Introduction to Jupyter Notebooks

1 Introduction

In this course, we will be doing some scientific computing, which will allow us to solve problems that we would not be able to solve with pencil and paper. We will be doing this work using jupyter notebooks. In the note book, we will us python to to our programs, and in particular, an add on to python known as visual python, or vpython. You are not expected to have had any programming experience prior to this course. During most of the course, we will provide program shells that only require you to code the physics, then run the programs.

2 Installation of Python, Jupyter Notebooks and VPython

It is advisable to install Jupyter Notebooks on your own computer. The easiest way to do this is to use the Anaconda distribution of Python available at Continuum Analytics. Use the Download link on their website, https://www.anaconda.com/, and follow the instructions there for your computer. There is support Windows, MacOS and Linux.

We will be using VPython, and you will need to install this in addition to anaconda. The instructions can be found on vpython.org. Once you have installed anaconda, open a Command Prompt (on Windows) or a terminal window on Mac OS (under Utilities) and Linux. In that window,

```
conda install -c vpython vpython
```

or

```
pip install vpython
```

You can update your installation using the corresponding command to how you installed.

```
conda update -c vpython vpython
```

or

```
pip install vpython --upgrade
```

On a Windows machine, you may also need to install *nodejs*. To do this, download from https://nodejs.org/en/download/ and then execute the command

```
jupyter labextension install vpython
```

3 Jupyter Notebooks

3.1 Start a Jupyter Notebook

From a Windows machine,

```
Windows Menu -> Anaconda 3 -> Jupyter Notebook
```

From a Mac, you can either launch from a terminal window (open in Utilities).

```
jupyter notebook
```

or to specify your browser

```
jupyter notebook --browser=firefox
```

Use can also use Anaconda-Navigator under Applications. On linux, it is the same a the terminal on a Mac.

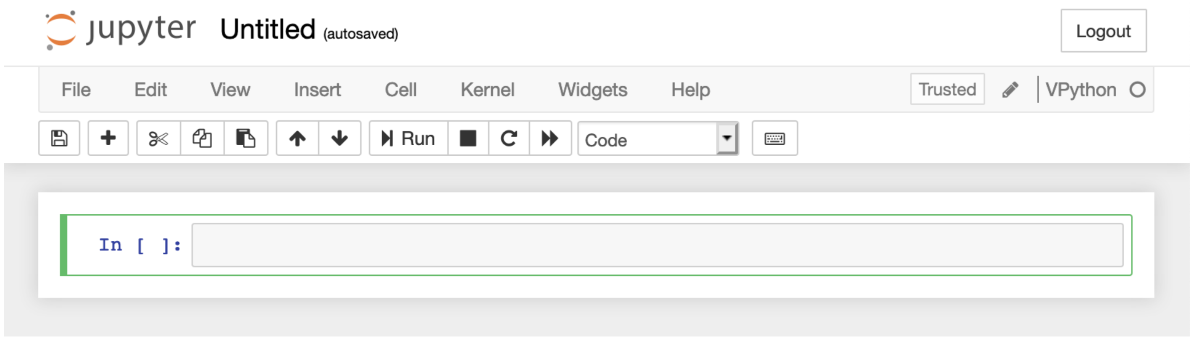
```
jupyter notebook
```

or to specify your browser

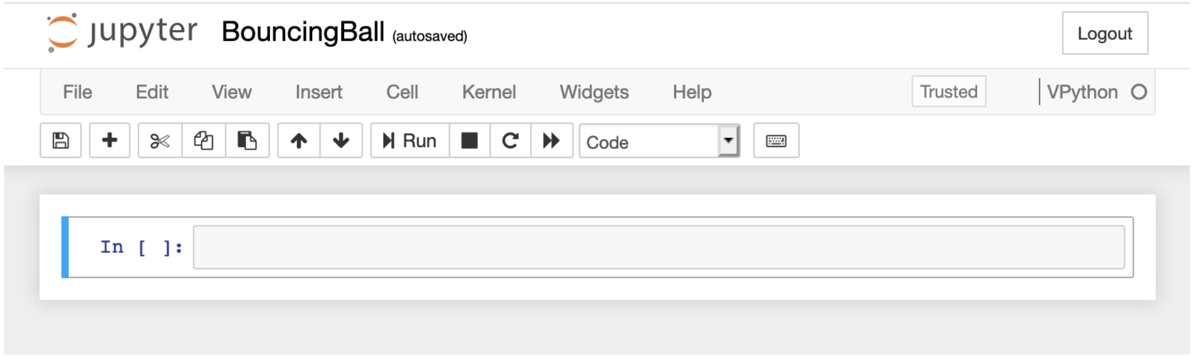
```
jupyter notebook --browser=firefox
```

Your browser will now be running Jupyter. In the upper right corner, click on the *New* button, and from the pulldown menu, select *Vpython*. You will now have a Jupyter Notebook that you can start using.

