Building Augmented Reality Spatial Music Compositions for iOS

A Guide for Use of AR Positional Tracking

v 2.1 (Updated 14 June 2022)

Introduction and Terms

This document outlines the procedures to develop and release immersive spatial audio applications for iOS and Android devices using AR positional tracking. Guidance to build similar spatial audio applications using GPS positional tracking, and GPS-based audio positioning, on iOS and Android can be found in a separate, similar document on the tcwav.com website.

- AR Positional Tracking: Used in this guide to refer to the practice of tracking a user's position and orientation in an environment at a scale granular and accurate enough to simulate real-world sound source positioning. Apple uses an approach called visual inertial odometry to do this. In plain language, visual inertial odometry means using a combination of the camera and sensors in your iOS or Android device to accomplish positional tracking.

For a more comprehensive look at immersive audio formats and terminology, see "Compositional Possibilities of New Interactive and Immersive Digital Formats" by Daniel Dehaan.

Spatial Audio Positioning

There's a ton of research online about digital audio spatialization, and several software implementations that integrate nicely with Unity—RealSpace3D Audio, Oculus Spatializer, Resonance Audio (Google), and more. This doesn't account for third-party tools, like FMOD and WWise. In this guide, we will use the Resonance Audio. It is effective, highly customizable, reliable, and easy to implement.

We'd encourage anyone to do additional audio research for advanced spatial implementation and understanding. One topic to start with is binaural processing and recording—to drastically simplify, a method of recording and playing audio that simulates our ears. Another is multi-mic recording and spatialization—a good example was demonstrated by Shaun Crook on the 4DSOUND system in Amsterdam in 2014. Shaun used 16 microphones spaced throughout a room to record footsteps walking and ping pong balls bouncing, then later mapped each microphone's recording to a similar position in space for playback. You could hear the balls and steps moving as if they were there, creating a simulation of an entire room.

There are many places to look for inspiration and to credit here—Google, for building nice Resonance Audio documentation; partners at the 4DSOUND Hack Lab in 2014

(particularly Peter Kirn and the 4DSOUND Team) for some of the compositional concepts; and the groups BLUEBRAIN, Matmos and other for releasing previous absolute positioning audio applications.

Now, to building:

Software and Costs

You will need several pieces of software and hardware to develop and publish functioning AR application or iOS. Additionally, there are fees to publish to the Apple App Store. Depending on the scale and intent (i.e. monetary) of your application, you should review all the Terms of Service to see if you should sign up for premium plans with some of these providers.

Overview:

- Unity Personal (Free) – this will be our primary environment for app creation.
    - You will need a version of Unity that supports Unity's ARFoundation, which allows you to build for both Apple's ARKit and Google's ARCore.
- Resonance Audio for Unity (Free/Optional) – audio spatializer for Resonance Audio
- To execute the build for iOS: a Mac (or an understanding friend with one).
    - Apple unfortunately limits iOS development to macOS, but you can develop on and export from PC and then borrow a Mac for a few hours. (You'll need about 5GB of space free, and a handy iOS device.)
    - Xcode for macOS (Free)
        - You'll need to ensure you have a version of Xcode that supports Apple's ARkit.
    - To publish to app store, an Apple Developer account ($99/year to publish apps)
- To easily distribute for Android: $25 fee for the Google Play store

Downloads and Initialization:

1. Download and install Unity from here. You only need "Unity Personal" for non-commercial purposes.
    a. Be absolutely sure during installation that you select the iOS and Android SDKs as part of the install.
2. If you choose to use Resonance Audio, you can download resources here: Resonance Audio
3. Download the Unity ARFoundation plugin if it wasn't in your install.
4. Consider phone emulators for testing. BlueStacks is wonderful for Android emulation.
5.

Beginning your Project

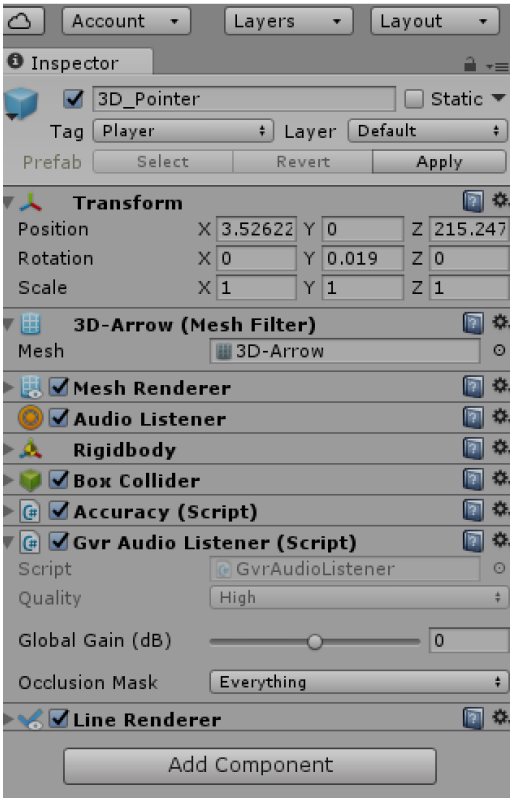
Open the ARFoundation demo scene with the cube. Recommend you re-title the scene, then title and save your project. Please note that, as we go, you will want to frequently save both your project and your scene.

