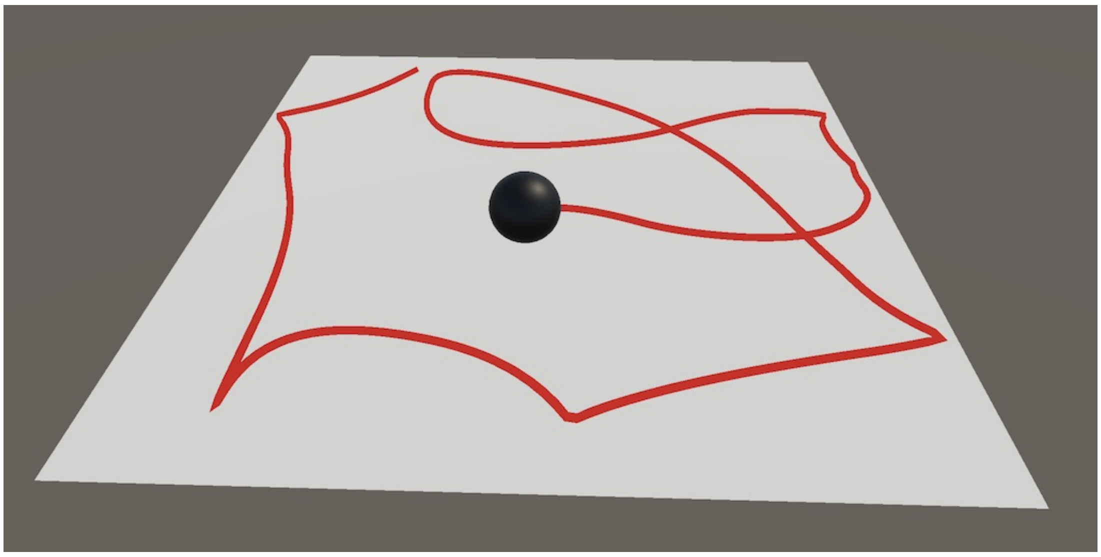
published 2019-10-25

Sliding a Sphere Player-Controlled Motion

Put a sphere with a trail on a plane.
Position the sphere based on player input.
Control velocity and acceleration.
Limit the sphere's position and make it bounce off edges.

This is the first installment of a tutorial series about controlling the movement of a character. Specifically, we'll slide a sphere based on player input.

This tutorial is made with Unity 2019.2.9f1. It assumes that you've gone through the Basics tutorials first.



A sphere stuck on a plane.

1 Controlling Position

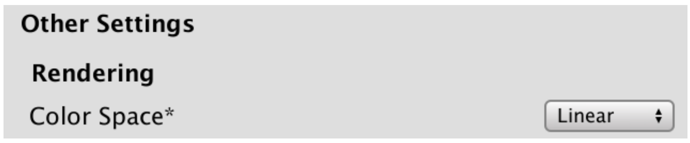
Many games are about a character that has to move around to accomplish some goal. The player's task is to guide the character. Action games give you direct control by steering the character, usually by pressing keys or turning a stick. Point-and-click games have you indicate a goal position and the character moves there automatically. Programming games make you write instructions that the character executes. And so on.

In this tutorial series we will focus on how to control a character in a 3D action game. We start simple, by sliding a sphere around on a small flat rectangle. Once we have a good grip on that we can make it more complex in the future.

1.1 Setting the Scene

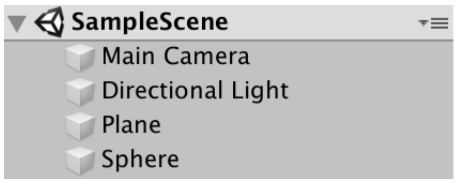
Start with a new default 3D project. We don't need anything from the package manager at this point, although you could use the render pipeline of your choice.

I always use linear color space, which you can configure in the project settings via *Edit / Project Settings / Player / Other Settings*.


Other Settings
Rendering
Color Space* Linear

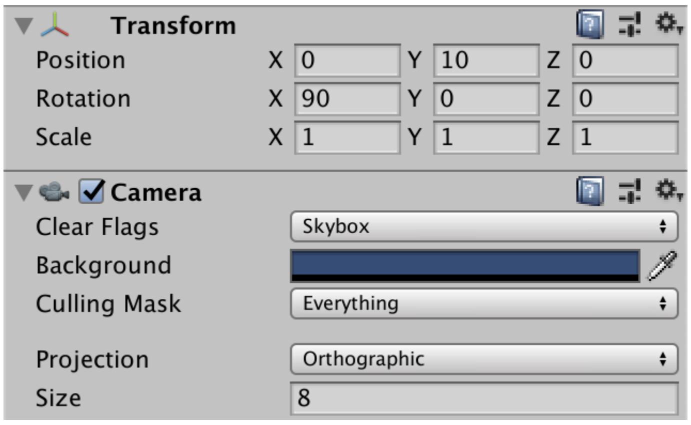
Linear color space.

The default *SampleScene* scene has a camera and a directional light, which we'll keep. Create a plane to represent the ground, plus a sphere, both positioned at the origin. The default sphere has a radius of 0.5, so set its Y coordinate to 0.5 to make it look like it sits on top of the ground plane.


SampleScene
Main Camera
Directional Light
Plane
Sphere

Scene hierarchy.

We're limiting ourselves to 2D movement on the ground, so let's position the camera above the plane looking down to get a good view of the play area in the game window. Also set its *Projection* mode to *Orthographic*. That gets rid of perspective, allowing us to see the 2D movement without distortion.



Transform

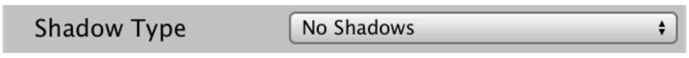
Position	X 0	Y 10	Z 0
Rotation	X 90	Y 0	Z 0
Scale	X 1	Y 1	Z 1

Camera

Clear Flags	Skybox
Background	
Culling Mask	Everything
Projection	Orthographic
Size	8

Orthographic camera looking down.