3.2 Getting Started



The first thing you should do is name your notebook. Click on the *Untitled* and give your notebook a name. I used “BouncingBall” for this example. Jupyter notebooks are organized into units called “cells”,



and is the region to the right of the

```
In [ ]:
```

in the figure. The type of cell is indicated by box labeled *code*. There are several types of cells, but the two that we will use here are

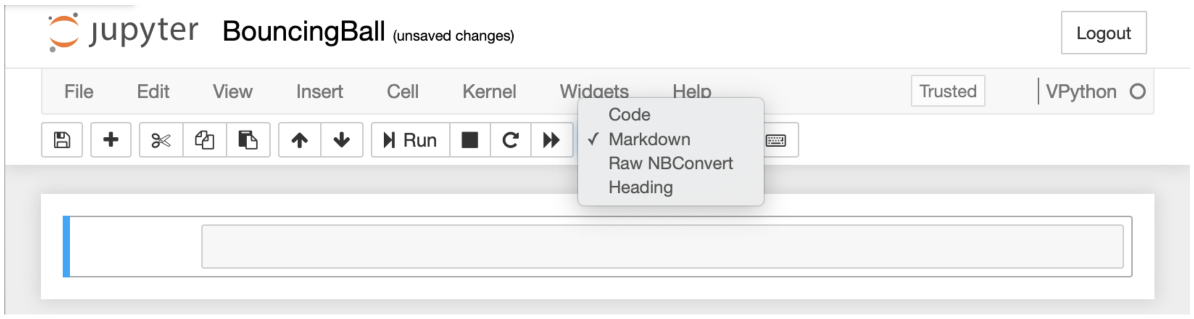
- *Markdown* cells where we can add and format comments to the notebook.
- *Code* cells, where we will be able to Vpyton code.

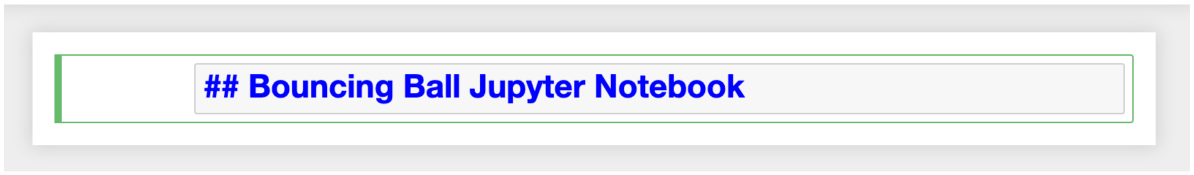
We will start by entering some comments, so we need to change our cell to a *Markdown* cell. We can now enter text in the markdown cell. and the format it by hitting

```
Shift+Enter
```

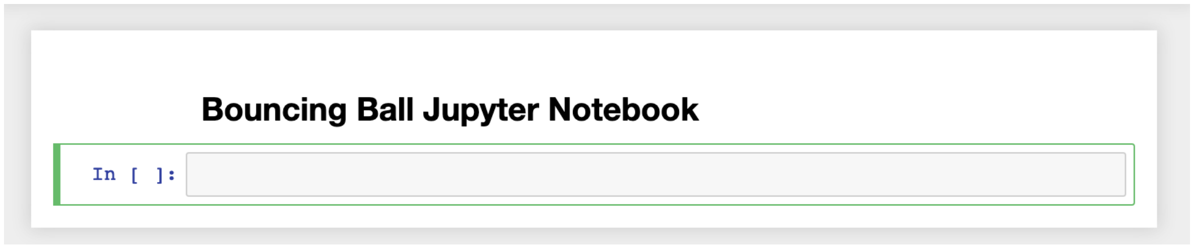
If you double click on the formatted text, you can edit it.

We can now go to the cell that is just below our comments and enter some code. A simple example is to type

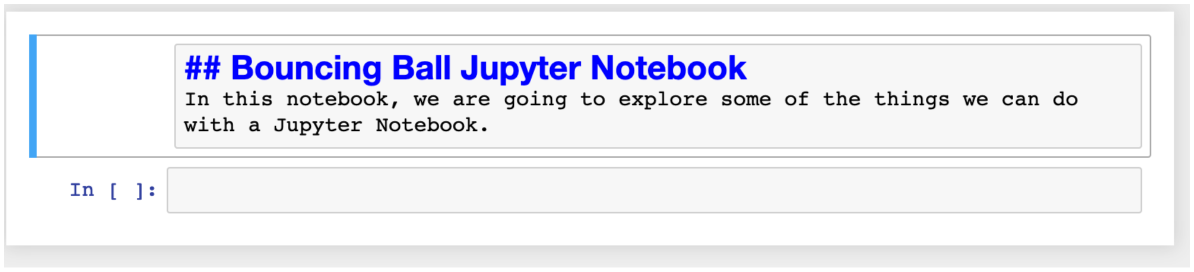




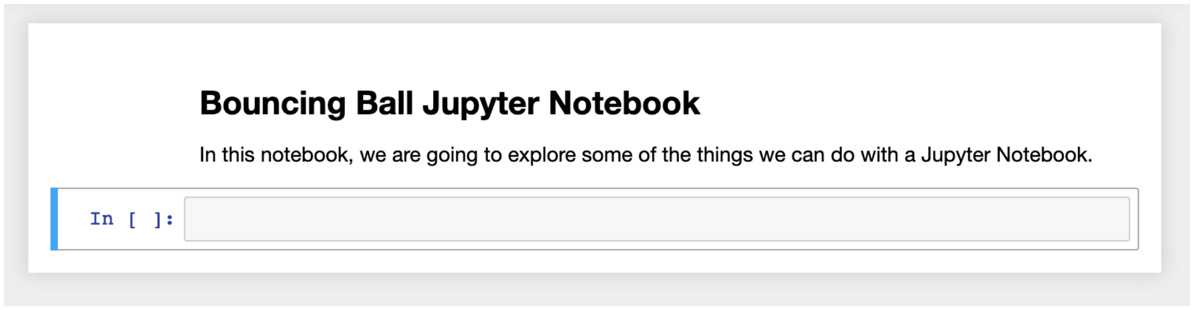
```
## Bouncing Ball Jupyter Notebook
```



