
ratcave Documentation

Release 0.5

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Dec 18, 2020

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1.1 Introduction

ratcave is a Python package for displaying 3D Graphics. It was inspired by a Virtual Reality CAVE Setup for rodents in a neuroscience lab in Munich, Germany, and was meant to make the creation of 3D experiments simple and accessible.

ratcave has since evolved into a standalone wrapper for modern OpenGL constructs, like programmable shaders, environment mapping, and deferred rendering. Because it wraps these OpenGL features directly, it also works with all popular python OpenGL graphics engines, including Pyglet, PsychoPy, and PyGame.

Finally, ratcave is written to reduce boilerplate code, in order to make writing simple 3D environments easy. It does this using many python features, including dictionary-like uniform assignment and context managers to bind OpenGL objects.

1.2 Installation

ratcave supports both Python 2 and Python 3, and can be installed via pip!:

```
pip install ratcave
```

1.3 Features

ratcave was created to be a graphics package for doing behavioral experiments with animals in a freely-moving virtual reality environment. The goals of this project are:

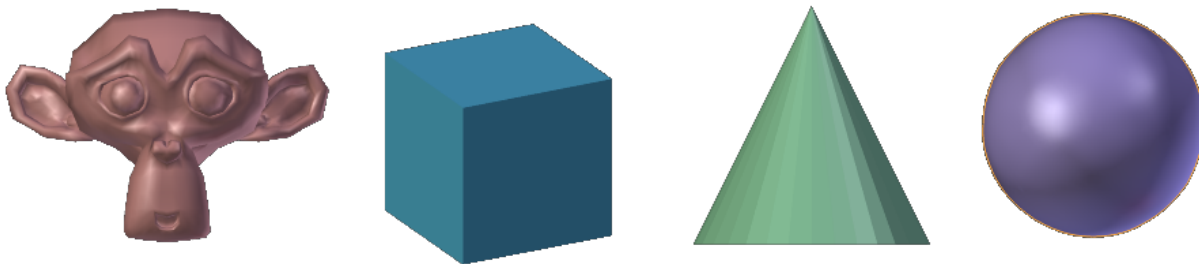
- *Less Boilerplate, more Coding*: More code means more errors. Many behavioral experiments tend to be complex sets of logic written in a single script, so I tried to make ratcave as low-profile as possible to keep the focus on the experiment, not on the graphics management.
- *Ease of Use*: Moving objects in a scene, displaying a window, and changing objects' colors should be intuitive.

- *high-temporal performance*: Lag is the enemy of immersive VR, and we wanted to take advantage of our 360 fps display for VR research. Advanced hardware-accelerated algorithms and modern OpenGL constructs are an essential part of doing high-performance graphics in Python.
- *Cubemapping Support* (the essential algorithmic approach for a single-projector CAVE VR system),
- *Free and Open Source*

What I've found so far is that ratcave makes for a succinct 3D graphics engine, even for simple 3D scenes, making it a useful candidate package for psychophysics research in general. To that end, I've made it very compatible with the PsychoPy package, as a way of extending PsychoPy experiments to 3D scenes. While we are still at an early stage of development with ratcave, we've already reached the requirements listed above, with a goal of continually refactoring and adding features to make ratcave the mature backend it has the potential to be. If you are interested in aiding the development of ratcave, either through contributions on GitHub, bug reporting, or even simply testing it out yourself and giving us feedback, we hope you'll get involved and help us develop this little project into something wonderful!

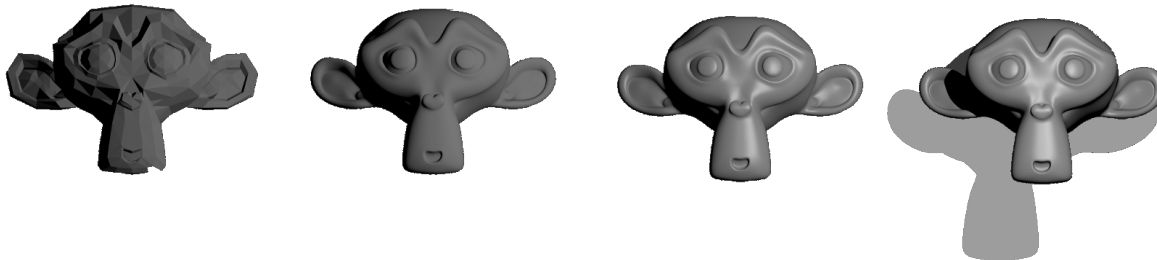
1.3.1 Supplied 3D Primitives

Blender 3D's built-in primitives (Cone, Sphere, Cube, etc) come packaged with ratcave, making it easier to get started and prototype your 3D application. A reader object for Blender's .obj Wavefront files is also included.



1.3.2 Supplied 3D Shaders

ratcave is “batteries-included”: You get diffuse shading, specular reflections, shadows, and even FXAA antialiasing in the packaged shaders. These shaders are open-source and free to be edited and improved!



1.3.3 Pythonic Interface

Framebuffer Context Managers

Normally, the OpenGL code to bind a framebuffer involves the following:

```
glGetIntegerv(GL_VIEWPORT, old_viewport_size)
glBindFramebufferEXT(GL_FRAMEBUFFER, fbo_id) # Rendering off-screen
glViewport(0, 0, texture_width, texture_height)
<< Draw Scene Here >>
glBindFramebufferEXT(GL_FRAMEBUFFER, 0)
glViewport(old_viewport_size)
```

In ratcave, this is a simple context manager:

```
with fbo:
    scene.draw()
```

Shader Uniforms

OpenGL Shader Uniform creation and setting is also wrapped in a pythonic way:

```
sphere.uniforms['diffuse_color'] = [1., 0., 0.] # RGB values
```

1.3.4 Fast Execution

ratcave uses Numpy arrays, c binaries, and GLSL OpenGL to make rendering detailed scenes fast!

1.4 System Requirements

At the moment, ratcave's shaders require OpenGL 3.3, though this is planned to change in future releases. If you'd like to use ratcave and don't have a graphics driver that supports OpenGL 3.3, however, you can already load your own shaders and it will work fine.

1.5 Tutorials

These Tutorials are meant to help you get started!

1.5.1 Tutorial 1: Displaying a 3D Object

This tutorial will show the process of displaying a 3D object onscreen. This will be done in four steps:

- We'll open a file containing 3D objects—a Wavefront .obj file containing basic 3D primitives that comes with ratcave (although you can use any .obj file outputted by 3D modeling software), using the WavefrontReader class.
- We then retrieve a Mesh object from the file. Mesh objects contain all information about the object, including its position (inside its Local and World attributes, which are Physical objects), color (inside its Material attribute, which are of the Material class), and even the vertex data itself.

- We'll put the `Mesh` inside a `Scene` object, which is a container class that holds `Mesh` objects, a `Camera` object, and a `Light` object, along with an RGB background color. Multiple `Scenes` can be created, even ones that contain the same `Meshes`, and rendering one vs another one is as simple as calling the scene's `Scene.draw()` method.

Note: Each tutorial follows from each other, assuming knowledge of the previous. To get the most out of `ratcave`, then, it is best to do them in order!