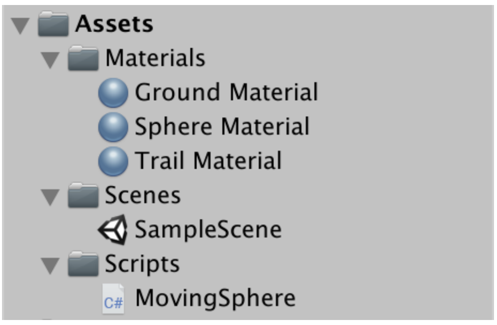
The only thing left that muddles our view is the sphere's shadow. Get rid of it by setting the light's *Shadow Type* to *None*, or *No Shadows* depending on the Unity version.



Shadow Type: No Shadows

Light casts no shadows.

Create materials for the ground and sphere and configure them as you like. I made the sphere black and the ground dull light gray. We'll also visualize the movement with a trail, so create a material for that as well. I'll use an unlit reddish material for it. Finally, we need a `MovingSphere` script to implement the movement.

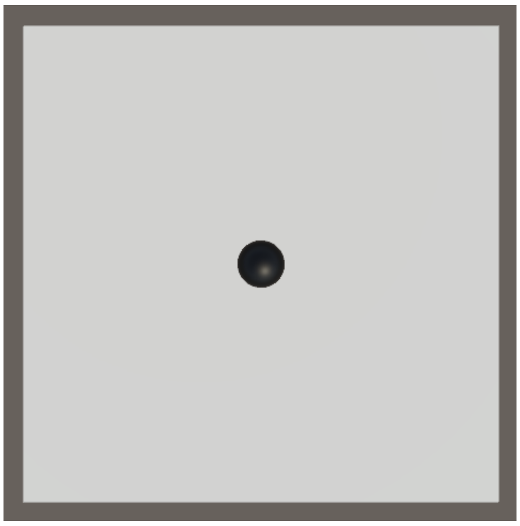


- Assets
  - Materials
    - Ground Material
    - Sphere Material
    - Trail Material
  - Scenes
    - SampleScene
  - Scripts
    - MovingSphere

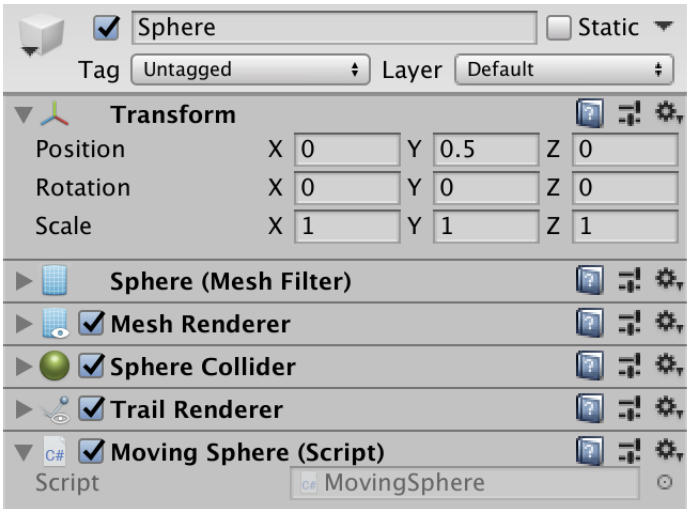
Project assets.

The script can start as an empty extension of `MonoBehaviour`.

```
using UnityEngine;

public class MovingSphere : MonoBehaviour { }
```


Game view.

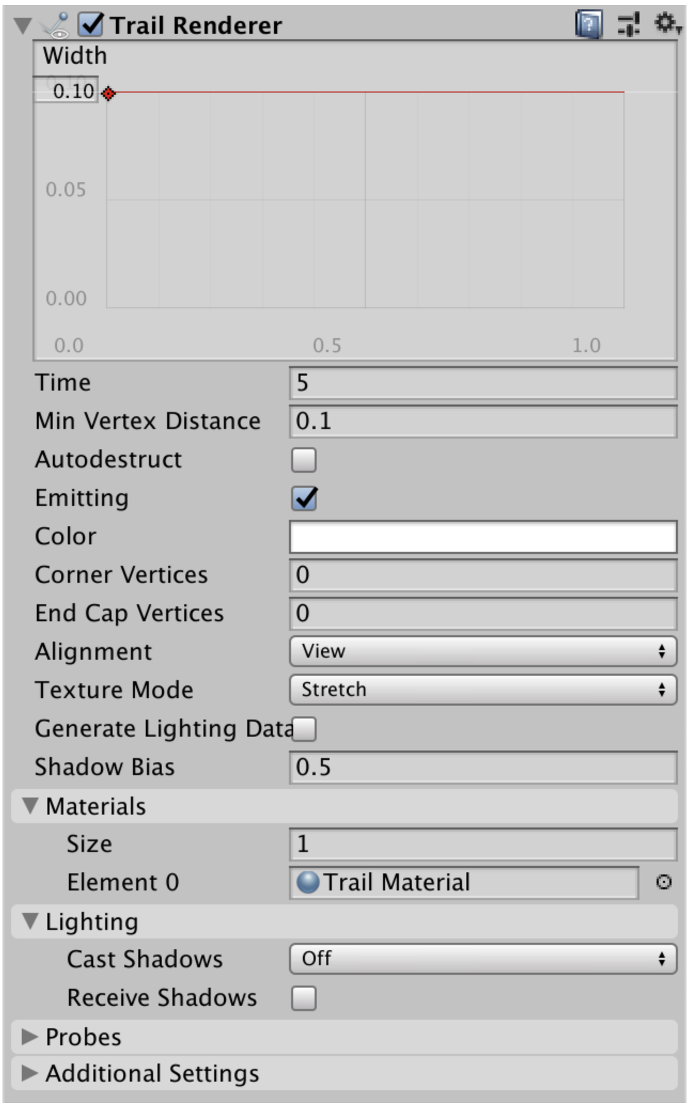
Add both a `TrailRenderer` and our `MovingSphere` component to the sphere. Leave everything else as it is.



```
☑ Sphere                         ☐ Static
Tag  Untagged          Layer  Default
▼ Transform
  Position      X 0      Y 0.5    Z 0
  Rotation      X 0      Y 0      Z 0
  Scale         X 1      Y 1      Z 1
▶ Sphere (Mesh Filter)
▶ ☑ Mesh Renderer
▶ ☑ Sphere Collider
▶ ☑ Trail Renderer
▼ ☑ Moving Sphere (Script)
  Script        MovingSphere
```

Sphere object with components.

