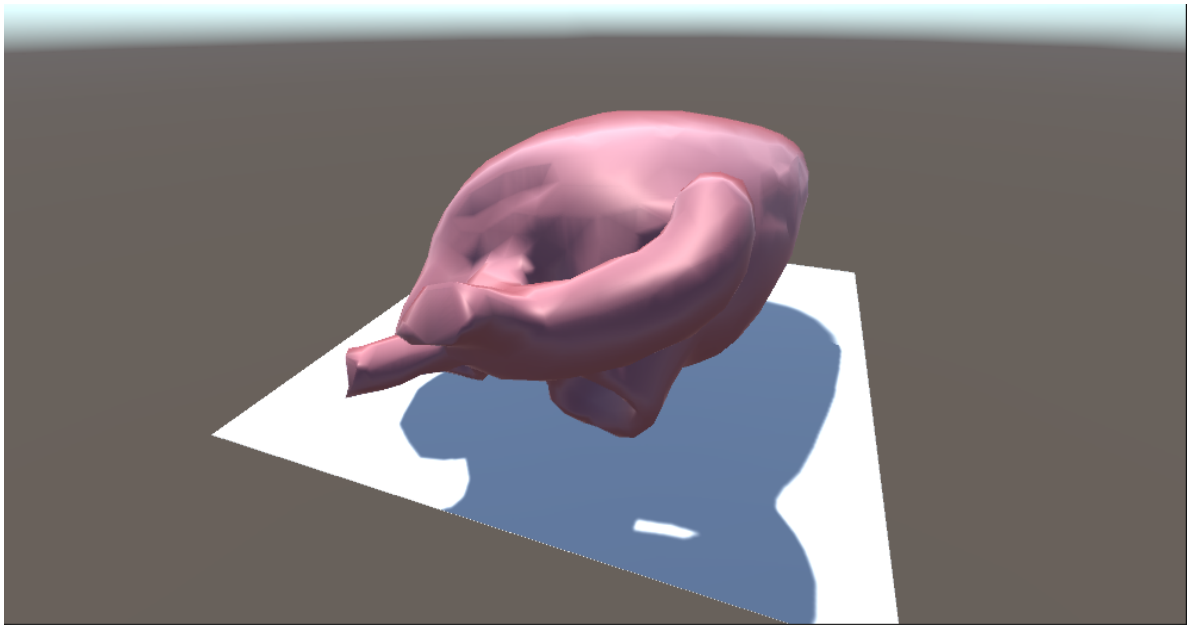


- Add the interaction between the Heart and the Plane

  iMSTK needs to know about which objects can interact with each other, in this case we want the heart and the plane to collide with each other. Click on the left pointing arrow at the bottom of the `Deformable` component to expand the *Collision* section. Here you will always see a list of all the objects that can be collided with, click on the checkbox next to "Plane" to enable the collision between the heart and the plane. In almost all cases you should be able to leave the other parameters at their default values.



- This concludes the tutorial scene setup, press play you should see the deformable object hit the plane and bounce slightly on it.



Please note that at the moment iMSTK-Unity is very sensitive to misconfigurations and may cause Unity to crash, we are working to improve the error handling and stability both on the Unity asset side and inside the iMSTK sources.

5 Example Scenes

5.1 ConnectiveTissue

Demonstrates the connective tissue attached to two deformable objects

5.2 Constraining

Shows various ways of how to constrain deformables to each other and to the surrounding space

5.3 PbdClothCollision

A scene with a freely moving deformable item (Cloth) that demonstrates how to set up a deformable (`PBDCloth`) with and various static obstacles.

5.4 PbdClothScene

A cloth constrained on the top that demonstrates how to set up boundary conditions on a `PbdObject`

5.5 PbdThread

This demonstrates a line mesh that can be used as a thread

5.6 RigidBodyScene

This is a simple example of two rigid spheres colliding with each other and the scenery. Uses geometric shapes rather than meshes, static colliders and collisions between dynamic objects

5.7 UnityController

Demonstrates how to control an iMSTK Rigid via a RigidController and a Unity transform. The syringe in the scene can be moved around via the keys, the `UnityDrivenDevice` takes the position and orientation of the object its assigned to and sends it to iMSTK. The object will collide with the cube in the scene. If you want to control and object in iMSTK via VR controllers this is the path to take.

5.8 Tutorial

A scene that is used in the tutorial. It uses a deformable model colliding with a plane

5.9 Devices

The scenes in the devices folder can only be used with VRPN or OpenHaptics built. You will have to build iMSTK and install it into the asset as described in *Setup for Development* to support these features. You can check for the supported devices in the installation that you have by opening the `Edit/ProjectSettings/Player` panel in the editor and navigating to the section `Script Compilation`. Any Devices that are built into your iMSTK installation will show up here as *IMSTK_USE_<Device>*. iMSTK-Unity will have code that is optionally enabled when one or more of the symbols in this panel is defined.