Bouncing Ball Jupyter Notebook



```
## Bouncing Ball Jupyter Notebook
In this notebook, we are going to explore some of the things we can do
with a Jupyter Notebook.
```

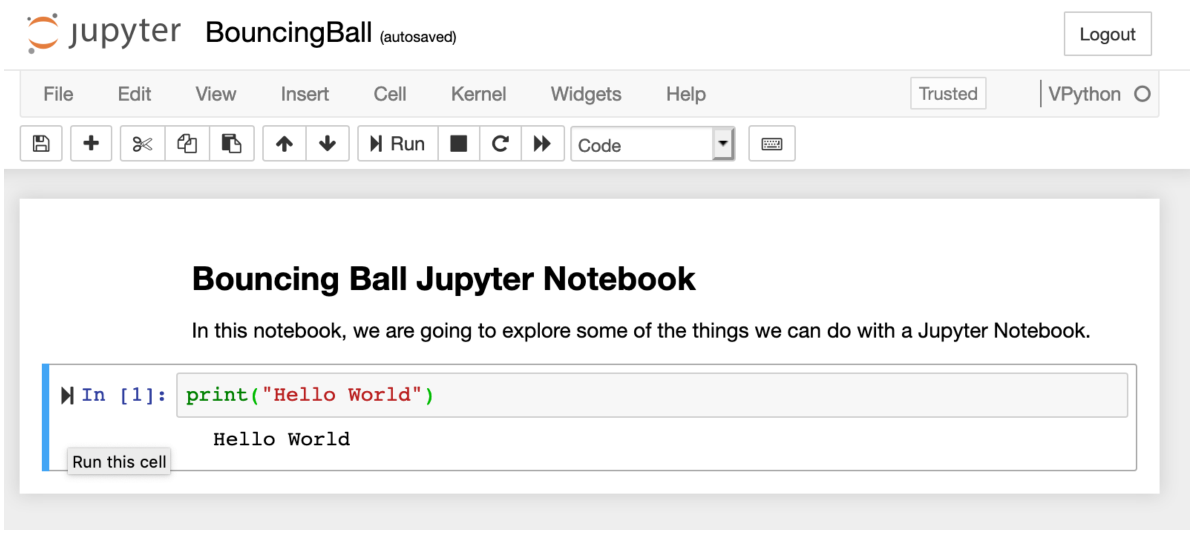


Bouncing Ball Jupyter Notebook

In this notebook, we are going to explore some of the things we can do with a Jupyter Notebook.

```
print("Hello World")
```

into the cell, and then "execute" or "run" the code. You run the code by clicking on the little arrow on the left side of the cell or the Run at the top of the notebook.


jupyter BouncingBall (autosaved)
Logout
File Edit View Insert Cell Kernel Widgets Help
Trusted
VPython
Run
Code
Run this cell

Bouncing Ball Jupyter Notebook

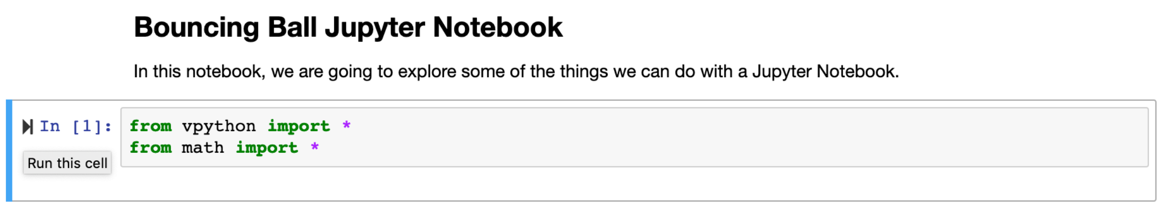
In this notebook, we are going to explore some of the things we can do with a Jupyter Notebook.

```
In [1]: print("Hello World")

Hello World
```

3.3 Starting Vpython

We now need to tell our notebook that we want to use *vpython*. To do this, we need to import a couple of modules by typing the following into our code cell and then running it. We can now start to execute