Assign the trail material to the first and only element of the *Materials* array of the `TrailRenderer` component. It doesn't need to cast shadows, though that's not essential as we've disabled those anyway. Besides that, reduce the *Width* from 1.0 to a more reasonable value like 0.1, which will generate a thin line.



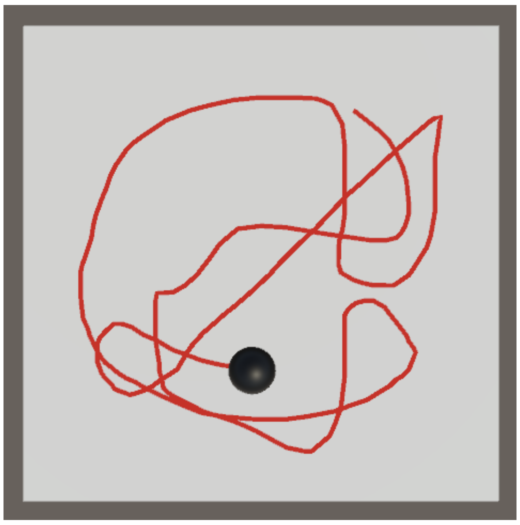
Trail Renderer

Width

Time	5
Min Vertex Distance	0.1
Autodestruct	☐
Emitting	✓
Color	
Corner Vertices	0
End Cap Vertices	0
Alignment	View
Texture Mode	Stretch
Generate Lighting Data	☐
Shadow Bias	0.5
Materials	
Size	1
Element 0	Trail Material
Lighting	
Cast Shadows	Off
Receive Shadows	☐
Probes	
Additional Settings	

Trail renderer.

Although we haven't coded any movement yet, we can get a preview of how it would look by entering play mode and moving the sphere around in the scene window.



Movement trail.

1.2 Reading Player Input

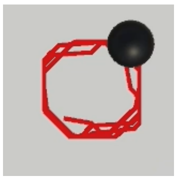
To move the sphere we have to read the player's input commands. We do this in the `Update` method of `MovingSphere`. The player input is 2D so we can store it in a `Vector2` variable. Initially we'll set both its X and Y components to zero, then use those to position the sphere in the XZ plane. Thus the input's Y component becomes the position's Z component. The Y position remains zero.

```
using UnityEngine;

public class MovingSphere : MonoBehaviour {

    void Update () {
        Vector2 playerInput;
        playerInput.x = 0f;
        playerInput.y = 0f;
        transform.localPosition = new Vector3(playerInput.x, 0.5f, playerInput.y);
    }
}
```

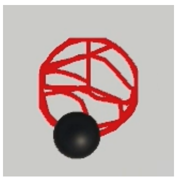
The simplest way to retrieve directional input from the player is by invoking `Input.GetAxis` with an axis name. Unity has both a *Horizontal* and *Vertical* input axis defined by default, which you can inspect in the *Input* section of the project settings. We'll use the horizontal value for X and the vertical value for Y.

```
        playerInput.x = Input.GetAxis("Horizontal");
        playerInput.y = Input.GetAxis("Vertical");
```

The default settings link these axes to the arrow and WASD keys. The input values are also tweaked so the keys behave somewhat like a controller stick. You could adjust these settings as you like, but I keep the default settings.


Using arrow or WASD keys.

Both axes also have a second definition, which link them to the input of a joystick or left controller stick. This allows for much smoother input, but I'll use the keys for all animations except the next one.


Using controller stick.

Why not use the *Input System* package?

You could do that, but the principle is the same. All we need is to retrieve two axis values. Also, at the time of this writing the package is still in preview, so not officially released and supported yet.

1.3 Normalizing the Input Vector

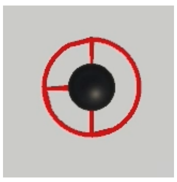
The axes return zero when they are at rest and -1 or 1 at their extremes. As we use the input to set the sphere's position it is constrained to a rectangle with the same range. At least, that's the case for key input because the keys are independent. In the case of a stick the dimensions are linked and we are usually constrained to a maximum distance of 1 from the origin in any direction, thus limiting the position to lie within a circle.

The advantage of the controller input is that the maximum length of the input vector is always 1, no matter the direction. So movement can be equally fast in all directions. This is not the case for keys, where the maximum is 1 for a single key but $\sqrt{2}$ when both keys are pressed, meaning that diagonal movement is the fastest.

The maximum for keys is $\sqrt{2}$ because of the Pythagorean theorem. The axis values define the lengths of two sides of a right triangle and the combined vector is the hypotenuse. Hence, the magnitude of the input vector is $\sqrt{x^2 + y^2}$.

We can make sure that the vector's length never exceeds 1 by dividing the input vector by its magnitude. The result is always unit-length vector, unless its initial length was zero in which case the result is undefined. This process is known as normalizing a vector. We can do this by invoking `Normalize` on the vector, which scales itself and becomes a zero vector if the result would be undefined.

```
		playerInput.x = Input.GetAxis("Horizontal");
		playerInput.y = Input.GetAxis("Vertical");
		playerInput.Normalize();
```


Normalized key input.

1.4 Constraining the Input Vector

Always normalizing the input vector limits the position to always lie on the circle, unless the input is neutral in which case we end up at the origin. The lines between the origin and the circle represent a single frame where the circle jumped from the center to the circle or back.

Such all-or-nothing input can be desirable, but let's make all positions inside the circle valid as well. We do that by only adjusting the input vector if its magnitude exceeds one. A convenient way to do this is by invoking the static `Vector2.ClampMagnitude` method instead of `Normalize`, with the vector and a maximum of 1 as arguments. The result is a vector that is either the same or scaled down to the provided maximum.

```
		~~//playerInput.Normalize();~~
		playerInput = Vector2.ClampMagnitude(playerInput, 1f);
```

Constrained key input.