Grasping

This scene demonstrates how to use the `SimpleGrasping` component together with the `GraspingManager` to enable the grasping of different objects.

RigidController

This sets up a `OpenHapticsDevice` with a `Rigid` and a `RigidController` to show how these pieces are interactive

RigidControllerVRPN

Uses the `VRPNDevice` in the same scene as the *RigidController*

TissueContact and PbdThinTissueContact

Demonstrates the use of a rigid with haptics interacting with two kinds of simulated tissue

6 Usage

For minimal usage of iMSTK-Unity, two things must be added to a Unity Scene.

- A `GameObject` with a `SimulationManager` attached to it
- A `GameObject` with either a `Deformable` or a `Rigid`.

Commonly a PhysicsGeometry is also needed on the Model `GameObject`.

This document will denote some of the basic classes available in iMSTK-Unity. For more information refer to the the source code documentation and the iMSTK documentation.

7 Component Structure

While the iMSTK C# wrapper supports almost all iMSTK classes. There is a subset that is made available as Unity components. These can be assembled in the editor to create simulations using iMSTK inside of Unity. The following section describes the roles and responsibilities of the available iMSTK-Unity classes.

While most components can be enabled and disabled in the Editor this will only be effective during the editing process. Disabled components will not be used for simulation. _BUT_ enabling or disabling a component during runtime will not affect the simulation and may cause issues. We also have made efforts to check for disabled components in other components that depend on them. If you find any combinations that do not work correctly please let us know.

7.1 Infrastructure

`SimulationManager`

This is a component responsible for controlling the simulation. There may only exist one. It also controls the construction, initialization, and destruction of `iMSTKBehaviour` to ensure execution ordering:

- Simulation Manager created
- iMSTK objects created and internally initialized
- iMSTK objects externally initialized
- `SimulationManager` Start
- Updates
- iMSTK objects cleaned up
- `SimulationManager` cleaned up.

This component is required to be in the scene for simulations to run. It is created before any other iMSTK components on any `GameObject`. It implements the start, stop, pause, and other global scene related tasks.

iMSTKBehaviour

An extension of MonoBehaviour to provide different callbacks for special construction, initialization, and destruction ordering. This is the base class for most iMSTK components. If you are creating a new component that needs to be initialized by the `SimulationManager` it should inherit from this class.

7.2 Models

The following classes are the building blocks of any simulation scene, these are the things that interact with each other and the world.

Deformable

Use this to represent deformable objects. Position Based Dynamics (PBD), is used to model the deformation. This model supports Lines (1D), Surface Meshes (2D) and, Tetrahedral Meshes (3D) dynamical models see the iMSTK Documentation for more information on constraints and models. Visual, physics and collision geometry can be assigned separately. If you do, a separate map will be necessary to update the various meshes.

The physics geometry determines the type of constraint that can be used, an invalid constraint may cause problems.

Table 1: Valid Constraint Combinations

Physics Geometry Type	Valid Constraints
Line Mesh (Threads)	Distance Stiffness, Bend Stiffness
Surface Mesh (Membranes, Bags)	Distance Stiffness, Dihedral Stiffness, Area Stiffness
Volumentric Mesh (Tissue)	Distance Stiffness, Volume Stiffness, Fem (all models)

Rigid

Use this to represent movable rigid object use this to represent movable rigid objects like forceps or scalpels. Physics and collision geometry can be assigned separately. Implements a rigid body using position based dynamics from imstk. Please note there are two ways rigids will be used in the simulation, one is as free rigid bodies like a needle or staples. The other is as tools that are driven via a controller through a device. Currently free rigids cannot be transformed through a unity parent transform.

StaticModel

Use this to represent un-moveable rigid objects like the ground plane or other obstacles.

7.3 Model Support

When creating a model you will need to assign a geometry to it. And possibly a geometry map as well.

GeometryFilter

Similar to a MeshFilter in Unity. It provides an input and output geometry. It may take in any iMSTK geometry, as well as a Unity Mesh (one can also drag/drop a MeshFilter to it). These are instances of geometries used in all of iMSTK unity scripts. Instances of this class fit into the `Visual Geometry`, `Physics Geometry`, and `Collision Geometry` slots on the model components.

GeometryMap

Allows the use of separate meshes for the deformable, visual and collision representation. Will move the vertices of the target mesh according to matching points on the source mesh The points do not have to completely coincide. In almost all cases you will need to map FROM the physics mesh TO the visual mesh, and FROM the physics mesh TO the collision mesh.

7.4 Supporting Classes

The following classes are used to your simulation development and provide additional functionality. This is not an exhaustive list, please check the source code for more information.