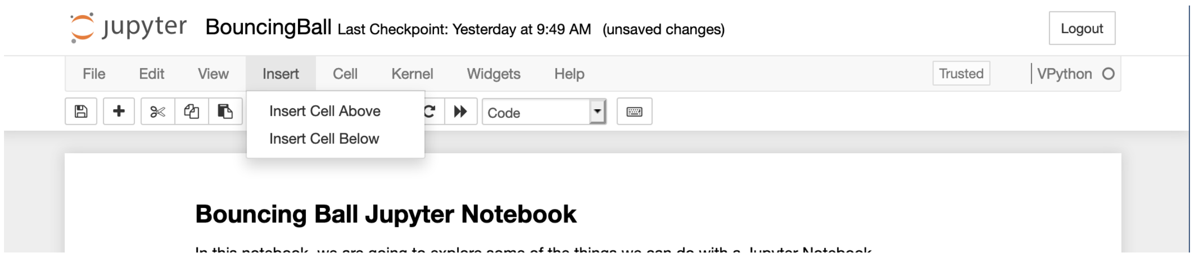


Bouncing Ball Jupyter Notebook

In this notebook, we are going to explore some of the things we can do with a Jupyter Notebook.

```
In [1]: from vpython import *
        from math import *
```

vpython and math expressions. To do this, we will create a new cell below the one we have by clicking on *Insert* and selecting *Insert Cell Below* from the dropdown menu. In the new cell you can now use python as


jupyter BouncingBall Last Checkpoint: Yesterday at 9:49 AM (unsaved changes)
Logout
File Edit View Insert Cell Kernel Widgets Help
Trusted
VPython
Insert Cell Above
Insert Cell Below
Code
Bouncing Ball Jupyter Notebook

a calculator. Type in various things below and see what you get.

```
> print (12+56)
> print (3**3)
> print (sqrt(25))
> a = vector(1,1,1)
  b = vector(-1,2,3)
  print (a+b)
  print (dot(a,b))
  print (cross(a,b))
  print (mag(a))
  print (norm(a+b))
> print (sin(2))
> print (cos(pi))
```

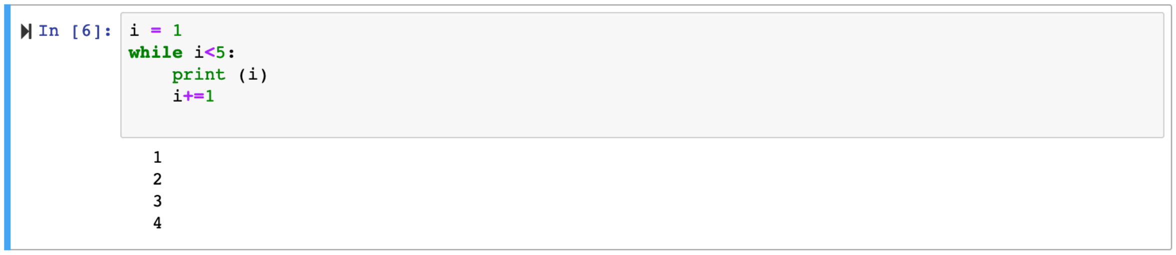
You can also do *loops* and *conditionals*. A loop will continue to execute the same piece of code until some condition is met, while a conditional will execute a piece of code if the condition is true. We have a few examples these here. A example of a loop is shown below, loops are started with the *while* command, and the indentation and punctuation are critical. The loop will continue as long as i is smaller than 5, then exit. The code

```
i += 1
```

adds one to the value of i. It could have also been written as

```
i = i + 1
```

where both are equivalent. Running this code produces the result as shown. Another type of loop is a



```
In [6]: i = 1
        while i<5:
            print (i)
            i+=1

          1
          2
          3
          4
```

so-called infinite loop, that will never stop. An example is given by

```
> i = 1
  while True:
      print (i)
      i+=1
```

Conditionals are started with the *if* command. A simple example is something like following which will loop over values of i between 1 and 9, and print when i is equal to 4.

```
> i=1
  while i<10:
      if i==4:
         print("i is equal to",i)
      i+=1
```

There are various logical expressions that we can use in both loops and conditional statements. In addition

==	equal to	!=	not equal to	<	less than
>	greater than	<=	less than or equal	>=	greater than or equal

to these comparative test, we can also use *and* and *or* in our comparisons.

4 Animating Physics

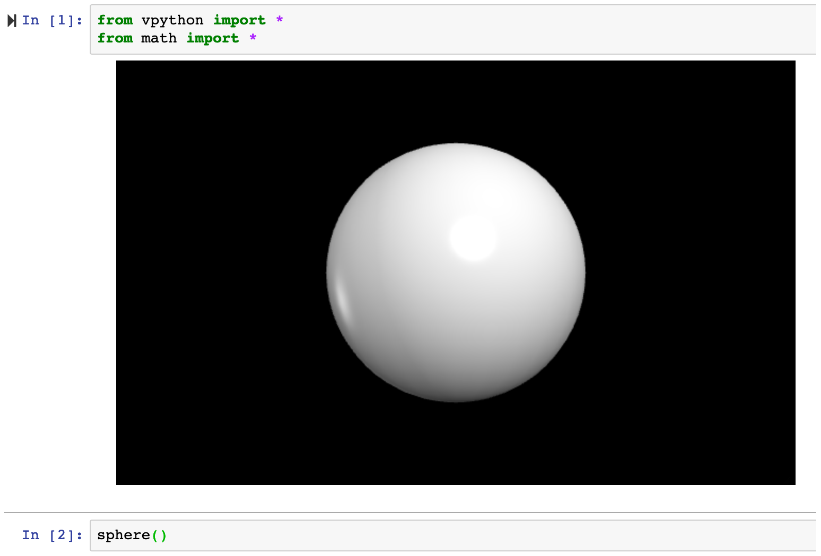
We are now going to move forward to

4.1 3D Geometric Objects

There are a number of three-dimensional objects that vpython know about. A full list can be found at https://vpython.org/contents/docs/primitives.html. We will introduce these shapes as needed throughout the course. The first that we will use is a *sphere*. If we start by entering

```
sphere()
```