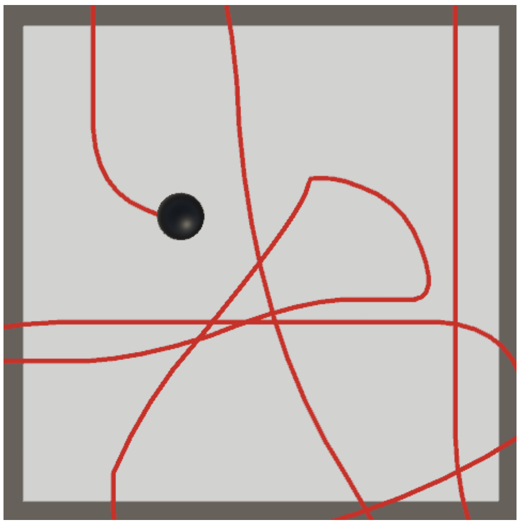
2 Controlling Velocity

What we've been doing so far is directly using the input to set the sphere's position. This means that when the input vector i changes the sphere's position p immediately changes to the same value. Hence $p = i$. This isn't proper motion, it's teleportation. A more natural way to control the sphere is to determine its next position p_1 by adding a displacement vector d to its old position p_0, so $p_1 = p_0 + d$.

2.1 Relative Movement

By using $d = i$ instead of $p = i$ we make the relationship between the input and position less direct. This removes the constrains on the position as it is now relative to itself instead of the origin after the first update. The position is thus described by an infinite iterative sequence $p_{n+1} = p_n + d$ with p_0 defined as the starting position.

```
		Vector3 displacement = new Vector3(playerInput.x, 0f, playerInput.y);
		transform.localPosition += displacement;
```



Relative movement.

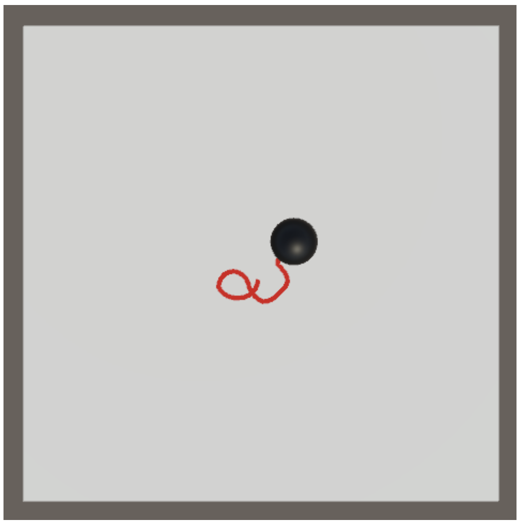
2.2 Velocity

Our sphere can indeed move anywhere, but it goes so fast that it's hard to control. It's a consequence of adding the input vector each update. The higher the frame rate the faster it goes. For consistent results we do not want the frame rate to affect our input. If we use a constant input then we want a constant displacement, regardless of the potentially fluctuating frame rate.

For our purposes a single frame represents a duration: how much time t passed between the start of the previous and the current frame, which we can access via `Time.deltaTime`. Our displacement is thus actually $d = it$ and we incorrectly assumed that t is constant.

The displacement is measured in Unity units, which are assumed to represent one meter. But we multiply the input by a duration, expressed in seconds. To arrive at meters the input must be measured in meter per second. Thus the input vector represents a velocity: $v = i$ and $d = vt$.

```
		Vector3 velocity = new Vector3(playerInput.x, 0f, playerInput.y);
		Vector3 displacement = velocity * Time.deltaTime;
		transform.localPosition += displacement;
```


Controlling velocity independent of frame rate.

2.3 Speed

Our maximum input vector has a magnitude of 1, which represents a velocity of one meter per second, which is equal to 3.6 kilometers per hour, about 2.24 miles per hour. That isn't very fast.

We can increase the maximum velocity by scaling the input vector. The scale factor represents a maximum speed, which is a velocity without direction. Add a `maxSpeed` field with a `SerializeField` attribute for it with a default of 10 and give it a `Range` attribute for something like 1–100.

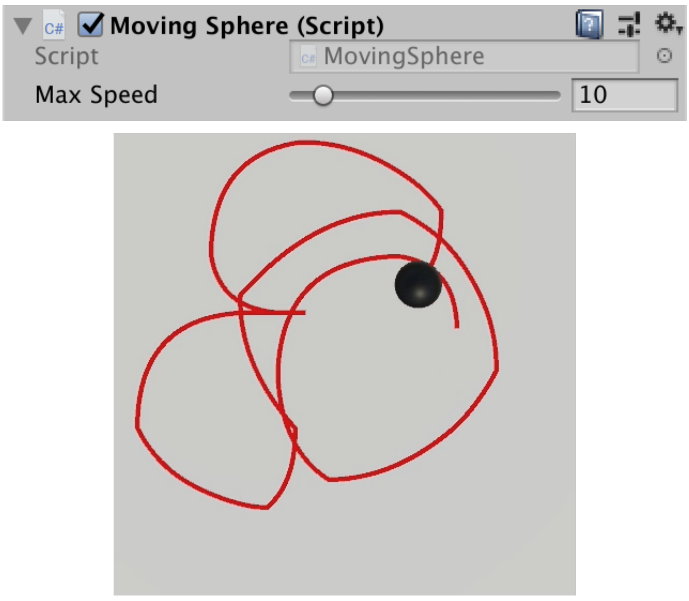
```
    [SerializeField, Range(0f, 100f)]
    float maxSpeed = 10f;
```

What does the `SerializeField` do?

It tells Unity to serialize the field, which means that it gets saved and exposed in the Unity editor, so it can be adjusted via the inspector. We could also make the field `public`, but this way the field remains shielded from code outside the `MovingSphere` class.

Multiply the input vector and max speed to find the desired velocity.

```
        Vector3 velocity =
            new Vector3(playerInput.x, 0f, playerInput.y) * maxSpeed;
```


Moving Sphere (Script)
Script MovingSphere
Max Speed 10

Max speed set to 10.