Applying Resonance Audio Spatialization

To use Resonance Audio, import it into your project by going to Assets->Import Package->Custom Package and finding the downloaded package. Wait a moment and hit “Import.”

- Hit “Play” to compile a build and see if the import worked correctly.
- Also, set the application to use the Resonance Audio spatialized. Go to Edit->Project Settings->Audio and set the Spatializer plugin and Ambisonic Decoder plugin to Resonance Audio.

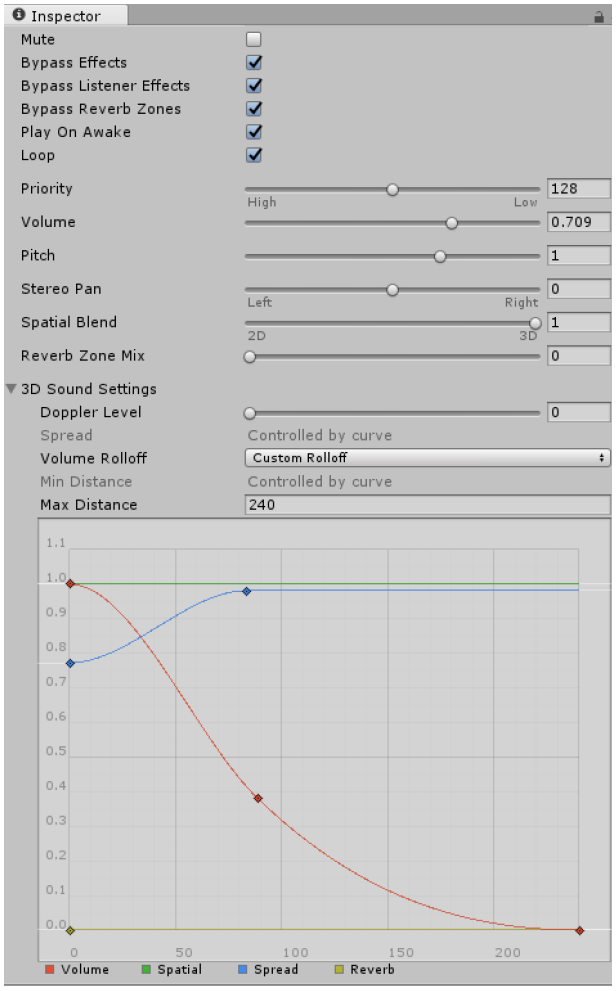
Now we can add the Resonance Audio plugins. First, go to the object “3D Pointer.” This pointer represents the user’s location, so it will be where we want our “listener” to be. In the inspector, hit “Add Component” and add Resonance Audio Listener. Leave the standard Audio Listener on.



Note: this picture shows an older version of the listener called “GVR Audio Listener”

We will now add our first audio object to the scene.

- GameObject->3D Object->Sphere.
- Import an audio file into your Unity project assets folder, then select it in “Audio Source” by hitting the small circle. You now have a sound object. (You can also use the “Resonance Audio Source” option for different controls. If you do this, uncheck the standard “Audio Source”).
    - It is a good practice to (by default) set your Audio Source rolloff to Linear versus Logarithmic, turn off Doppler (if you don’t like the sound of it, like us), and set the scale (size) of the sphere to a number two times the size of the max distance. Then you will be able to visually see the audio distance as you program.
        - Note: an audio source distance of 10 would correspond roughly to a sphere size of 20.
        - You can adjust rolloff patterns intuitively using the 3D Sound settings by setting the rolloff to “Custom Rolloff” or by clicking the rolloff graph to modify it (double-click to add points). Always ensure the tail end of your line or curve hits 0 before it reaches the right end of the graph--otherwise the object’s volume will never decrease to 0, no matter the distance.
- We also suggest you bypass effects and zones by default, then selectively reenable these options as you program for artistic effect. Ensure you “Spatialize” the effects at first.

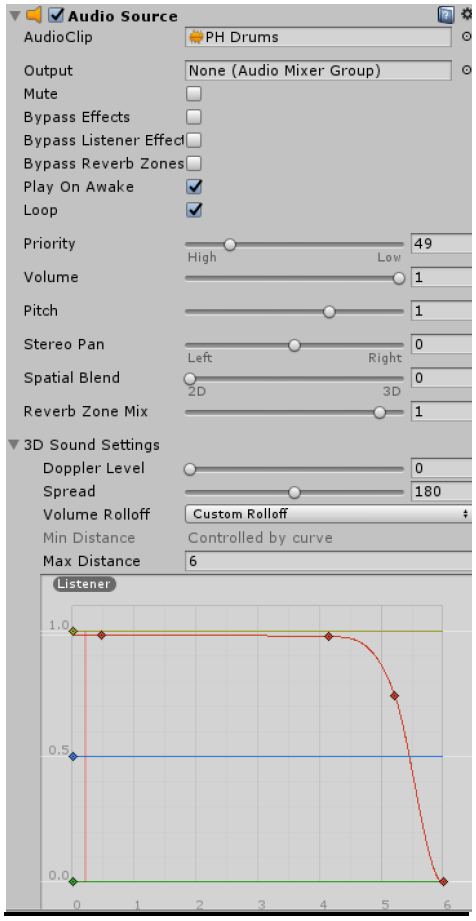


An example "Audio Source" with custom rolloffs.