and then running the code will produce a new cell above the code cell. This cell contains a grey sphere on a black background as shown below. You can manipulate the object. On a Mac, using two fingers on your track bad zooms in or out on the object. Using *Shift* and one finger allows you to move the point of view, and *Control* and one finger allows you to rotate about the center of the screen. We can also control



```
In [1]: from vpython import *
        from math import *
```

```
In [2]: sphere()
```

the attributes of the sphere, which make it more useful to use. We will name our sphere, “ball”, which will allow us to have several. We will also define the center, radius and color of the sphere. The nominal colors are reb, blue, green, yellow, cyan, magenta, white and black. You can also specify the color using rgb with `color=vector(r,g,b)`. If we run the following code snippet, we will see a cyan ball in the middle of the screen.

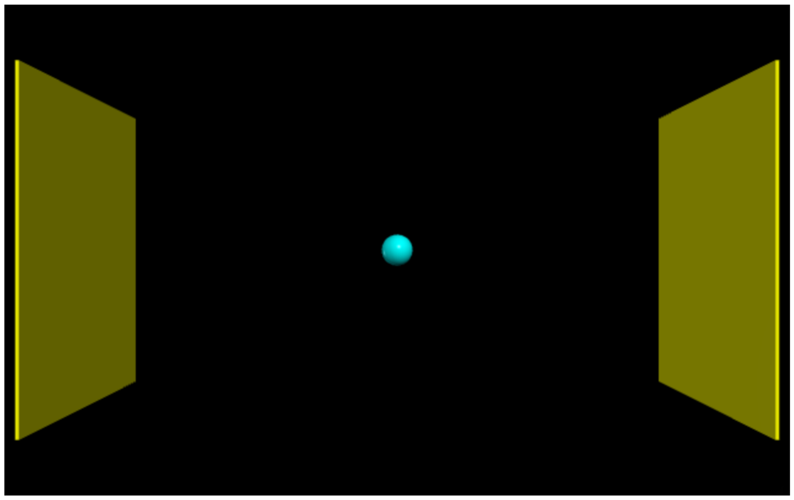
```
ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan)
```

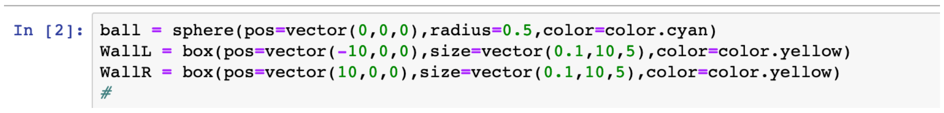
A second object that is useful is the *box*. With the following commands, we will create a pair of boxes, which we call *WallL* and *WallR*, at the left and right sides of the screen. Running these commands will produce an image with a ball at the center of the screen, and walls on the left and right-hand sides. You can now explore the varios zoom and perspective functions with this image.

```
WallL = box(pos=vector(-10,0,0),size=vector(0.1,10,5),color=color.blue)
WallR = box(pos=vector(10,0,0),size=vector(0.1,10,5),color=color.blue)
```

4.2 Animating the Ball

We would now like to animate the ball so that it can move across the screen. To do this, we will need to define new attributes of the ball. If it is going to move, we need a velocity, which we can set using the command below. At this point, we note that python knows nothing about units. We have defined positions and sizes as numbers. For simplicity, we assume that these are all in meters, but we need to manage the units. For a velocity, we will assume that the units are m/s, and we give the ball velocity $\vec{v} = (1,0,0)\, m/s$.





```
In [2]: ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan)
        WallL = box(pos=vector(-10,0,0),size=vector(0.1,10,5),color=color.yellow)
        WallR = box(pos=vector(10,0,0),size=vector(0.1,10,5),color=color.yellow)
        #
```

```
ball.velocity = vector(1,0,0)
```

In addition to position and velocity, we will also need time (assumed to be in seconds). In animation, there are actually two times that may be relevant, the total elapsed time, and the time step between each animation frame. We need to set these as well. We will use t for the total elapsed time and dt for the time step. We initially set the elapsed time to 0 and the time step to be $0.1\,s$.

```
t  = 0
dt = 0.1
```

We can now animate our ball. The underlying physics can be written as a difference equation:

$$\Delta\vec{r} \quad = \quad \vec{t}\,\Delta t$$

which we will implement using the logic that after one time step, the new position will be the old position plus the change in position. We also see that python is managing all the vectors for us. The following expression represents three equations, one for each of the x, y and z coordinates. We can just let python worry about that detail!

$$\vec{r}_{new} \quad = \quad \vec{r}_{old} + \Delta\vec{r}$$

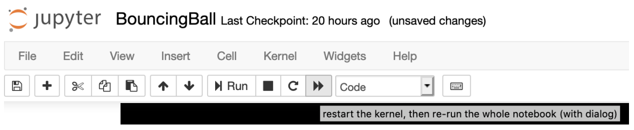
When coding, we implement such an action using the expression