2.4 Acceleration

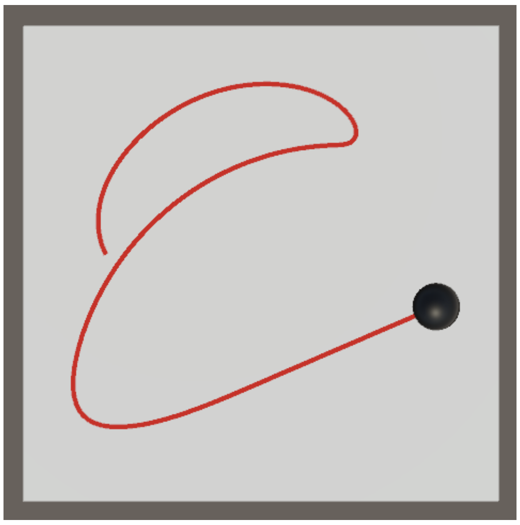
Because we have direct control over the velocity it can be changed instantaneously. Only the filtering applied by the input system slows down the change somewhat. In reality velocity cannot change immediately. A change requires some effort and time, just like changing a position does. The rate of change of a velocity is known as acceleration a, which leads to $v_{n+1} = v_n + at$ with v_0 being the zero vector. Deceleration is simply an acceleration opposite to the current velocity so doesn't require special treatment.

Let's see what happens if we use the input vector to control acceleration instead of velocity directly. This requires us to keep track of the current velocity, so store it in a field.

```
	Vector3 velocity;
```

The input vector now defines the acceleration in **`Update`**, but let's keep multiplying it with `maxSpeed` for now, temporarily reinterpreting it as max acceleration. Then add it to the velocity before calculating displacement.

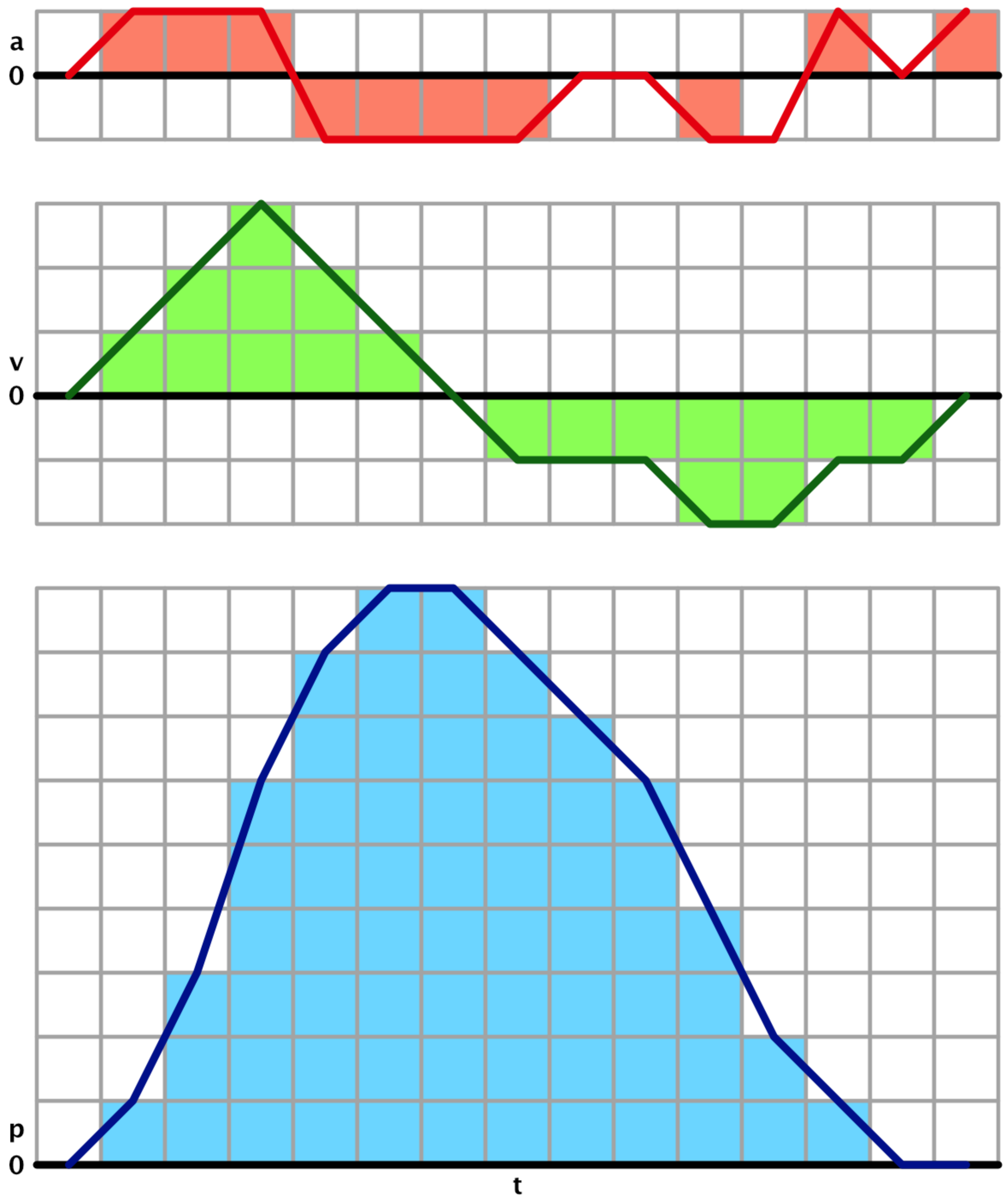
```
		Vector3 acceleration =
			new Vector3(playerInput.x, 0f, playerInput.y) * maxSpeed;
		velocity += acceleration * Time.deltaTime;
		Vector3 displacement = velocity * Time.deltaTime;
```



Smooth velocity change.

2.5 Desired Velocity

Controlling acceleration instead of velocity produces much smoother motion, but it also weakens our control over the sphere. It's like we're driving a car instead of walking. In most games a more direct control over velocity is required, so let's go back to that approach. However, the application of acceleration does produce smoother motion.