- Add a color to the sphere for identification. Go to Assets-Create->Material. Change the color and drop it onto your sphere you just created in the Hierarchy pane. You may create many spheres, we strongly suggest using multiple colors to keep track.

Quick Notes on Audio Sources

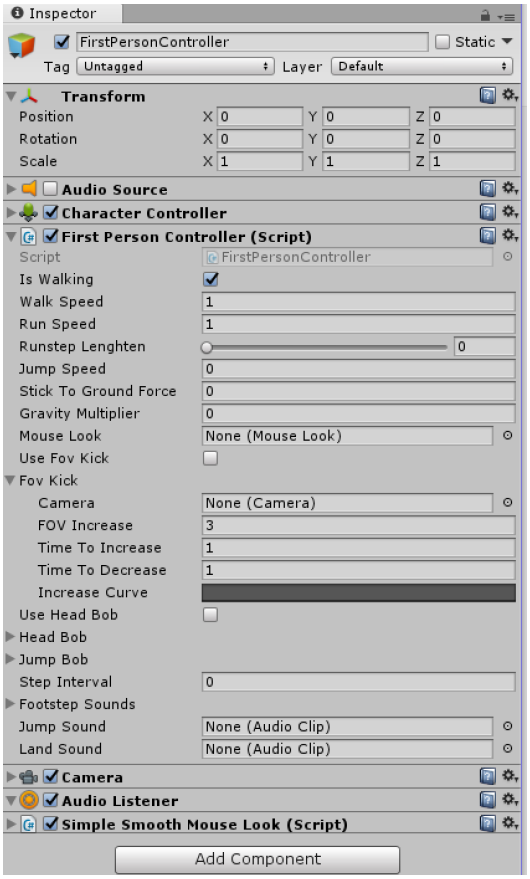
- A 2D spatial blend will eliminate much of the 3D sound positioning of the source
- A "180" spread (as pictured below) will make your sound sound less like it's coming from a center point source and more spread over the circumference of the sphere. This works very well for sound sources you'd like to remain equal in both ears no matter the orientation of the listener (like, perhaps, bass and drums). It can sound natural to increase the spread of a sound toward its center.



Input for Programming

Particularly on PC, developing and testing AR applications on iOS can be a cumbersome process. We recommend you instead add a first-person controller, third-person controller, and additional cameras to the scene. In this way, you can simulate walking through the environment on your computer from multiple vantage points.

- An excellent First-Person Controller can be found in the Asset Store. Navigate there and download “Standard Assets” by Unity. After installation, find the First Person Controller and add it to your scene. You can also add a mouse look script, as we have done here, and an Audio Listener.



- Remember that this controller will conflict with your AR controller. Make a note to yourself:
    - To use the First-Person Controller, ensure this object is ON and “Camera Parent” and “AR Camera Manager” are OFF.
    - For building to AR, turn OFF the First-Person Controller and turn ON “Camera Parent” and “AR Camera Manager.”

- Some Unity betas turn “Mobile Input” on by default. This option seems to override the ability to use arrow keys to navigate the space. You can turn it off from the top menu.

Your Spheres in Space

You now have spheres in an environment you can navigate, and you also know how to create sound objects. Now we will discuss positioning those sound objects spatially.

Positioning

- All you need to do is set the X, Y, and Z coordinates in the sphere's "Transform" component. Just adjust and experiment. Please note that sometimes your created spheres will inherit default values of approximately -625. We are unsure why this happens, but it's an easy fix—just reset them to 0.

Movement

You can use Unity Animations or use custom scripts to control your object movement.

There are tons of tutorials on the Internet, and you can use any knowledge of C# or Java to write your own. We recommend you begin with animations for simplicity. To get started with scripts, here is code for a new script that will oscillate a sphere back and forth between two points. Just select your sphere in Unity and go to Add Component->New Script->Create and Add (C#). Call it "TCWMoveOscillate" (or whatever you want, but then adjust the name in the script code later accordingly). Right click the script and select "Edit Script." Now, populate it with this code and hit "Save." Hit play in Unity and you will see a sphere begin to move. We have created several movement scripts and are happy to share—just reach out to us.

```
using UnityEngine;
using System.Collections;
public class TCWMoveOscillate : MonoBehaviour
{
	public Vector3 pointB;

	IEnumerator Start()
	{
		var pointA = transform.position;
		while (true) {
			yield return StartCoroutine(MoveObject(transform, pointA, pointB,
3.0f));
			yield return StartCoroutine(MoveObject(transform, pointB, pointA,
3.0f));
		}
	}

	IEnumerator MoveObject (Transform thisTransform, Vector3 startPos, Vector3 endPos,
float time)
	{
		var i = 0.0f;
		var rate = 1.0f / time;
		while (i < 1.0f) {
			i += Time.deltaTime * rate;
			thisTransform.position = Vector3.Lerp (startPos, endPos, i);
			yield return null;
		}
	}
}
```

Other Movement Patterns

You will find videos and descriptions of some movement patterns on our Concepts page, http://www.tcwav.com/concepts.html

Spatially Generative Music

One specific type of movement that really excites us, and needs more explanation than the concept video on tcwav.com, is spatially generative music. This randomizes the location of spheres within a set range. Imagine each sphere as a note or quick melody, and they pop up at random places around the listener. Perhaps the distance changes an effect, like their pitch. The listener will never hear the same sequence and spaces twice.