ConstrainDeformables

This will set up a set of distance constraints between two deformable objects. The constraints will be limited to the area encompassed by the assigned mesh,. constraints will be generated for _all_ pairs of points whose distance is smaller than or equal the cutoff distance. The length of the constraint will be set to the original distance * restLength. Use this if you want to attach a deformable to another deformable. E.g. a vessel to another organ.

ConstrainInSpace

This will set up a set of distance constraints between the points of deformable that are found inside the constrained area and virtual points, effectively attaching the deformable to those points in space. The constraints will be limited to the area encompassed by the assigned mesh constraints will be generated for _all_ points. The length of the constraint will be set to `restLength`. Use this if you want to attach a deformable to a point in space. E.g. Suspend an organ in the body cavity.

ConnectiveTissue

This component represents connective tissue as a multitude of strands between opposing surfaces. Given two opposing geometries strands will be generated with configurable parameters. The generated object is physical and can be interacted with. The connective tissue will consist of multiple "strands" each going from one of the reference objects to the other. Each strand will be made up of a given number of segments. The amount of strands is roughly the number of faces on one bounding object * `segmentsPerFace`. Note that increasing the density and/or the number of segments per strand will also increase the computational load to simulate this object.

RigidController

Object used between a device handled by the user and a Rigid. It utilizes a mass spring system to correct for latency in the system. It corrects for problems with haptics in simulation systems. By manipulating the spring parameters the haptic response can be tuned to the behavior of the computer and the simulated system.

7.5 Collisions

While you can set up a collision using the CollisionInteraction class it is easier to use the Collisions panel that is situated in both of the Deformable and Rigid components. This panel will allow you to set up collisions between the object and the world, as well as other objects. CollisionInteraction class is used to set up collisions between two objects.

CollisionInteraction

Use this behavior to set up collisions between two objects, in general this behavior can detect what the type of the two objects is that are interacting (mode *Auto*). But you can also select the algorithm that should be used.

7.6 Grasping

Grasping is handled via the Grasping component. But in almost all cases it will be easier to utilize the GraspingManager as it will handle the creation and destruction of the Grasping component for you. If you have tools that you want to manipulate you can also investigate the GraspingController it can play hand in hand with the above components but also deals with animating tool jaws for example.

Importers

iMSTK-Unity provides a custom Unity importer to import geometry using iMSTK. This can import point, line, surface, tetrahedral, & hexahedral meshes (vtk, vtu, stl, ply, veg, ...). If the mesh imported is a point, line, or surface mesh then it will be imported as a Unity Mesh object. Anything else not supported by Unity, is loaded as an iMSTK-Unity Geometry Object. When a volumetric mesh (such as a tetrahedral mesh) is imported the accompanying surface is extracted and provided as an additional asset.

Editor Scripts

iMSTK-Unity provides extensions to the Unity editor. These extensions include:

- Custom inspectors for the models and geometry components.
- A global settings menu.
- Menu Items for quick creation of GameObject with iMSTK items already setup.
- Editors/windows for various operations

7.7 Devices

`OpenHapticsDevice`

This device is only available with a custom build of iMSTK. It enables the use of the 3DSystems haptic device family.

`VrpnDevice`

This device is only available with a custom build if iMSTK. It enables interactions with devices run by a VRPN server.

7.8 Other

`SimulationStats`

This component can be used to display timing information on the game screen, this is aside the data that is pushed to the profiler. The data shown is the `Update()` rate, the avg. time used to run 1 physics update *simulationManager->advance()* and information about mesh updates.

7.9 Classes removed in this version

- `RbdModel` has been removed, use `Rigid` instead.
- `PbdModel` has been removed, use `Deformable` instead.
- `PbdRigidGraspingInteraction` has been removed, use `Grasping` instead.

8 Releases

2023-oct v2.0

- iMSTK Version 7.0
- Unity 2021.3
- Refactored PbdObject to *Deformable* and *Rigid*
- Added Collision Editing to *Deformable* and *Rigid*
- Decoupled Simulation manager from Unity fixed update
- Enhanced Support for Grasping w/ Unity Editors
- Support for anisotropic deformables
- Support for constraining deformables through Unity meshes
- Support for suturing
- Better handling of disabled components
- Various Bug fixes

2022-jul v1.0 First release (amongst others):

- iMSTK Version 6.0
- Support to import VTK and other mesh formats (e.g. vtk, vtu, stl, ply, veg, ...)

- Deformable & Rigid Body Models to be used in Unity
- Custom Editors for iMSTK Behaviors
- Helper Scripts to create simple dynamic objects

9 Apache License

Version 2.0

Date January 2004

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10 Other Resources

- iMSTK Discourse Forum
- iMSTK-Unity Gitlab
- iMSTK Documentation
- iMSTK Gitlab