Acceleration changes velocity which in turn changes position.

We can combine both approaches by directly controlling a target velocity and applying acceleration to the actual velocity until it matches the desired one. We can then tune the responsiveness of the sphere by adjusting its maximum acceleration. Add a serializable field for that.

```
	[SerializeField, Range(0f, 100f)]
	float maxAcceleration = 10f;
```

In `Update` we now use the input vector to define a desired velocity and no longer adjust velocity the old way.

```
		Vector3 desiredVelocity =
			new Vector3(playerInput.x, 0f, playerInput.y) * maxSpeed;
		~~//velocity += acceleration * Time.deltaTime;~~
```

Instead, we first find the maximum speed change by multiplying the max acceleration with t. That's by how much we're able to change velocity this update.

```
		Vector3 desiredVelocity =
			new Vector3(playerInput.x, 0f, playerInput.y) * maxSpeed;
		float maxSpeedChange = maxAcceleration * Time.deltaTime;
```

Let's first consider only the X component of the velocity. If it's less than desired then add the maximum change.

```
		float maxSpeedChange = maxAcceleration * Time.deltaTime;
		if (velocity.x < desiredVelocity.x) {
			velocity.x += maxSpeedChange;
		}
```

That might cause an overshoot, which we can prevent by taking the minimum of the increased and desired value. There's a `Mathf.Min` method that we can use here.

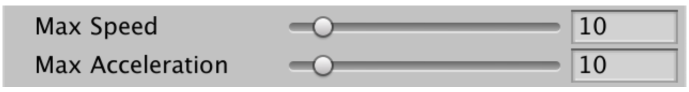
```
		if (velocity.x < desiredVelocity.x) {
			~~//velocity.x += maxSpeedChange;~~
			velocity.x =
				Mathf.Min(velocity.x + maxSpeedChange, desiredVelocity.x);
		}
```

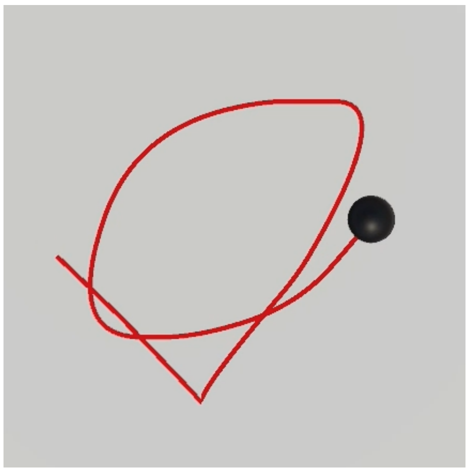
Alternatively, the velocity might be greater than desired. In that case we subtract the max change and take the maximum of that and the desired value, via `Mathf.Max`.

```
        if (velocity.x < desiredVelocity.x) {
            velocity.x =
                Mathf.Min(velocity.x + maxSpeedChange, desiredVelocity.x);
        }
        else if (velocity.x > desiredVelocity.x) {
            velocity.x =
                Mathf.Max(velocity.x - maxSpeedChange, desiredVelocity.x);
        }
```

We could also do all that via the convenient `Mathf.MoveTowards` method, passing it the current and desired values plus the maximum allowed change. Do that for both the X and Z components separately.

```
        float maxSpeedChange = maxAcceleration * Time.deltaTime;
        ~~//if (velocity.x < desiredVelocity.x) {~~
        ~~//  velocity.x =~~
        ~~//      Mathf.Min(velocity.x + maxSpeedChange, desiredVelocity.x);~~
        ~~//}~~
        ~~//else if (velocity.x > desiredVelocity.x) {~~
        ~~//  velocity.x =~~
        ~~//      Mathf.Max(velocity.x - maxSpeedChange, desiredVelocity.x);~~
        ~~//}~~
        velocity.x =
            Mathf.MoveTowards(velocity.x, desiredVelocity.x, maxSpeedChange);
        velocity.z =
            Mathf.MoveTowards(velocity.z, desiredVelocity.z, maxSpeedChange);
```


Max Speed 10
Max Acceleration 10



Both max speed and acceleration set to 10.

Now we can tweak the maximum acceleration to arrive at a desired trade-off between smooth motion and responsiveness.

3 Constraining Position

Besides controlling the velocity of a character a big part of games is limiting where it can go. Our simple scene contains a plane that represents the ground. Let's make it so the sphere must remain on the plane.

3.1 Staying Within the Square

Rather than use the plane itself we'll simply make the allowed area a serializable field of the sphere. We can use a `Rect` struct value for this. Give it a default value that matches the default plane, by invoking its constructor method with −5 as its first two arguments and 10 as the last two. These define its bottom left corner and size.

```
	[SerializeField]
	Rect allowedArea = new Rect(-5f, -5f, 10f, 10f);
```

We constrain the sphere by constraining the new position before assigning it to `transform.localPosition`. So store it in a variable first.

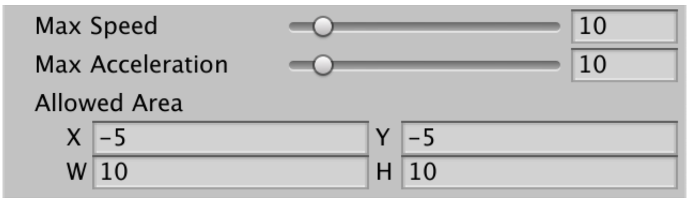
```
		~~//transform.localPosition += displacement;~~
		Vector3 newPosition = transform.localPosition + displacement;
		transform.localPosition = newPosition;
```

We can invoke `Contains` on the allowed area to check whether a point lies inside it or on its edge. If this isn't the case for the new position then let's set it to the current position, negating the movement during this update.