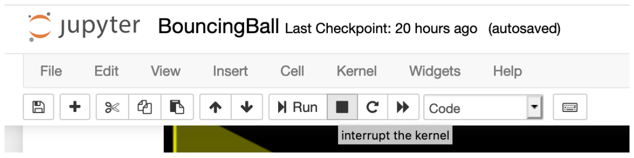
```
ball.pos = ball.pos + ball.velocity * dt
```

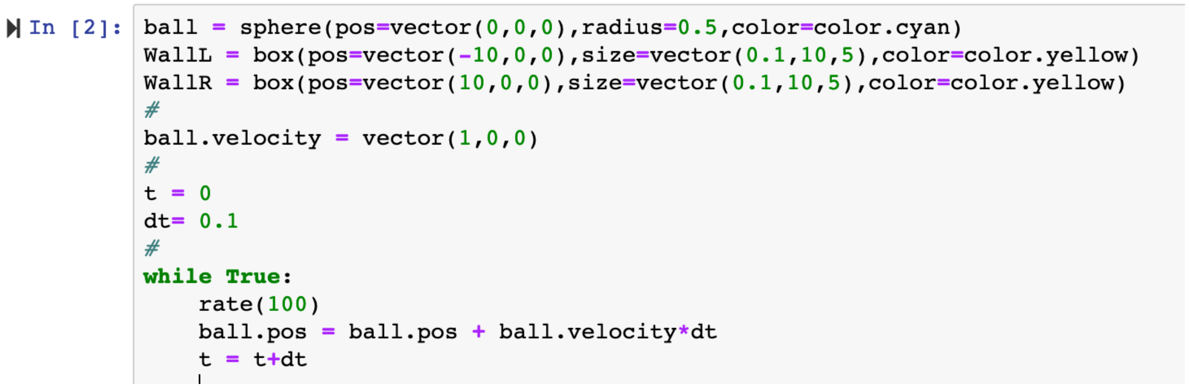
This leads to the following loop to animate the ball.

```
while True:
    ball.pos = ball.pos + ball.velocity*dt
    t = t + dt
```

Our code now looks like the following, and if we run this, the ball just goes off to the right forever. We run the code by clicking on the ¿¿ button at the top of the notebook. It knows nothing about walls, and we


jupyter BouncingBall Last Checkpoint: 20 hours ago (unsaved changes)
File Edit View Insert Cell Kernel Widgets Help
Run
Code
restart the kernel, then re-run the whole notebook (with dialog)


jupyter BouncingBall Last Checkpoint: 20 hours ago (autosaved)
File Edit View Insert Cell Kernel Widgets Help
Run
Code
interrupt the kernel



```
In [2]: ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan)
        WallL = box(pos=vector(-10,0,0),size=vector(0.1,10,5),color=color.yellow)
        WallR = box(pos=vector(10,0,0),size=vector(0.1,10,5),color=color.yellow)
        #
        ball.velocity = vector(1,0,0)
        #
        t = 0
        dt= 0.1
        #
        while True:
            rate(100)
            ball.pos = ball.pos + ball.velocity*dt
            t = t+dt
```

have an infinite loop, so it never stops. *An object in motion remains in motion, except to the extent which it interacts with other objects.* We can force the program to stop by clicking on the stop symbol, as shown.

One other thing to note in the code below is the *rate(100)* that is in the loop. This limits the number of steps we take per real second, and without it our computer may run so fast that we see nothing.

We now want to tell the ball how to interact with the walls. This is a simple elastic reflection that we need to consider. In a reflection, the component of the velocity that is normal to the reflecting surface changes sign. For us, this means that we need to reverse the x component of velocity, or

$$v_x \quad \to \quad -v_x \,.$$

We also need to determine if the ball is interacting with the wall. We can approximate this by checking to see of the center of the ball would move to the opposite side of the wall. If it would, we apply the interaction. This can be done with the following conditional statements inside our animation loop.

```
if ball.pos.x < WallL.pos.x:
     ball.velocity.x = - ball.velocity.x
if ball.pos.x > WallR.pos.x:
     ball.velocity.x = - bal.velocity.x
```

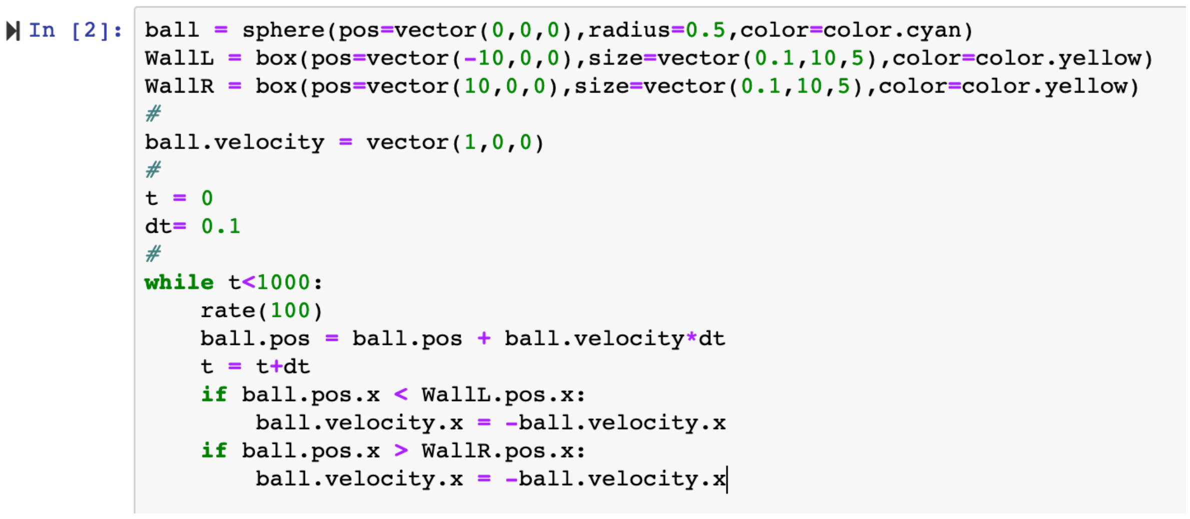
f we run this code, the ball will bounce back and forth between the two walls forever. We could change this by setting a finite time on the loop and stopping it after we have reached some total elapsed time.

```
while t < 1000:
     rate(100)
```