Note: Some of the constructs in this tutorial, like decorators and event loops, come from `Pyglet`. While completely understanding them isn't necessary, it'll probably best to start out with a `Pyglet` tutorial to get your feet wet. This one is good: http://www.natan.termijnjak.net/tutorials/pyglet_basic.html

Starting an OpenGL Context and a Window

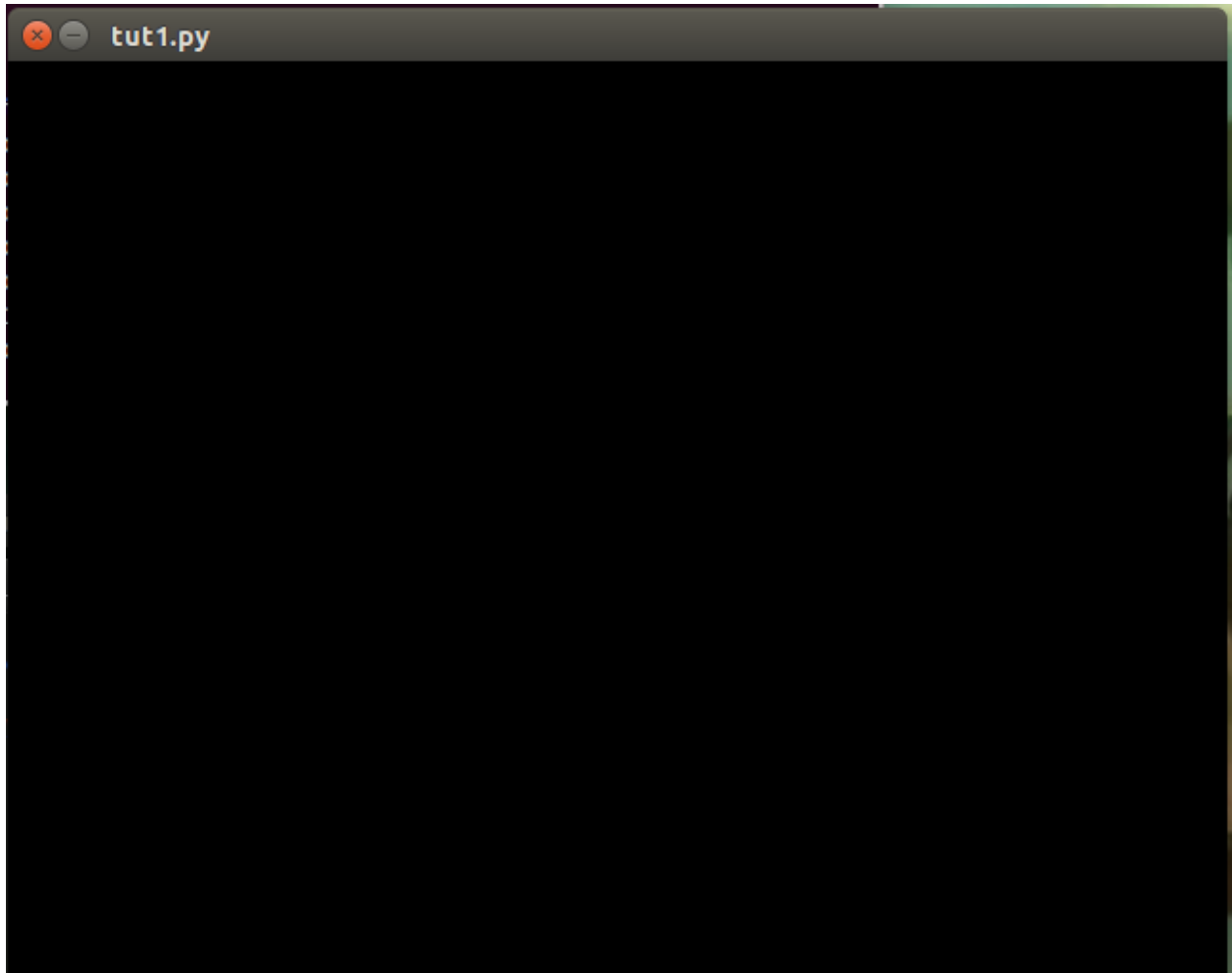
`ratcave` depends on there already being an OpenGL context set up before loading objects. This can be done by any OpenGL manager (`Pyglet` and `PsychoPy` are useful, but `PyGame` and `Qt OpenGL` windows should work fine as well). So, before doing anything in `ratcave`, a window must first be created. In these tutorials, I'll show it with `Pyglet`:

```
import pyglet
import ratcave as rc

window = pyglet.window.Window()
```

If you want to verify that `Pyglet` is working and the window gets created, just start `Pyglet`'s event loop at the end of your script. This script will create a `Pyglet` window that closes when you press the escape key:

```
pyglet.app.run()
```

Warning: Creating a Window automatically starts the OpenGL context, which is important for many aspects of ratcave. As a general rule, it's good to make your window first, before doing anything else!

Getting Pyglet Actively Drawing

Pyglet's event loop won't automatically update the scene, so we'll stick in a function that does nothing, that gets called every frame, to guarantee that everything appears onscreen. Anything you want done between frames (updating positions, logging events, etc) can go in this function.:

```
def update(dt):  
    pass  
pyglet.clock.schedule(update)
```

Reading a Wavefront .obj file

To load a 3D object, let's read in a .obj file! The built-in `WavefrontReader` can read triangulated, uv-mapped .obj files exported from Blender. ratcave comes with some primitive 3D objects in its `resoufruites` module, so let's use one of those.:

```
# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Check which meshes can be found inside the Wavefront file, and extract it into a
↳Mesh object for rendering.
print(obj_reader.bodies.keys())
>>> ['Torus', 'Sphere', 'Monkey', 'Cube']
```

Loading a Mesh from the WavefrontReader and Positioning it

Loading a mesh can be done through the `WavefrontReader.get_mesh()` method. By default, the mesh will have its position in the same location as in its `.obj` file, but this can be easily changed. Because the camera is in the `-z` direction by default per OpenGL convention, let's set it in front of the camera:

```
monkey = obj_reader.get_mesh("Monkey")
monkey.position.xyz = 0, 0, -2
```

Creating a Scene

Scenes consist of meshes, lights, and a camera—everything we need to view and position and object in the real world! Let's put the monkey Mesh into a Scene:

```
scene = rc.Scene(meshes=[monkey])
```

Drawing the Scene

To draw the scene, we need a 3D shader (discussed in more detail in the next tutorial). Luckily, ratcave provides one to start with! Simply call the `Scene.draw()` method in your draw loop! In Pyglet, this looks like this:

```
@window.event
def on_draw():
    with rc.default_shader:
        scene.draw()

pyglet.app.run()
```

Summary

That's it! Here's the final script, in one place. This script will be modified in the next tutorial to animate the scene.:

```
import pyglet
import ratcave as rc

# Create Window
window = pyglet.window.Window()

def update(dt):
    pass
pyglet.clock.schedule(update)
```

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```
# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Create Mesh
monkey = obj_reader.get_mesh("Monkey")
monkey.position.xyz = 0, 0, -2

# Create Scene
scene = rc.Scene(meshes=[monkey])

@window.event
def on_draw():
    with rc.default_shader:
        scene.draw()

pyglet.app.run()
```

Version using PsychoPy

Alternatively, you can see the same example using a PsychoPy window:

```
import ratcave as rc
from psychopy import visual, event

# Create Window
window = visual.Window()

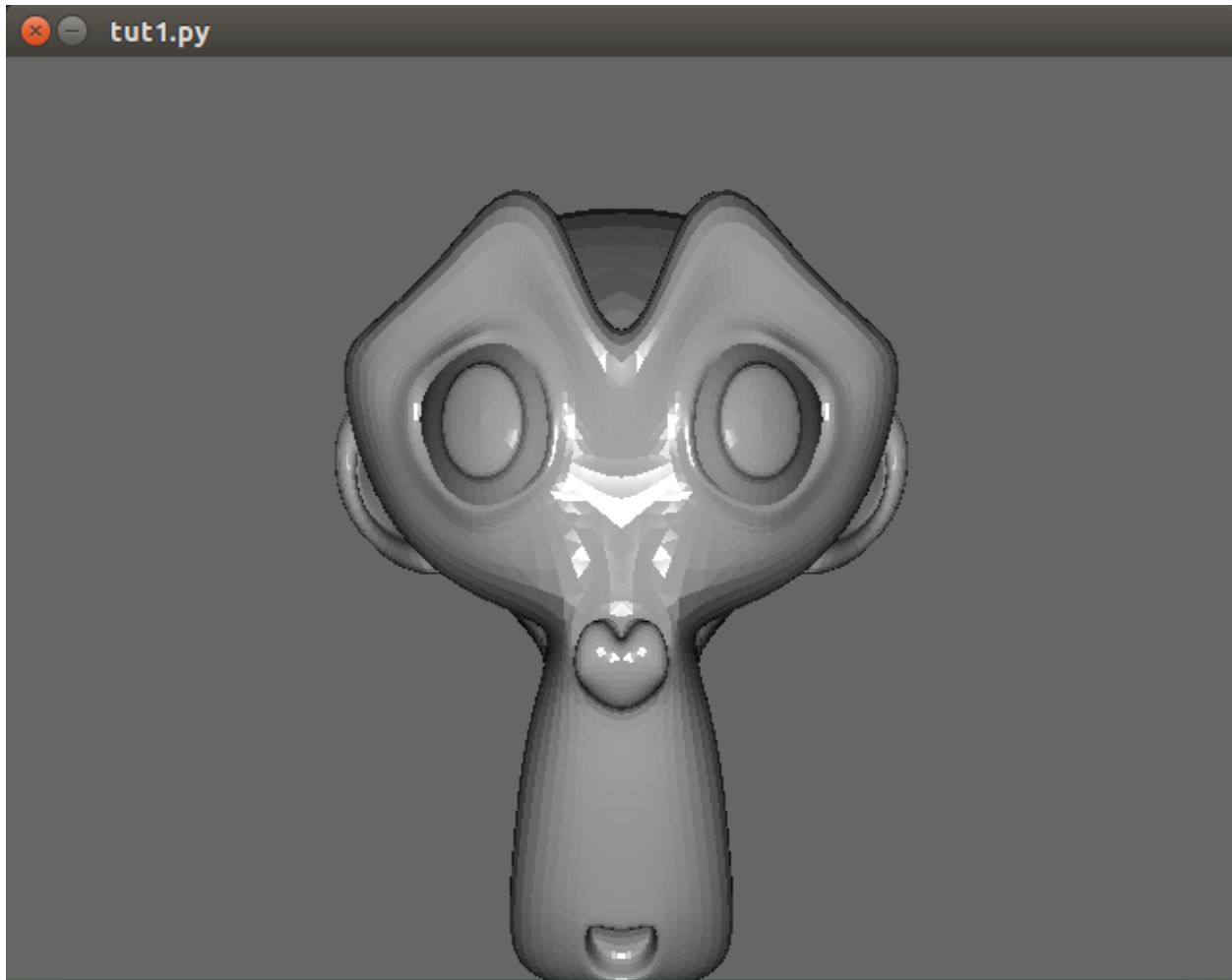
# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Create Mesh
monkey = obj_reader.get_mesh("Monkey")
monkey.position.xyz = 0, 0, -2

# Create Scene
scene = rc.Scene(meshes=[monkey])

while 'escape' not in event.getKeys():
    with rc.default_shader:
        scene.draw()
    window.flip()

window.close()
```



1.5.2 Tutorial 2: Animating a Scene with Multiple Meshes and Moving the Camera with the Keyboard

This tutorial will build on the previous one by adding some more interesting elements. We'll allow the user to move the scene's camera by pressing the left and right arrow keys, and have multiple meshes in the scene that move.

Warning: This tutorial builds on code from Tutorial 1. If you have not yet completed Tutorial 1, it's best to go and do that, first!

Scenes Hold Lists of Meshes

Let's insert a couple Meshes from our `obj_reader` `WavefrontReader` object into the scene!:

```
# Create Meshes from WavefrontReader
monkey = obj_reader.get_mesh("Monkey", position=(0, 0, -1.5), scale=.6)
torus = obj_reader.get_mesh("Torus", position=(-1, 0, -1.5), scale=.4)

# Create Scenes with Meshes.
scene = rc.Scene([monkey, torus])
```

Moving a Mesh

Now, we'll animate the Meshes by changing their rotation attributes in the update function:

```
def rotate_meshes(dt):  
    monkey.rotation.y += 15 * dt  # dt is the time between frames  
    torus.rotation.x += 80 * dt  
pyglet.clock.schedule(rotate_meshes)
```

Modifying Scene's Background Color

Scenes also have a background color, saved as an RGB tuple in the Scene.bgColor attribute:

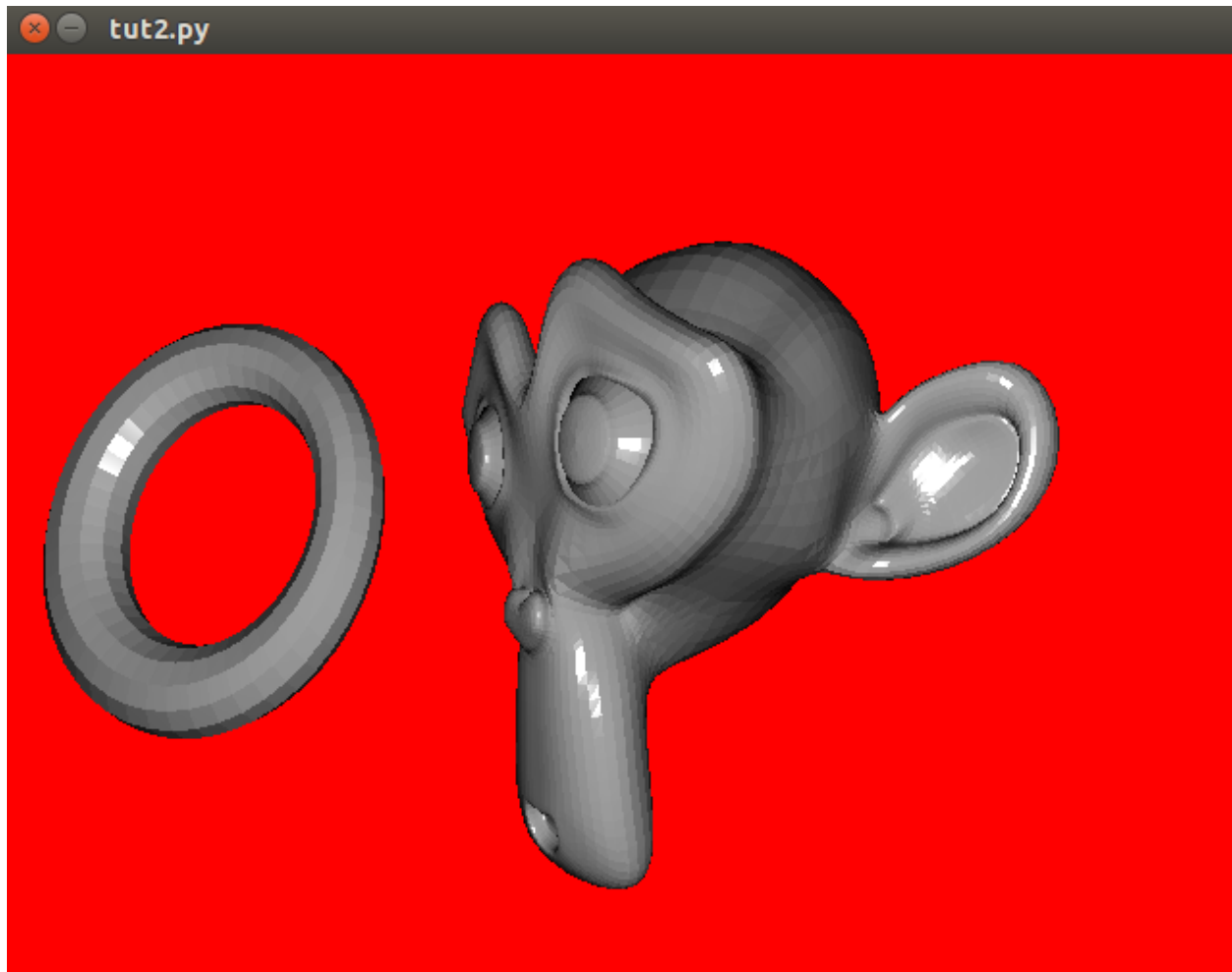
```
scene.bgColor = 1, 0, 0
```

Moving the Camera with the Keyboard

While we could easily make a new Camera object from scratch, we'll just grab the scene's camera and have it accept keyboard inputs for movement:

```
# This is how to get keyboard input in pyglet:  
from pyglet.window import key  
keys = key.KeyStateHandler()  
window.push_handlers(keys)  
  
def move_camera(dt):  
    camera_speed = 3  
    if keys[key.LEFT]:  
        scene.camera.x -= camera_speed * dt  
    if keys[key.RIGHT]:  
        scene.camera.x += camera_speed * dt  
pyglet.clock.schedule(move_camera)
```

Now you should have an interactive scene! Don't forget to use the arrow keys to move around!



Summary

Here's the full code for Tutorial 2:

```
import pyglet
from pyglet.window import key
import ratcave as rc

# Create Window and Add Keyboard State Handler to it's Event Loop
window = pyglet.window.Window()
keys = key.KeyStateHandler()
window.push_handlers(keys)

# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Create Mesh
monkey = obj_reader.get_mesh("Monkey", position=(0, 0, -1.5), scale=.6)
torus = obj_reader.get_mesh("Torus", position=(-1, 0, -1.5), scale=.4)

# Create Scene
```

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```

scene = rc.Scene(meshes=[monkey, torus])
scene.bgColor = 1, 0, 0

# Functions to Run in Event Loop
def rotate_meshes(dt):
    monkey.rotation.y += 15 * dt # dt is the time between frames
    torus.rotation.x += 80 * dt
pyglet.clock.schedule(rotate_meshes)

def move_camera(dt):
    camera_speed = 3
    if keys[key.LEFT]:
        scene.camera.position.x -= camera_speed * dt
    if keys[key.RIGHT]:
        scene.camera.position.x += camera_speed * dt
pyglet.clock.schedule(move_camera)

@window.event
def on_draw():
    with rc.default_shader:
        scene.draw()

pyglet.app.run()

```

PsychoPy Version

Here's the same scenario, done in PsychoPy:

```

from psychopy import visual, event
import ratcave as rc

camera_speed = 2

# Create Window and Add Keyboard State Handler to it's Event Loop
window = visual.Window()

# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Create Mesh
monkey = obj_reader.get_mesh("Monkey", position=(0, 0, -1.5), scale=.6)
torus = obj_reader.get_mesh("Torus", position=(-1, 0, -1.5), scale=.4)

# Create Scene
scene = rc.Scene(meshes=[monkey, torus])
scene.bgColor = 1, 0, 0

while True:

    dt = .016

```

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```

keys_pressed = event.getKeys()
if 'escape' in keys_pressed:
    window.close()
    break

# Move Camera
for key in keys_pressed:
    if key == 'left':
        scene.camera.x -= camera_speed * dt
    elif key == 'right':
        scene.camera.x += camera_speed * dt

# Rotate Meshes
monkey.rot_y += 15 * dt # dt is the time between frames
torus.rot_x += 80 * dt

# Draw Scene and Flip to Window
with rc.default_shader:
    scene.draw()
window.flip()

```

1.5.3 Tutorial 3: Custom GLSL Shaders, Sending Data to the Graphics Card

To get the most out of our graphics, many newer graphics engines use programs running on the graphics card called “shaders” to specify how objects should be shown on-screen. While teaching GLSL shaders is beyond the scope of this tutorial, and ratcave allows you to completely skip writing shaders at all by supplying a few useful ones, you’ll likely want to use a shader of your own.

In this tutorial, you’ll learn how to use ratcave to:

- Compile a Shader object and use it in the `Scene.draw()` function.
- Send data to the shader from Python as a Uniform variable.

Warning: This tutorial builds on the previous tutorials. If you’re just getting started, it’s recommended to go back and do those tutorials first!

Initial Script

Since the previous tutorials have already covered a lot of ratcave methods, let’s just start with the following script:

```

import pygame
import ratcave as rc

# Create window and OpenGL context (always must come first!)
window = pygame.window.Window()

# Load Meshes and put into a Scene
obj_reader = rc.WavefrontReader(rc.resources.obj_primitives)
torus = obj_reader.get_mesh('Torus', position=(0, 0, -2))

scene = rc.Scene(meshes=[torus])

```

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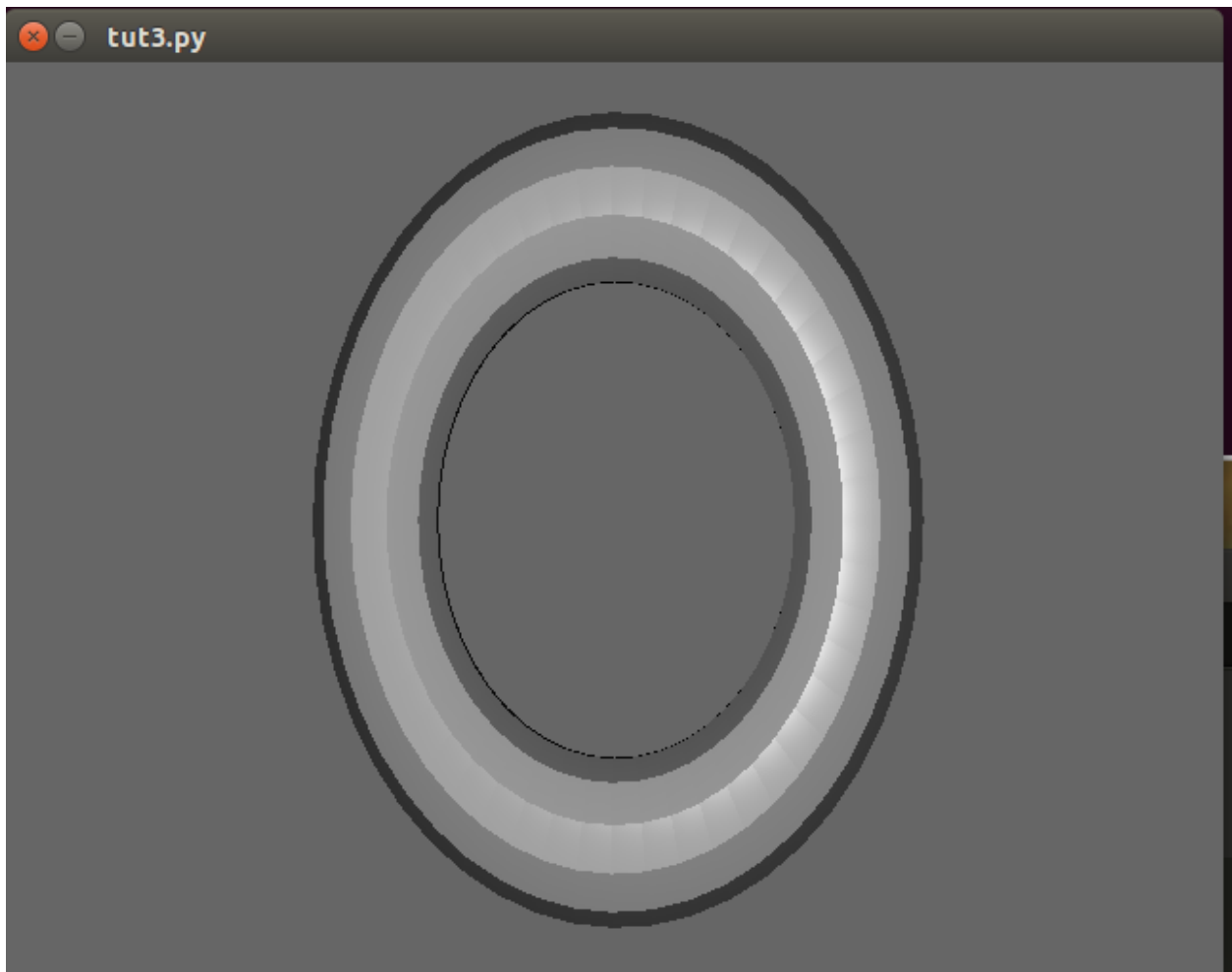
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```
# Constantly-Running mesh rotation, for fun
def update(dt):
    torus.rotation.y += 20. * dt
pyglet.clock.schedule(update)

# Draw Function
@window.event
def on_draw():
    with rc.default_shader:
        scene.draw()

# Pyglet's event loop run function
pyglet.app.run()
```

This code should display a rotating torus on the window.



Creating a Custom GLSL Shader

Now, one thing ratcave does automatically is use its built-in **genShader** Shader, if none is specified. This is to make it easier to get started. Let's replace it with our own custom shader program, which simply positions the mesh in 3D

space.

Shader programs come in two types. **Vertex Shaders** tell the graphics card where a vertex will appear on your screen. Our shader here will take data from the meshes, the lights, and the camera to determine where everything goes:

```
vert_shader = """
#version 120
attribute vec4 vertexPosition;
uniform mat4 projection_matrix, view_matrix, model_matrix;

void main()
{
    gl_Position = projection_matrix * view_matrix * model_matrix * vertexPosition;
}
"""
```

Warning: This shader requires OpenGL 3.3 drivers to be installed, along with an OpenGL 3.3-compatible graphics card on your system.

The **fragment shader** takes the vertex shader's position data determines what color a pixel on the screen will be. These can get quite complex, but we'll use a fairly simple one here, and just make everything automatically appear red:

```
frag_shader = """
#version 120
uniform vec3 diffuse;
void main()
{
    gl_FragColor = vec4(diffuse, 1.);
}
"""
```

Note: Normally, you would just put these shaders in their own files, but here we'll keep everything together and use them as strings.

Now, to make the Shader

```
shader = rc.Shader(vert=vert_shader, frag=frag_shader)
```

Using the shader during drawing is done in a shader keyword argument in `Scene.draw()`:

```
scene.draw(shader=shader)
```

Here is what the code should look like now:

```
import pyglet
import ratcave as rc
import time
import math

vert_shader = """
#version 120
attribute vec4 vertexPosition;
uniform mat4 projection_matrix, view_matrix, model_matrix;
```

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```

void main()
{
    gl_Position = projection_matrix * view_matrix * model_matrix * vertexPosition;
}
"""

frag_shader = """
#version 120
uniform vec3 diffuse;
void main()
{
    gl_FragColor = vec4(diffuse, 1.);
}
"""

shader = rc.Shader(vert=vert_shader, frag=frag_shader)

# Create window and OpenGL context (always must come first!)
window = pyglet.window.Window()

# Load Meshes and put into a Scene
obj_reader = rc.WavefrontReader(rc.resources.obj_primitives)
torus = obj_reader.get_mesh('Torus', position=(0, 0, -2))
torus.uniforms['diffuse'] = [.5, .0, .8]

scene = rc.Scene(meshes=[torus])

# Constantly-Running mesh rotation, for fun
def update(dt):
    torus.rotation.y += 20. * dt
    pyglet.clock.schedule(update)

def update_color(dt):
    torus.uniforms['diffuse'][0] = 0.5 * math.sin(time.clock() * 30) + .5
    pyglet.clock.schedule(update_color)

# Draw Function
@window.event
def on_draw():
    with shader:
        scene.draw()

# Pyglet's event loop run function
pyglet.app.run()

```

If you run it, you should see a flat red torus!



Sending Data to the Shader using Uniforms

Data can be attached to each object and sent to the shaders, to customize their behavior. Here, let's let the `Mesh.uniforms['diffuse']()` uniform control what color the torus takes.

In the fragment shader, add this line to initialize the **diffuse** uniform variable before the main function:

```
uniform vec3 diffuse;
```

In the python code, modify the `diffuse` key in the `Mesh.uniforms()` attribute:

```
torus.uniforms['diffuse'] = [.2, .8, .8]
```

Note: All ratcave objects come with some default uniforms, to make setting up easier and to make naming schemas more consistent. This shouldn't restrict you, though—new uniforms are automatically initialized when you add them dictionary-style, like `torus.uniforms['my_uniform'] = 3.0`!

If you run the code now, you should now see a cyan rotating torus. Let's make it a little more dynamic, shall we?