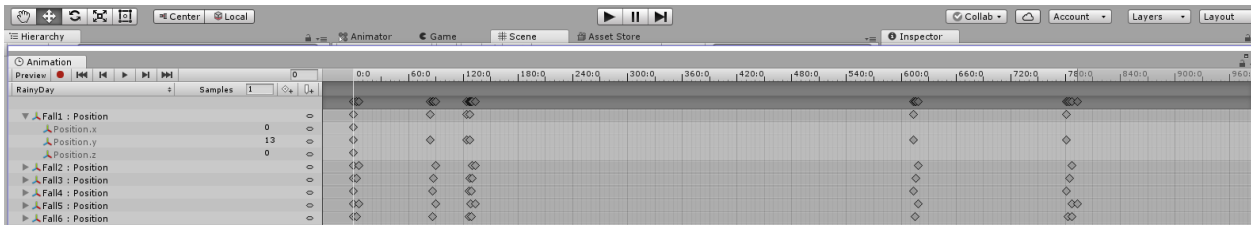
This code will randomize the position of a sphere across the X and Z planes. Adjust and/or it to multiple spheres to create spatially generative music.

```
using UnityEngine;
using System.Collections;

public class Random : MonoBehaviour
{

    private Vector3 _centre;
    public Vector3 Velocity = new Vector3(0, 0, 0);
    float x;
    float y;
    float z;
    public float speed = 5f;

    // Use this for initialization
    void Start()
    {
        _centre = transform.position;
        InvokeRepeating("LaunchProjectile", 2.0f, 2f);
    }

    // Update is called once per frame
    void Update()
    {
    }

    private void LaunchProjectile()
    {
        _centre += Velocity * Time.deltaTime;


        var offset = new Vector3(UnityEngine.Random.Range(-2, 2), y,
UnityEngine.Random.Range(-2, 2));

        transform.localPosition = _centre + offset;

    }
```

}

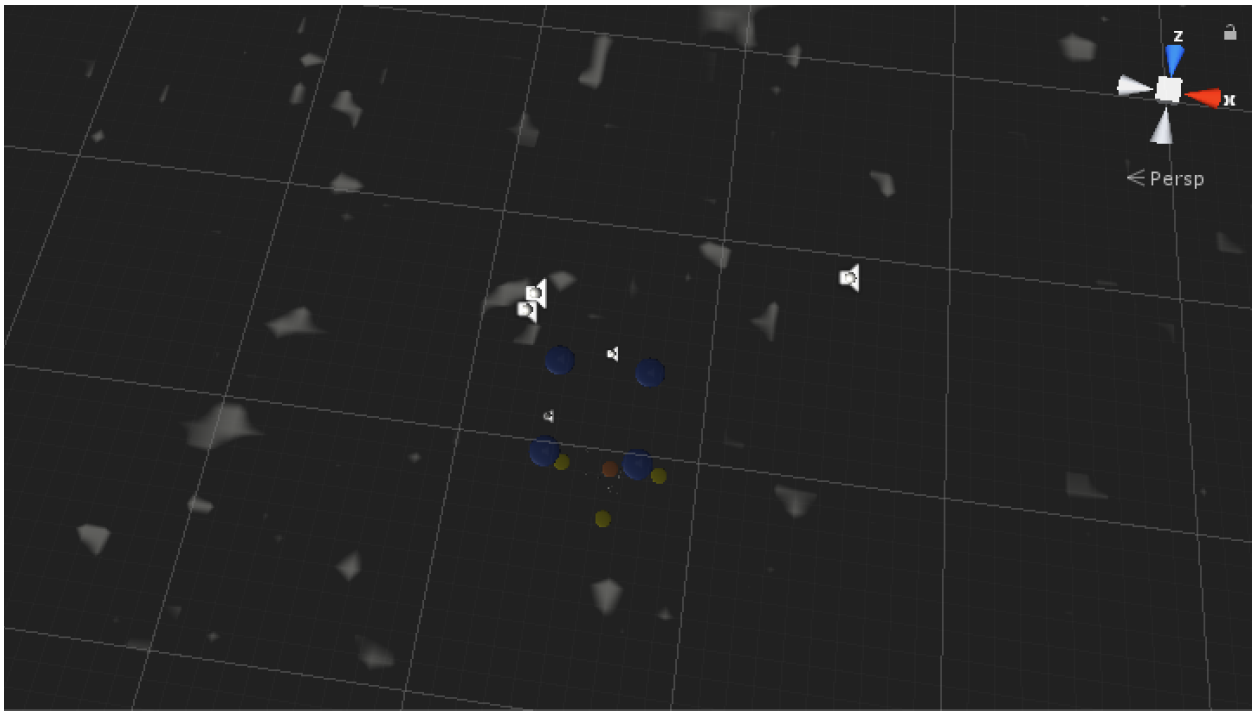
Rain

The rain functionality is detailed in a concept video. In short, we use Unity's animator to control the Y coordinates of grouped objects. In this way, they "drop" through the ground.



Unity's Animator window

Naturally, when rain hits the ground, it should stop. Fortunately, there are ways to alter the audio sounds when they "hit" the "ground"—so that either they quickly fade, distort, or anything else you'd want.