Because we have vectors, we can change the balls velocity to be in more than one dimension. A simple change is to give the velocity a small y component.

```
ball.velocity = vector(1,0.1,0)
```

Running the code now, the ball will slowly move upward, bouncing between invisible walls as we neglected to code in the extent of the two walls.



In [2]:

```
ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan)
WallL = box(pos=vector(-10,0,0),size=vector(0.1,10,5),color=color.yellow)
WallR = box(pos=vector(10,0,0),size=vector(0.1,10,5),color=color.yellow)
#
ball.velocity = vector(1,0,0)
#
t = 0
dt= 0.1
#
while t<1000:
    rate(100)
    ball.pos = ball.pos + ball.velocity*dt
    t = t+dt
    if ball.pos.x < WallL.pos.x:
        ball.velocity.x = -ball.velocity.x
    if ball.pos.x > WallR.pos.x:
        ball.velocity.x = -ball.velocity.x
```

4.3 Following the Object

Now that we have the ball bouncing around, we can introduce a couple of additional shapes to help us visualize the motion. The first shape is an *arrow* that we will use to to indicate the direction of the ball. We need to initially create the arrow after we have defined both the ball and its velocity using the command.

```
ball.bv = arrow(pos=ball.pos,axis=ball.velocity,color=ball.color)
```

The arrow then needs to be updated every time the ball moves, so at the end our loop we will add the line

```
     ball.bv.pos = ball.pos
     ball.bv.axis = ball.velocity
```

The arrow also has a *length* attribute that we can change. The default is 1, but we may want to scale it to the actual length of the vector we are following. We would do that by setting the length of the arrow be equal to the magnitude of the velocity vector.

```
ball.bv = arrow(pos=ball.pos,axis=ball.velocity,color=ball.color,length=mag(ball.velocity))
```

and

```
     ball.bv.pos = ball.pos
     ball.bv.axis = ball.velocity
     ball.bv.length = mag(ball.velocity)
```

We can also have the object leave a trail. There are a couple of ways to do this. The easiest is to use the *make_trail* attribute of the sphere when we created the ball. This will draw a trail that is the same color as the ball, and follows the ball forever.

```
ball = sphere(pos=vector(0,0,0),radius=0.5,make_trail=True,color=color.cyan)
```

If we want more control over the trail, we can set additional attributes. We can either have a *curve* which is the default, or *points*. We can set the *interval* of how often a point is added, the default is every step, and we can set how many steps to retain on the trail using *retain*. Finally, it is possible to set the color.

```
ball = sphere(pos=vector(0,0,0),radius=0.5,make_trail=True,color=color.cyan,interval=10,
       retain=250,trail_color=magenta)
```