```
import time
import math
def update_color(dt):
    torus.uniforms['diffuse'][0] = 0.5 * math.sin(time.clock()) + 1
pyglet.clock.schedule(update_color)
```

Now the torus will change color!



Summary

Here's the updated code:

```
import pyglet
import ratcave as rc
import time
import math

vert_shader = """
#version 330

layout(location = 0) in vec3 vertexPosition;
```

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```

uniform mat4 projection_matrix, view_matrix, model_matrix;
out vec4 vVertex;

void main()
{
    vVertex = model_matrix * vec4(vertexPosition, 1.0);
    gl_Position = projection_matrix * view_matrix * vVertex;
}
"""

frag_shader = """
#version 330
out vec4 final_color;
uniform vec3 diffuse;
void main()
{
    final_color = vec4(diffuse, 1.);
}
"""

shader = rc.Shader(vert=vert_shader, frag=frag_shader)

# Create window and OpenGL context (always must come first!)
window = pyglet.window.Window()

# Load Meshes and put into a Scene
obj_reader = rc.WavefrontReader(rc.resources.obj_primitives)
torus = obj_reader.get_mesh('Torus', position=(0, 0, -2))
torus.uniforms['diffuse'] = [.5, .0, .8]

scene = rc.Scene(meshes=[torus])

# Constantly-Running mesh rotation, for fun
def update(dt):
    torus.rotation.y += 20. * dt
    pyglet.clock.schedule(update)

def update_color(dt):
    torus.uniforms['diffuse'][0] = 0.5 * math.sin(time.clock() * 10) + .5
    pyglet.clock.schedule(update_color)

# Draw Function
@window.event
def on_draw():
    with shader:
        scene.draw()

# Pyglet's event loop run function
pyglet.app.run()

```

In the next tutorial, we'll follow this up by drawing to an FBO dynamically!

1.5.4 Tutorial 4: Using Cubemapping to Render a CAVE VR System

CAVE VR relies on position updates from head trackers to render a virtual scene from the subject's perspective in virtual space.

- Two different `Scene` objects are used: - a virtual `Scene`, which contains the virtual environment to be cubemapped which is rendered from the subject's perspective (meaning, the camera goes where the subject is) - a "real" `Scene`, which contains just the model (also a `Mesh`) of the screen on which the VR is being projected, seen from the perspective of the video projector.

While this is difficult to show without having an actual tracking system, we'll illustrate this effect and the code needed to run it by making an animation:

Warning: This tutorial assumes knowledge gained from the previous tutorials. If you are just getting started, it's recommended to start from Tutorial 1!

Import Pyglet and ratcave, and Start the Window and OpenGL Context

At the beginning of the script:

```
import pyglet
import ratcave as rc
from ratcave.resources import cube_shader

window = pyglet.window.Window(resizable=True)
```

At the end of the script:

```
pyglet.app.run()
```

Create the Virtual Scene

Let's say that our virtual scene contains a red sphere and a cyan cube:

```
obj_reader = rc.WavefrontReader(rc.resources.obj_primitives)
sphere = obj_reader.get_mesh("Sphere", position=(0, 0, 2), scale=0.2)
sphere.uniforms['diffuse'] = 1, 0, 0

cube = obj_reader.get_mesh("Cube", position=(0, 0, 0), scale=0.2)
cube.uniforms['diffuse'] = 1, 1, 0

# Put inside a Scene
virtual_scene = rc.Scene(meshes=[sphere, cube])
```

Note that we have one object at the origin (0, 0, 0). Since our light is also at 0,0,0 by default, this may affect how things appear. Let's move the scene's light:

```
virtual_scene.light.position = 0, 3, -1
```

Create the Projected Scene

The Projected Scene is what is actually sent to the display. It will contain the screen (or rodent arena, if you're in a rodent neuroscience lab like us!). Here, let's just use a flat plane as our screen and use a monkey to show where

the subject is looking from (note: the subject isn't necessary for actual VR, it's just used here for illustration of the cubemapping approach).

```
monkey = obj_reader.get_mesh("Monkey", position=(0, 0, -1), scale=0.8)
screen = obj_reader.get_mesh("Plane", position=(0, 0, 1), rotation=(1.5, 180, 0))

projected_scene = rc.Scene(meshes=[monkey, screen], bgColor=(1., 1., 1.))
projected_scene.light.position = virtual_scene.light.position
projected_scene.camera = rc.Camera(position=(0, 4, 0), rotation=(-90, 0, 0))
```

Setting Your Cameras

A Camera used for Cubemapping

Cubemapping involves rendering an image from six different angles: up, down, left, right, forward, and backward, and stitching each of these six images onto the faces of a cube (for more info, see http://www.nvidia.com/object/cube_map_ogl_tutorial.html). For this algorithm to work, then, two of the Camera's properties must be customized:

- `Camera.aspect()`: The camera's image must be square (meaning it's width-to-height aspect ratio must be 1.0)
- `Camera.fov_y()`: The camera must be able to see 90-degrees, so that the sides all match up.

Altering the camera to be useful for cubemapping is straightforward:

```
cube_camera = rc.Camera(projection=rc.PerspectiveProjection(fov_y=90, aspect=1.))
virtual_scene.camera = cube_camera
```

The Projector Camera

In order to do CAVE VR, the camera you use to render the screen must exactly match not only the position and rotation of your video projector relative to the screen, but also the lens characteristics as well. This requires some calibration and measuring on your part, which will differ based on your setup and hardware. Since this is just a demo, let's just arbitrarily place the camera above the scene, looking down:

```
projected_scene.camera = rc.Camera(position=(0, 4, 0), rotation=(-90, 0, 0), z_far=6)
```

The aspect of the camera should, ideally, match that of the window. Let's do that here, using Pyglet's `on_resize` event handler so that it will happen automatically, even when the screen is resized:

```
@window.event
def on_resize(width, height):
    projected_scene.camera.aspect = width / float(height)
```

Create the OpenGL FrameBuffer and Cube Texture

So far, we've always rendered our Scenes straight to the monitor. However, we can also render to a texture! This lets us do all kinds of image postprocessing effects, but here we'll just use it to update a cube texture, so the screen always has the latest VR image:

```
cube_texture = rc.texture.TextureCube() # this is the actual cube texture
cube_fbo = rc.FBO(cube_texture)
```


All that's left is to apply the texture the screen:

```
screen.textures.append(cube_texture)
```

Warning: The built-in shader that comes with ratcave requires the subject's position to be sent to it through the **playerPos** uniform. This may be remedied in future releases, or can be changed in your own custom shaders. To do this, use: `screen.uniforms['playerPos'] = virtual_scene.camera.position`

Move the Subject

Let's have the Monkey move left-to-right, just to illustrate what cubemapping does:

```
clock = 0.
def update(dt):
    global clock
    clock += dt
    monkey.position.x = math.sin(1.3 * clock)
    virtual_scene.camera.position.xyz = monkey.position.xyz
    screen.uniforms['playerPos'] = virtual_scene.camera.position.xyz
pyglet.clock.schedule(update)
```