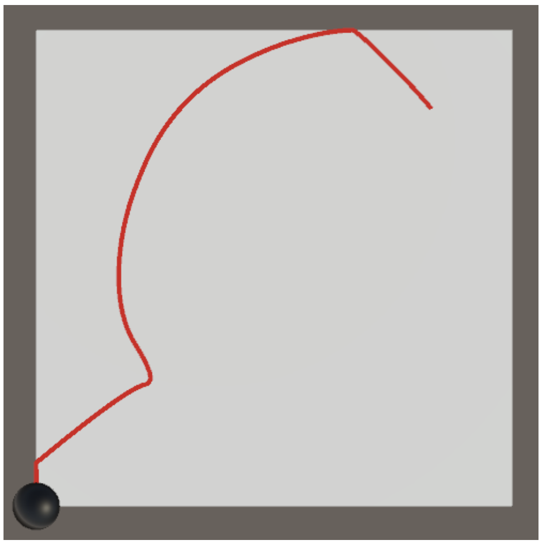
```
		Vector3 newPosition = transform.localPosition + displacement;
		if (!allowedArea.Contains(newPosition)) {
			newPosition = transform.localPosition;
		}
		transform.localPosition = newPosition;
```

When we pass a `Vector3` to `Contains` it checks the XY coordinates, which isn't correct in our case. So pass it a new `Vector2` with the XZ coordinates.

```
		if (!allowedArea.Contains(new Vector2(newPosition.x, newPosition.z))) {
			newPosition = transform.localPosition;
		}
```



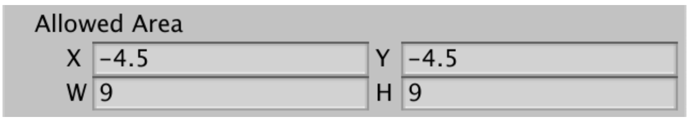
Max Speed 10
Max Acceleration 10
Allowed Area
X -5 Y -5
W 10 H 10



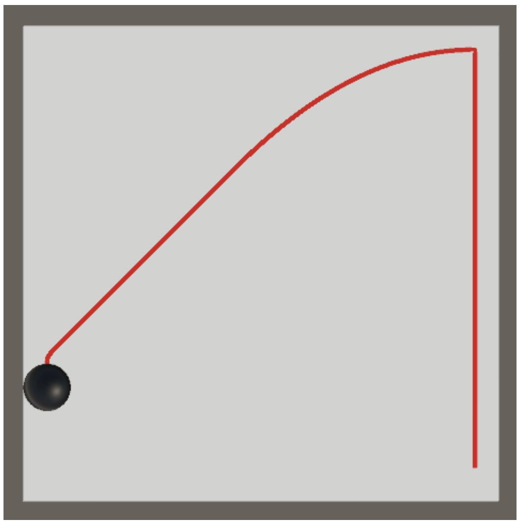
Stopped on the plane's edges.

Our sphere can no longer escape, coming to a halt when it tries to. The result is jerky because movement is ignored during some frames, but we'll deal with that shortly. Before that note that the sphere can move all the way until it sits on top of the plane's edge. That's because we're limiting its position and don't take its radius into consideration. It would look better if the entire sphere remains inside the allowed area. We could change our code to take the radius into account, but the alternative is to simply shrink the allowed area. That's sufficient for our simple scene.

Move the area's corner up by 0.5 and decrease its size by 1 in both dimensions.



Allowed Area
X -4.5 Y -4.5
W 9 H 9

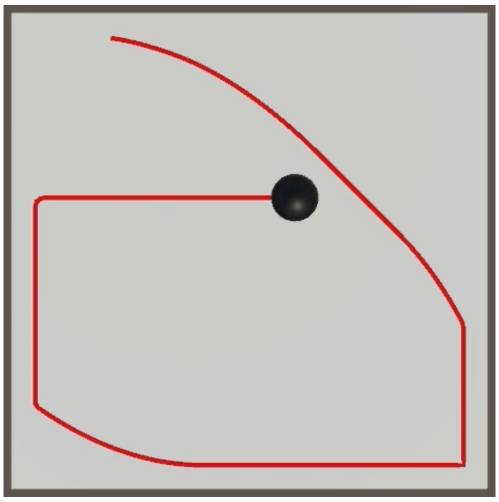


Stopped when touching the plane's edges.

3.2 Exact Placement

We can get rid of the jerky movement by clamping the new position to the allowed area instead of ignoring it. We can do that by invoking `Mathf.Clamp` with a value and its allowed minimum and maximum. Use the `xMin` and `xMax` properties of the area for X and the `yMin` and `yMax` properties for Z.

```
		if (!allowedArea.Contains(new Vector2(newPosition.x, newPosition.z))) {
			~~//newPosition = transform.localPosition;~~
			newPosition.x =
				Mathf.Clamp(newPosition.x, allowedArea.xMin, allowedArea.xMax);
			newPosition.z =
				Mathf.Clamp(newPosition.z, allowedArea.yMin, allowedArea.yMax);
		}
```


Sticking to edges.

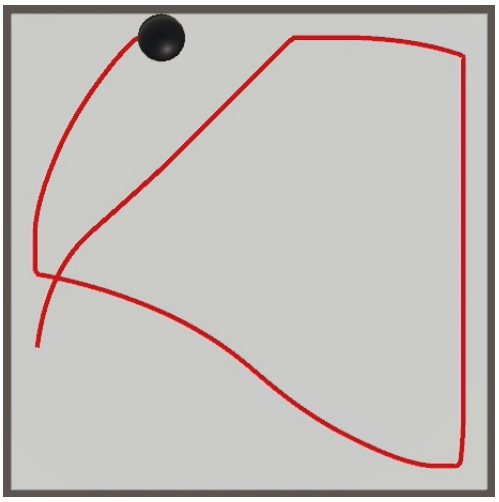
3.3 Eliminating Velocity

The sphere now appears to stick to edges. After reaching an edge we slide along it, but it takes a while before we can move away from the edge. This happens because the sphere's velocity still points toward the edge. We have to change direction by acceleration away from the edge, which takes a while depending on the max acceleration.

If our sphere were a ball and the area's edge a wall, then if it hits the wall it should come to a stop. This indeed happens. But if the wall were to suddenly disappear the ball wouldn't regain its earlier velocity. The momentum is gone, its energy transferred during the collision, which might've caused damage. So we have to get rid of the velocity when hitting an edge. But it's still possible to slide along the edge, thus only the velocity component that points in the direction of that edge should be eliminated.