Raindrops (white) collide with our "ground," a giant rectangle.

Add a distortion filter and a lowpass filter to your raindrops, turn them off then add this script, "TCWCollision." This script will turn on the distortion filter and lowpass filter as

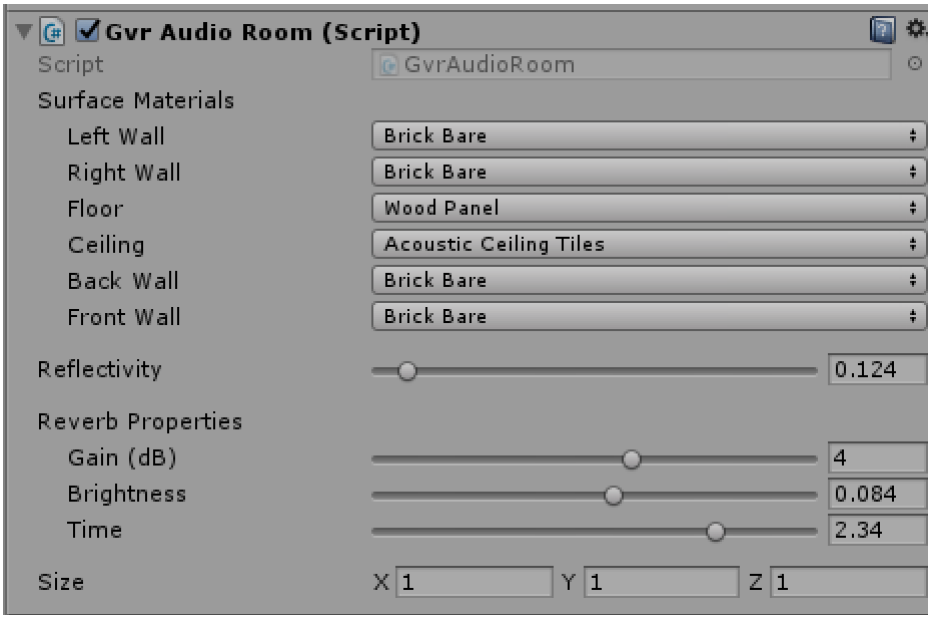
soon as a collision is detected. Ensure you have a “Box Collider” component on your giant rectangle, with “Is Trigger” checked, and a “Sphere Collider” on each raindrop (you don’t need “Is Trigger” checked here). This will ensure Unity is detecting the collisions for these objects.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class TCWCollision : MonoBehaviour {

    // Use this for initialization
    private AudioDistortionFilter myLight;
    private AudioLowPassFilter myLight2;


    void Start()
    {
        myLight = GetComponent<AudioDistortionFilter>();
        myLight2 = GetComponent<AudioLowPassFilter>();
    }


    void OnTriggerEnter(Collider other)
    {

        myLight.enabled = !myLight.enabled;
        myLight2.enabled = !myLight2.enabled;