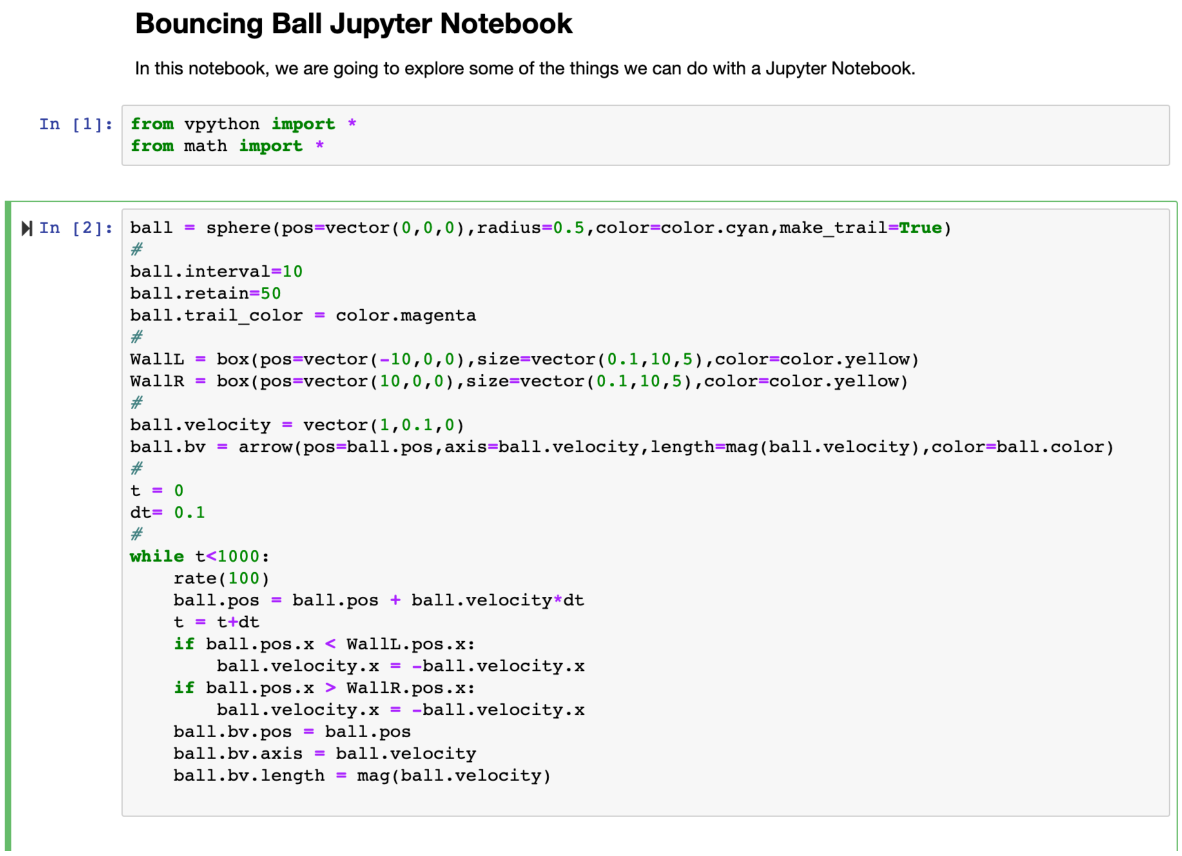
There is an alternative way to leave a trail using the *curve* object. This has more attributes and functionality than the *make_trail*, so we describe it here. For most of our work in the course, they are 100% equivalent, especially if you have a finite trail length. The one place they differ is that the *make_trail* approach may have a glitch at the start of the trail. The *curve* will not. To use this method, we need to define the curve after we have defined the ball.

```
ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan)
ball.trail = curve(color=color.magenta)
ball.trail.append(pos=ball.pos)
```

and then every time we move the ball, we need to append the position to the trail

```
    ball.pos = ball.pos + ball.velocity * dt
    ball.trail.append(pos=ball.pos)
```

As a checkpoint, we show the current version of our code here where we have chosen to use the *make_trail* because we are only retaining 250 points along the path.



Bouncing Ball Jupyter Notebook

In this notebook, we are going to explore some of the things we can do with a Jupyter Notebook.

```
In [1]: from vpython import *
        from math import *
```

```
In [2]: ball = sphere(pos=vector(0,0,0),radius=0.5,color=color.cyan,make_trail=True)
        #
        ball.interval=10
        ball.retain=50
        ball.trail_color = color.magenta
        #
        WallL = box(pos=vector(-10,0,0),size=vector(0.1,10,5),color=color.yellow)
        WallR = box(pos=vector(10,0,0),size=vector(0.1,10,5),color=color.yellow)
        #
        ball.velocity = vector(1,0.1,0)
        ball.bv = arrow(pos=ball.pos,axis=ball.velocity,length=mag(ball.velocity),color=ball.color)
        #
        t = 0
        dt= 0.1
        #
        while t<1000:
            rate(100)
            ball.pos = ball.pos + ball.velocity*dt
            t = t+dt
            if ball.pos.x < WallL.pos.x:
                ball.velocity.x = -ball.velocity.x
            if ball.pos.x > WallR.pos.x:
                ball.velocity.x = -ball.velocity.x
            ball.bv.pos = ball.pos
            ball.bv.axis = ball.velocity
            ball.bv.length = mag(ball.velocity)
```

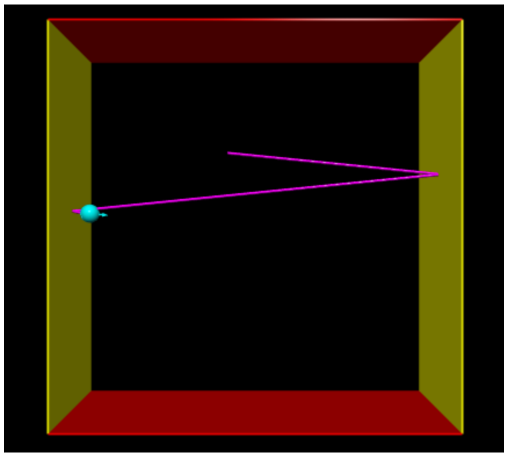
5 Additional Things to Do

Now that you have a working program, there are a few additional things to try.

First, add top and bottom walls, and make them touch, and then modify your code so the ball bounces off all four walls. If you want you can add *invisible* front and back walls as well.

Next add a constant acceleration to your program. The acceleration should update the velocity, and then the velocity will update the position.

Add a second ball bouncing around in the box. You can allow the two balls to interact if you would like.



6 References

- Vpython documentation can be found online at https://vpython.org/contents/docs/index.html.
- Python documentation can be found online at https://docs.python.org.
- Additional documentation on Jupyter notebooks can be found online at https://jupyter-notebook.readthedocs.io/en/stal