To set the appropriate velocity component to zero we have to check whether we're out of bounds in both directions for both dimensions. At this point we might as well clamp the position ourselves, as we're performing the same checks as `Mathf.Clamp` and `Contains`.

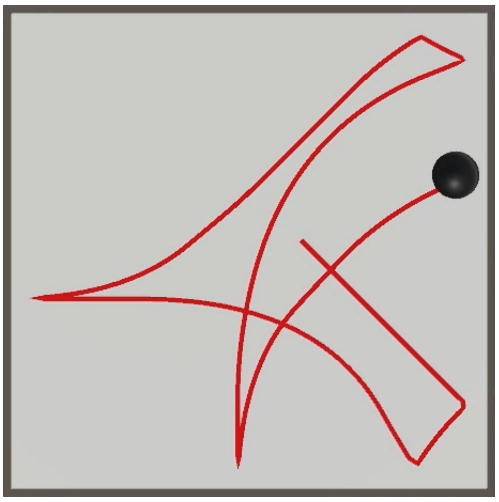
```
		~~//if (!allowedArea.Contains(new Vector2(newPosition.x, newPosition.z))) {~~
			~~//newPosition.x =~~
			~~//	Mathf.Clamp(newPosition.x, allowedArea.xMin, allowedArea.xMax);~~
			~~//newPosition.z =~~
			~~//	Mathf.Clamp(newPosition.z, allowedArea.yMin, allowedArea.yMax);~~
		~~//}~~
		if (newPosition.x < allowedArea.xMin) {
			newPosition.x = allowedArea.xMin;
			velocity.x = 0f;
		}
		else if (newPosition.x > allowedArea.xMax) {
			newPosition.x = allowedArea.xMax;
			velocity.x = 0f;
		}
		if (newPosition.z < allowedArea.yMin) {
			newPosition.z = allowedArea.yMin;
			velocity.z = 0f;
		}
		else if (newPosition.z > allowedArea.yMax) {
			newPosition.z = allowedArea.yMax;
			velocity.z = 0f;
		}
```


No longer sticking to edges.

3.4 Bouncing

Velocity isn't always eliminated during a collision. If our sphere was a perfectly bouncing ball it would reverse direction in the relevant dimension instead. Let's try that.

```
		if (newPosition.x < allowedArea.xMin) {
			newPosition.x = allowedArea.xMin;
			velocity.x = -velocity.x;
		}
		else if (newPosition.x > allowedArea.xMax) {
			newPosition.x = allowedArea.xMax;
			velocity.x = -velocity.x;
		}
		if (newPosition.z < allowedArea.yMin) {
			newPosition.z = allowedArea.yMin;
			velocity.z = -velocity.z;
		}
		else if (newPosition.z > allowedArea.yMax) {
			newPosition.z = allowedArea.yMax;
			velocity.z = -velocity.z;
		}
```


Bouncing off edges.

The sphere now keeps it momentum, it just changes direction when it hits a wall. It does slow down a bit because after bouncing its velocity will no longer match the desired velocity. To get the best bounces the player has to immediately adjust their input.

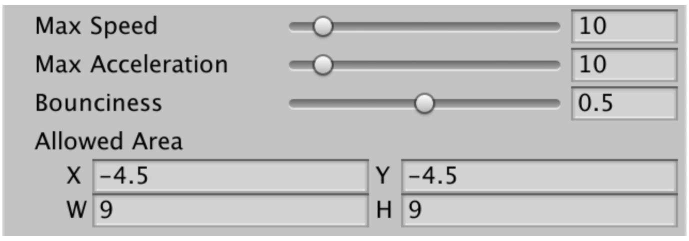
3.5 Bounciness

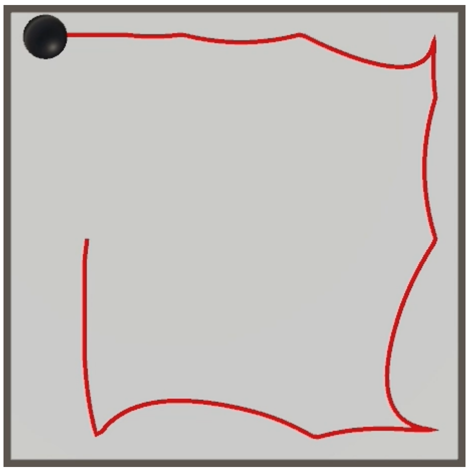
We don't need to retain the entire velocity when reversing it. Some things bounce more than others. So let's make it configurable by adding a `bounciness` field, set to 0.5 by default with a range of 0–1. This allows us to make our sphere perfectly bouncy or not bounce at all, or anything in between.

```
	[SerializeField, Range(0f, 1f)]
	float bounciness = 0.5f;
```

Factor the bounciness into the new velocity value when hitting an edge.

```
		if (newPosition.x < allowedArea.xMin) {
			newPosition.x = allowedArea.xMin;
			velocity.x = -velocity.x * bounciness;
		}
		else if (newPosition.x > allowedArea.xMax) {
			newPosition.x = allowedArea.xMax;
			velocity.x = -velocity.x * bounciness;
		}
		if (newPosition.z < allowedArea.yMin) {
			newPosition.z = allowedArea.yMin;
			velocity.z = -velocity.z * bounciness;
		}
		else if (newPosition.z > allowedArea.yMax) {
			newPosition.z = allowedArea.yMax;
			velocity.z = -velocity.z * bounciness;
		}
```


Max Speed 10
Max Acceleration 10
Bounciness 0.5
Allowed Area
X -4.5 Y -4.5
W 9 H 9


Bounciness set to 0.5.

This doesn't represent realistic physics, which is much more complicated. But it's starting to look like it, which is good enough for most games. Also, we aren't very precise with our movement. Our calculations are only correct if an edge is reached exactly at the end of movement during a frame. This most likely isn't the case, which means that we should've moved the sphere a bit away from the edge immediately. First calculate the remaining time and then use that along with the new velocity in the relevant dimension. However, this might result in a second bounce, which makes things more complicated. Fortunately we don't need such precision to present a convincing illusion of a sphere bouncing around.

The next tutorial is Physics.