    }

}
```

Audio Rooms

The Resonance Audio package also includes “Audio Rooms,” which virtually simulate rooms of different materials (wood panels, concrete, etc.) We found the reflectivity to be a bit much generally, and the implementation not perfect—but these rooms can certainly be implemented to interesting effect. They seem fairly resource-intensive.

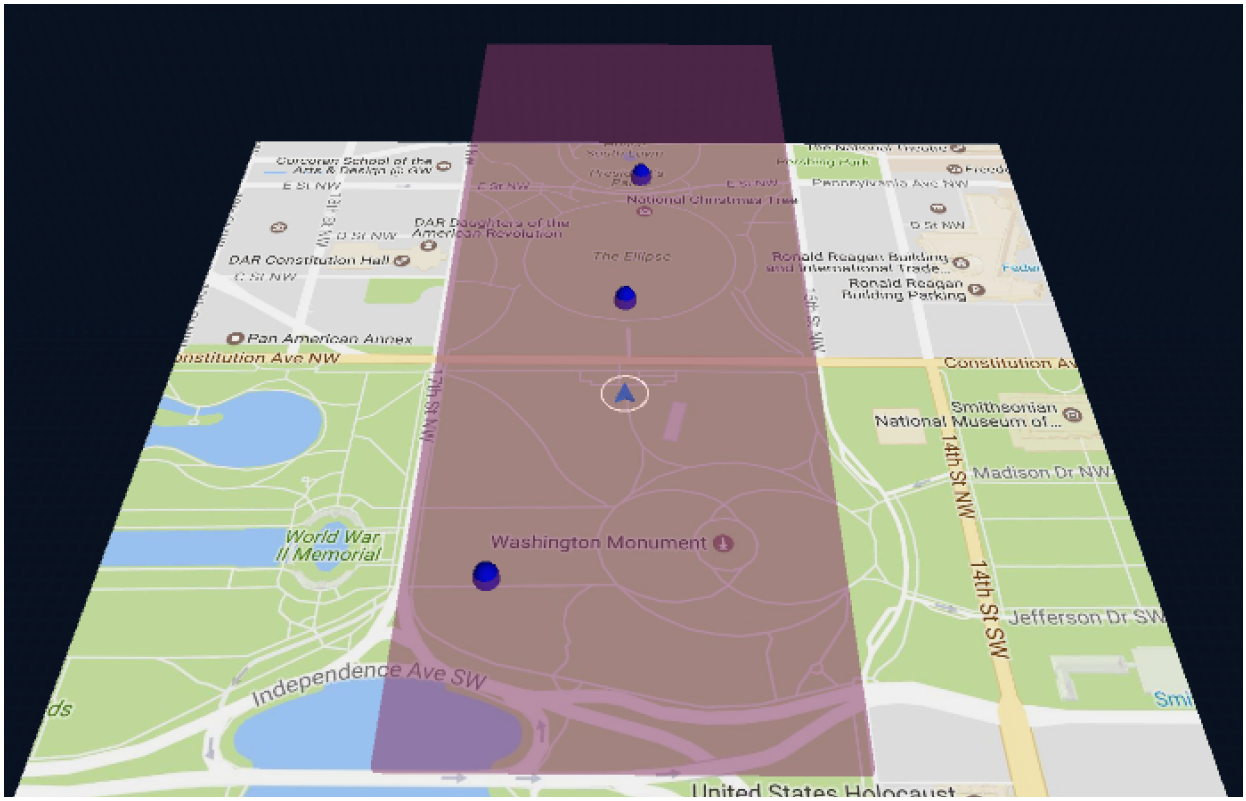
One practical use we implemented was to use the rooms to create a subtle reverb tail.



Here, you will see the reflectivity is down, but the time and gain on the reverb are fairly high.

This subtle reverb is great at masking sharp transitions or melding various sounds together. Here, we placed a room (purple) over the entire spatial range of our piece. This room can be made by creating a cube instead of a sphere and following the positioning methods described earlier. The spatially generative sounds, as described above, originally sounded too jarring when they suddenly moved mid-note. The reverb on this room smoothed the transitions out nicely.

- Ensure your other sounds all have “Bypass Room Effects” checked to avoid unwanted reverb. Only leave Room Effects enabled on the objects where you want the extra reverb.

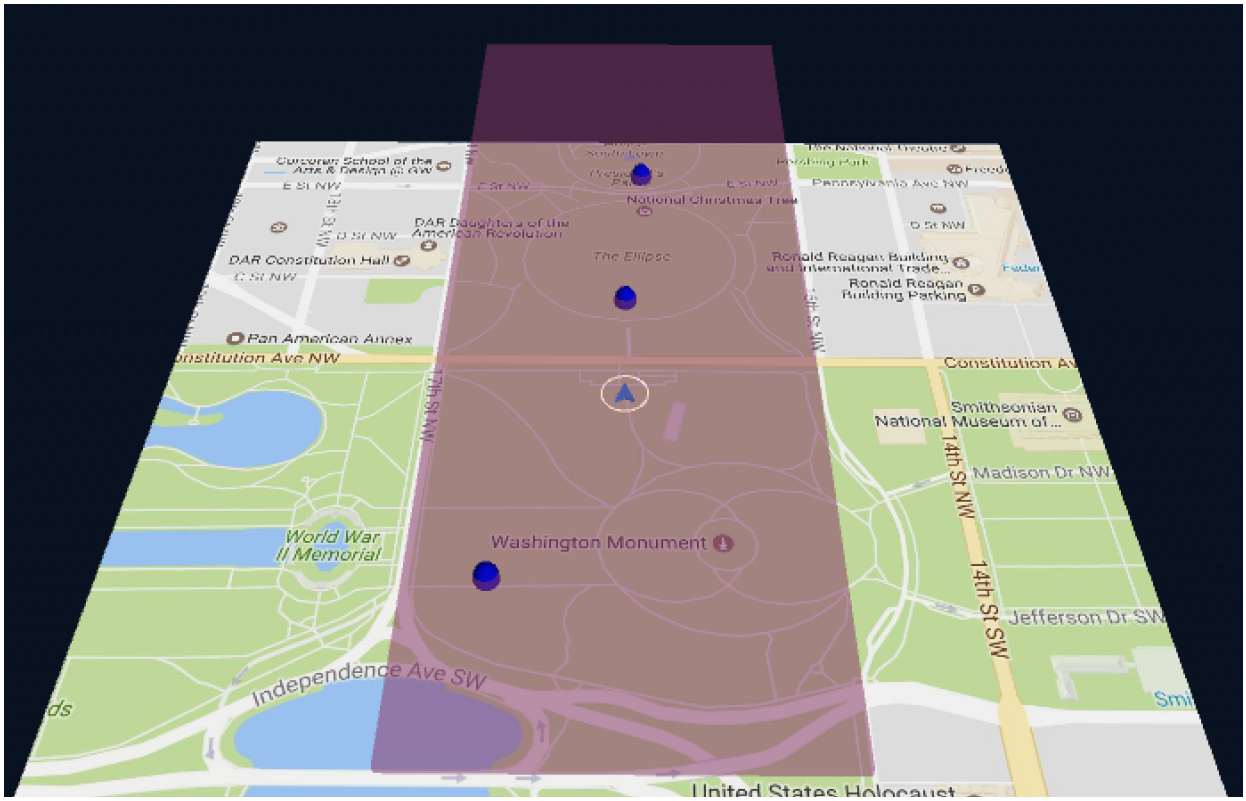


A large “room” of reverb

Reverb Zones

By default, Unity includes Chorus, Distortion, Reverb, EQ filters, and more. These are all fairly self-explanatory. It also includes “Reverb Zones,” which can be very effective for your compositions. Similar to the Resonance Audio Rooms described above, reverb zones are great at masking sharp transitions or melding various sounds together. Here, use the same rectangle we used for the Resonance Audio Room example. This room can be made by creating a cube instead of a sphere and following the positioning methods described earlier. The spatially generative sounds, as described above, originally sounded too jarring when they suddenly moved mid-note. The reverb zone on this rectangle smoothed the transitions out nicely.

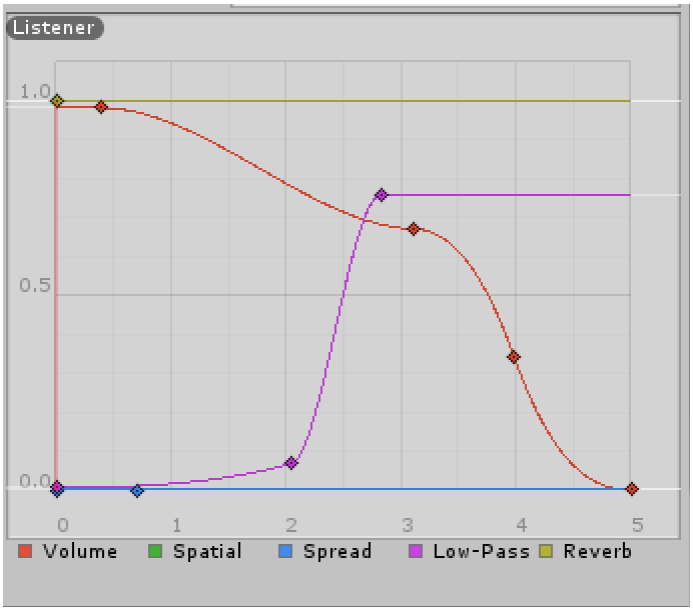
- Ensure your other sounds all have “Bypass Reverb Zones” checked to avoid unwanted reverb. Only leave Reverb Zones enabled on the objects where you want the extra reverb.
- Make sure you set the Min and Max distances appropriately for your objects. This is easily done by picking an extreme reverb, like “Arena,” and adjusting the settings during runtime through quick trial and error.



A reverb zone

Controlling All Audio Effects with Distance

Elsewhere in this guide, we've discussed how to adjust curves on audio sources to impact the amount of volume, spatial blend, spread, or reverb based on the distance between the object's center and the player. Unity allows these same curves to control its low-pass filter frequency if you add the low-pass effect.



However, if you want to control things like echo or distortion, or want to use entirely different object's distances to control audio, you need a different approach. We'll walk through an example. This is a bit more complex than above but opens up a whole world of creative possibilities.

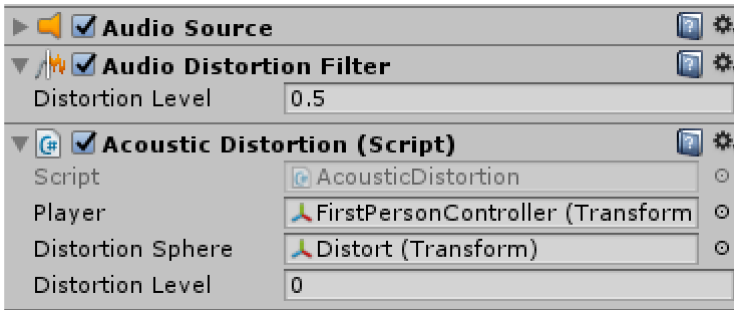
Create a sphere called "Distort" and place it at X=6, Y=0.2, Z=0. Create another sphere with a sound of Max Distance=5 and place it at X=0, Y=0, Z=0. We'll call this "Acoustic" for the acoustic guitar we used in our composition. We are going to modify the sound of "Acoustic" based on the distance between our player and the "Distort" sphere.

- Add the Audio Distortion Filter to "Acoustic."
- Create a new script called "AcousticDistortion" and add it to "Acoustic"
- Insert this code:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class AcousticDistortion : MonoBehaviour
{


    public Transform Player;
    public Transform DistortionSphere;
    public float distortionLevel;

    float distanceBetweenThem;
    // Use this for initialization
    void Start()
    {
        AudioDistortionFilter bob = gameObject.GetComponent<AudioDistortionFilter>();
```

```
    }

    void Update()
    {
        distanceBetweenThem = Vector3.Distance(Player.position,
DistortionSphere.position);


        if (Vector3.Distance(Player.position, DistortionSphere.position) < 6.2)
        {
            distortionLevel = 0;
            gameObject.GetComponent<AudioDistortionFilter>().distortionLevel = 0;

        }

        if (Vector3.Distance(Player.position, DistortionSphere.position) > 7.82)
        {
            distortionLevel = 0.79f;
            gameObject.GetComponent<AudioDistortionFilter>().distortionLevel = 0.79f;

        }


        //D
        else
        {
            gameObject.GetComponent<AudioDistortionFilter>().distortionLevel =
distanceBetweenThem / 2 - 3.055f;
            distortionLevel = (distanceBetweenThem / 2 - 3.055f);
        }

        Debug.Log("Distance between obj1 and obj2 is " + distanceBetweenThem);
    }
}
```

- In the inspector, ensure you assign “Distortion Sphere” to our object “Distort” and “Player” to our “FirstPersonController.” (Important: remember later to change this from “FirstPersonController” to our AR “Main Camera” for your final release or for testing.)



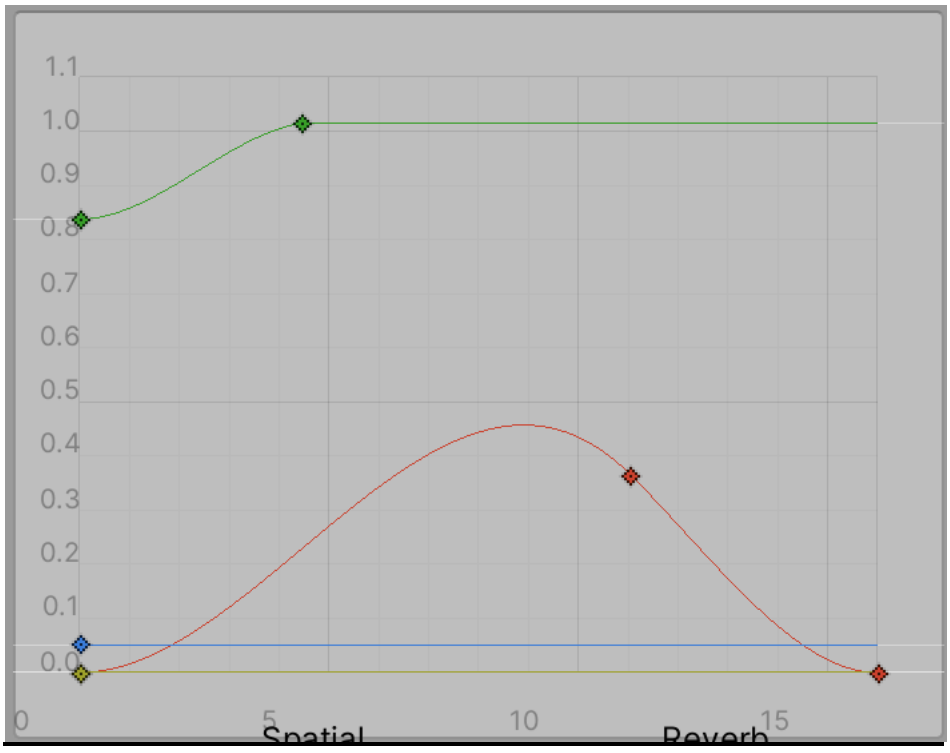
- You will see that this code calculates the distance between object “Player” and object “Distortion Sphere,” divides them by 2, and subtracts 3.055. This math is based on the distance we set between “Distortion” and “Acoustic” earlier.

    - The code also determines if the player is relatively close to the DistortionSphere and sets distortion to 0.
    - The code also determines if the player is relatively far from the DistortionSphere and caps distortion at .79, as the distortion gets unmusical between 0.8-1.0

As you test this code, you'll see that the half of our "Acoustic" sound closer to the "Distort" sphere remains undistorted. As you walk away from the "Distort" sphere, the distortion turns on, gradually increasing until it caps at .79. You can use this logic with any sound effect to build soundscapes that can vary dramatically based on user location or based on the movement of other objects. Some other handy effect code:

- When using reverb instead of distortion, adjust both:
    - `gameObject.GetComponent<AudioReverbFilter>().room`
    - `gameObject.GetComponent<AudioReverbFilter>().dryLevel`
- When using echo:
    - `gameObject.GetComponent<AudioEchoFilter>().wetMix`

Another great way to implement distance-based effects is to take a normal (clean) sound, insert it onto a sphere, and duplicate the sphere. Now, use your DAW or similar to add effects you want to the clean sound, and save the effected sound into Unity. Add it to the duplicated sphere, and set it so the volume rises or oscillates as the listener moves farther away. Now, the clean sound appears to become effected as the listener moves from it.



Additional Points

Here are some random notes that didn't fit elsewhere:

iOS development specifics:

- Starting from iOS 10, Apple requires you to set the 'NSLocationWhenInUseUsageDescription' field in an App's info.plist file when location services are used--same for Camera & Microphone. You can set it in the iOS Player Settings 'Location Usage Description,' 'Camera Usage Description,' etc. We just used the text "Camera required for audio spatialization" for the camera; when combining the AR with GPS, we do the same for "Location Usage Description." You should get warnings both when building the project in Unity & in Xcode if you are attempting to use location or camera services but this description is not set—however, sometimes you will not, and the app will simply not work correctly. Set it and save it early.

Android development specifics:

- We successfully built our app targeting OSes 4.4 (Kit Kat) and up with the default Unity audio spatialization.
- If you have conflicting Android Manifests (Standard, Daydream, and Cardboard)—you can likely standardize them using the text in "Android-Manifest Cardboard."

Contact/About TCW

We are a duo from Washington, DC. You can contact us at tcw@tcwav.com.

- If you need help or get stuck, please do not hesitate to ask us. This process can be frustrating, especially if you aren't familiar with Unity. Please also share your creations with us—we can't wait to see what you do.
- If you are interested in having us compose a spatial audio composition for your space, or know someone who may be interested, please reach out to us or let them know.
- We are also interested in collaborating on spatial compositions.

Learn on our website tcwav.com.