Draw the Scenes

All that's left is for the scenes to be drawn. The `virtual_scene` should be drawn to the FBO, and the projected_scene to the window. To perform the rotations correctly and in the right order, a convenient `Scene.draw360_to_texture()` method has been supplied:

```
@window.event
def on_draw():
    with cube_shader:
        with cube_fbo as fbo:
            virtual_scene.draw360_to_texture(fbo.texture)
        projected_scene.draw()
```

Summary

Here's the full code:

```
import pyglet
import ratcave as rc
import math, time
from ratcave.resources import cube_shader

window = pyglet.window.Window(resizable=True)

# Assemble the Virtual Scene
obj_reader = rc.WavefrontReader(rc.resources.obj_primitives)
sphere = obj_reader.get_mesh("Sphere", position=(0, 0, 2), scale=0.2)
sphere.uniforms['diffuse'] = 1, 0, 0

cube = obj_reader.get_mesh("Cube", position=(0, 0, 0), scale=0.2)
```

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```

cube.uniforms['diffuse'] = 1, 1, 0

# virtual_scene = rc.Scene(meshes=[sphere, cube], bgColor=(0., 0., 1.))
virtual_scene = rc.Scene(meshes=[cube, sphere], bgColor=(0., 0., 1.))
virtual_scene.light.position.xyz = 0, 3, -1

cube_camera = rc.Camera(projection=rc.PerspectiveProjection(fov_y=90, aspect=1.))
virtual_scene.camera = cube_camera

# Assemble the Projected Scene
monkey = obj_reader.get_mesh("Monkey", position=(0, 0, -1), scale=0.8)
screen = obj_reader.get_mesh("Plane", position=(0, 0, 1), rotation=(1.5, 180, 0))

projected_scene = rc.Scene(meshes=[monkey, screen, sphere, cube], bgColor=(1., .5, 1.
↪))
projected_scene.light.position = virtual_scene.light.position
projected_scene.camera = rc.Camera(position=(0, 4, 0), rotation=(-90, 0, 0))
projected_scene.camera.projection.z_far = 6

# Create Framebuffer and Textures
cube_texture = rc.texture.TextureCube(width=1024, height=1024) # this is the actual_
↪cube texture
cube_fbo = rc.FBO(texture=cube_texture)
screen.textures.append(cube_texture)

clock = 0.
def update(dt):
    global clock
    clock += dt
    monkey.position.x = math.sin(1.3 * clock)
    virtual_scene.camera.position.xyz = monkey.position.xyz
    screen.uniforms['playerPos'] = virtual_scene.camera.position.xyz
    pygamelet.clock.schedule(update)

@window.event
def on_draw():
    with cube_shader:
        with cube_fbo as fbo:
            virtual_scene.draw360_to_texture(fbo.texture)
            projected_scene.draw()

pygamelet.app.run()

```

1.5.5 Tutorial 5: Parenting objects together - Solar System

In this tutorial you will learn how to use ratcave to create solar system animation. We will show how to create layout dependencies (in between parent and children objects), by defining relationships between objects. Additionally the Empty Entity objects will be introduced.

Warning: This tutorial builds on the previous tutorials. If you're just getting started, it's recommended to go back and do those tutorials first!

Initial Script

Since the previous tutorials have already covered a lot of ratcave methods, let's just start with the following script:

```
import pyglet
import ratcave as rc

# Create Window
window = pyglet.window.Window(resizable=True)

def update(dt):
    pass
pyglet.clock.schedule(update)

# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)
```

Meshes and Empty Entities

We can not define more than one rotation speed for the sun object. To introduce different rotation for each of the planets, we need to use Empty Entities. Empty Entities are objects, that occupy physical space, but doesn't actually draw anything when `Scene.draw()` is called (just passing the values). Later, we can set rotation speed for each of the Empty Entity object:

```
# Create Meshes
sun = obj_reader.get_mesh("Sphere", name='sun')
mercury = obj_reader.get_mesh("Sphere", scale=.1, name='mercury')
venus = obj_reader.get_mesh("Sphere", scale=.2, name='venus')
earth = obj_reader.get_mesh("Sphere", scale=.2, name='earth')
mars = obj_reader.get_mesh("Sphere", scale=.2, name='mars')
jupyter = obj_reader.get_mesh("Sphere", scale=.4, name='jupyter')
moon = obj_reader.get_mesh("Sphere", scale=.5, name='moon')

# Create Empty Entities
empty_mercury = rc.EmptyEntity(name='sun_mercury')
empty_venus = rc.EmptyEntity(name='sun_venus')
empty_earth = rc.EmptyEntity(name='sun_earth')
empty_mars = rc.EmptyEntity(name='sun_mars')
empty_jupyter = rc.EmptyEntity(name='sun_jupyter')
```

Define Relationships and Relative Positions

Relationships Between Objects

To define layout relationship in between objects in ratcave, user has to link them together using `SceneGraph` properties:

- `Mesh.add_child()`

- `Mesh.add_children()`
- `Mesh.parent()`

The following code does the job:

```
# Define Relationships
sun.add_children(empty_merkury, empty_earth, empty_venus, empty_mars, empty_jupyter)

empty_merkury.add_child(merkury)
empty_venus.add_child(venus)
empty_earth.add_child(earth)
empty_mars.add_child(mars)
empty_jupyter.add_child(jupyter)

earth.add_child(moon)
```

Relative Objects Positions

Additionally it is important to define the position of the children in relative position to the parent (position of planets in relation to the sun). This can be done in a following way:

```
# Define Relative Positions
sun.rotation.x = 50
sun.position.xyz = 0, 0, -12

merkury.position.z += 1
venus.position.z += 2
earth.position.z += 3
mars.position.z += 4
jupyter.position.z += 5

moon.position.z += 1
```

Setting Rotations

Each of the roations has to be set separately:

```
def on_draw():
    with rc.default_shader:
        sun.rotation.y += 0.5
        earth.rotation.y += 0.5
        empty_merkury.rotation.y += 2
        empty_venus.rotation.y += 1.5
        empty_earth.rotation.y += 1
        empty_mars.rotation.y += 0.75
        empty_jupyter.rotation.y += 0.5
```

Scene - Update

After defintion of a scene:

```
scene = rc.Scene(meshes=sun, bgColor=(0,0,0))
```

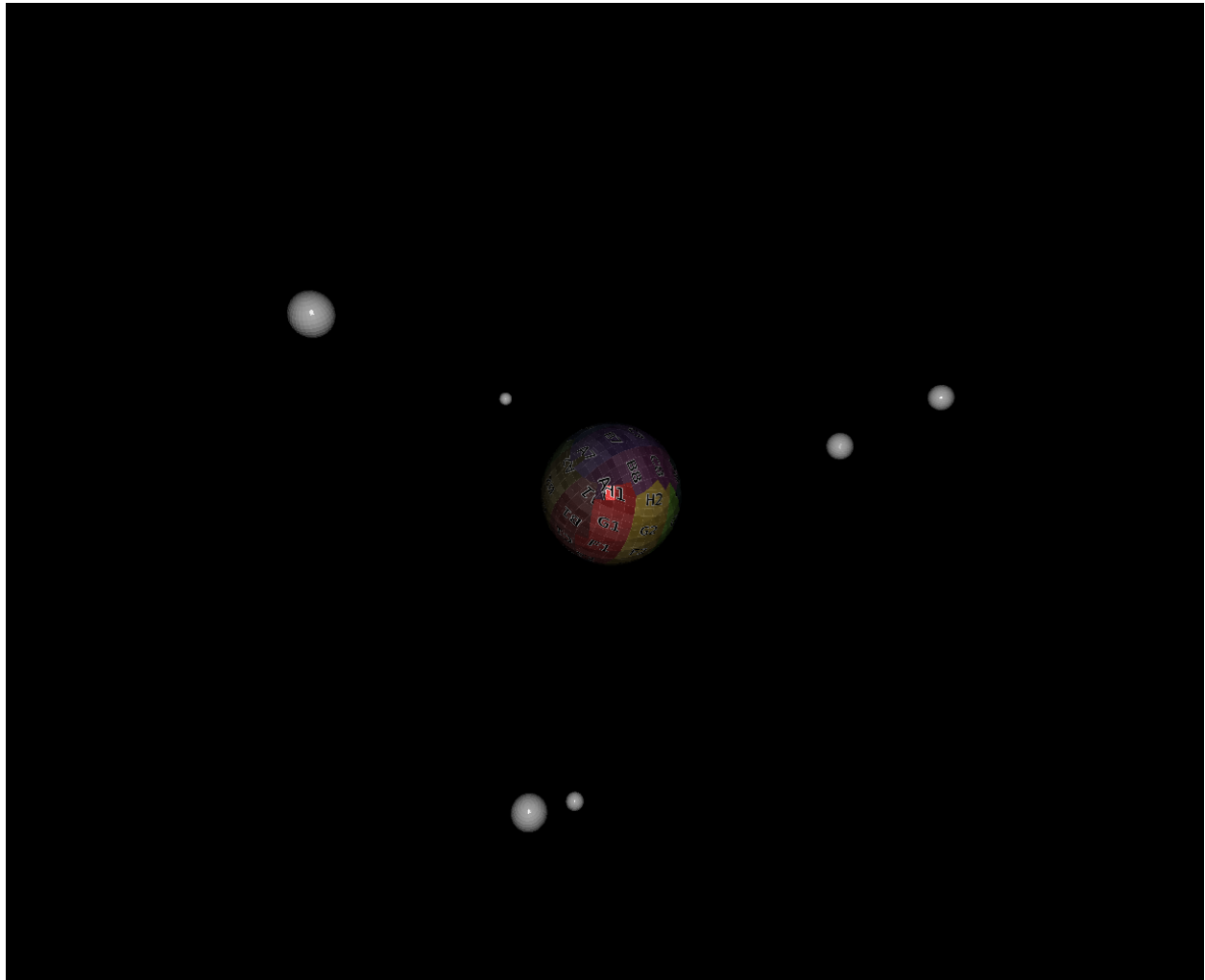
sun and all of its children now get drawn when `scene.draw()` gets called. There is no further need of updating any of the Meshes (or its children) included in the scene. You can also decide which of the elements are going to be drawn, by calling them separately, the position of the planets will still be relative to the sun (also when sun itself is not being drawn):

```
def on_draw():
    window.clear()
    with rc.default_shader, scene.camera, scene.light:
        sun.draw()
        earth.draw()
```

Additionally you can parent the camera and light to one of the Mesh objects. It can be done in following manner:

```
#Define Relationships For Cameras and Objects
earth.add_child(scene.camera)
earth.add_child(scene.light)
```

If you run it, you should see this simulation of solar system:



Summary

Here is the full code for the Tutorial 5:

```
import pyglet
from pyglet.window import key
import ratcave as rc

# Create Window
window = pyglet.window.Window(resizable=True)
keys = key.KeyStateHandler()
window.push_handlers(keys)

def update(dt):
    pass
pyglet.clock.schedule(update)

# Insert filename into WavefrontReader.
obj_filename = rc.resources.obj_primitives
obj_reader = rc.WavefrontReader(obj_filename)

# Create Meshes
sun = obj_reader.get_mesh("Sphere", name='sun')
merkury = obj_reader.get_mesh("Sphere", scale=.1, name='merkury')
venus = obj_reader.get_mesh("Sphere", scale=.2, name='venus')
earth = obj_reader.get_mesh("Sphere", scale=.2, name='earth')
mars = obj_reader.get_mesh("Sphere", scale=.2, name='mars')
jupyter = obj_reader.get_mesh("Sphere", scale=.4, name='jupyter')
moon = obj_reader.get_mesh("Sphere", scale=.5, name='moon')

# Create Empty Entities
empty_merkury = rc.EmptyEntity(name='sun_merkury')
empty_venus = rc.EmptyEntity(name='sun_venus')
empty_earth = rc.EmptyEntity(name='sun_earth')
empty_mars = rc.EmptyEntity(name='sun_mars')
empty_jupyter = rc.EmptyEntity(name='sun_jupyter')

# Define Relationships
sun.add_children(empty_merkury, empty_earth, empty_venus, empty_mars, empty_jupyter)

empty_merkury.add_child(merkury)
empty_venus.add_child(venus)
empty_earth.add_child(earth)
empty_mars.add_child(mars)
empty_jupyter.add_child(jupyter)

earth.add_child(moon)

# Define Relative Positions
sun.rotation.x = 50
sun.position.xyz = 0, 0, -12

merkury.position.z += 1
venus.position.z += 2
earth.position.z += 3
mars.position.z += 4
jupyter.position.z += 5

moon.position.z += 1
```

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```
sun.textures.append(rc.Texture.from_image(rc.resources.img_colorgrid))

# Create Scene
scene = rc.Scene(meshes=sun, bgColor=(0,0,0))
scene.camera.projection.z_far = 20

# Define Relationships For Cameras and Objects
# earth.add_child(scene.camera)
# earth.add_child(scene.light)

planets = [sun, earth, jupyter]

def move_camera(dt):
    '''function used to parent the camera to a different planet'''
    if keys[key.LEFT]:
        cam_parent = planets.pop(0)
        cam_parent.add_child(scene.camera)
        planets.append(cam_parent)

pyglet.clock.schedule(move_camera)

@window.event
def on_draw():
    window.clear()
    sun.rotation.y += 0.5
    earth.rotation.y += 0.5
    empty_merkury.rotation.y += 2
    empty_venus.rotation.y += 1.5
    empty_earth.rotation.y += 1
    empty_mars.rotation.y += 0.75
    empty_jupyter.rotation.y += 0.5

    with rc.default_shader:
        scene.draw()

pyglet.app.run()
```

1.5.6 Tutorial 6: Stereopsis (3D)

Up until now, we were creating a scene that contains 3D objects, and we were looking at the scene through our screen(s). This means the 3D scene is projected onto a 2D screen. We still observe depth due to motion parallax, lighting, and other so-called monocular cues, but we do not have a 3D view which gives us a better sense of objects' depth.

Stereopsis is the perception of depth obtained through binocular disparity, which requires the graphics package to provide separate images for each eye. Luckily, ratcave does that!

Let's get the monkey on our screen.

Initial Script

Here is a script which displays the monkey on your screen:

```
import pyglet
import ratcave as rc

window = pyglet.window.Window(resizable=True)

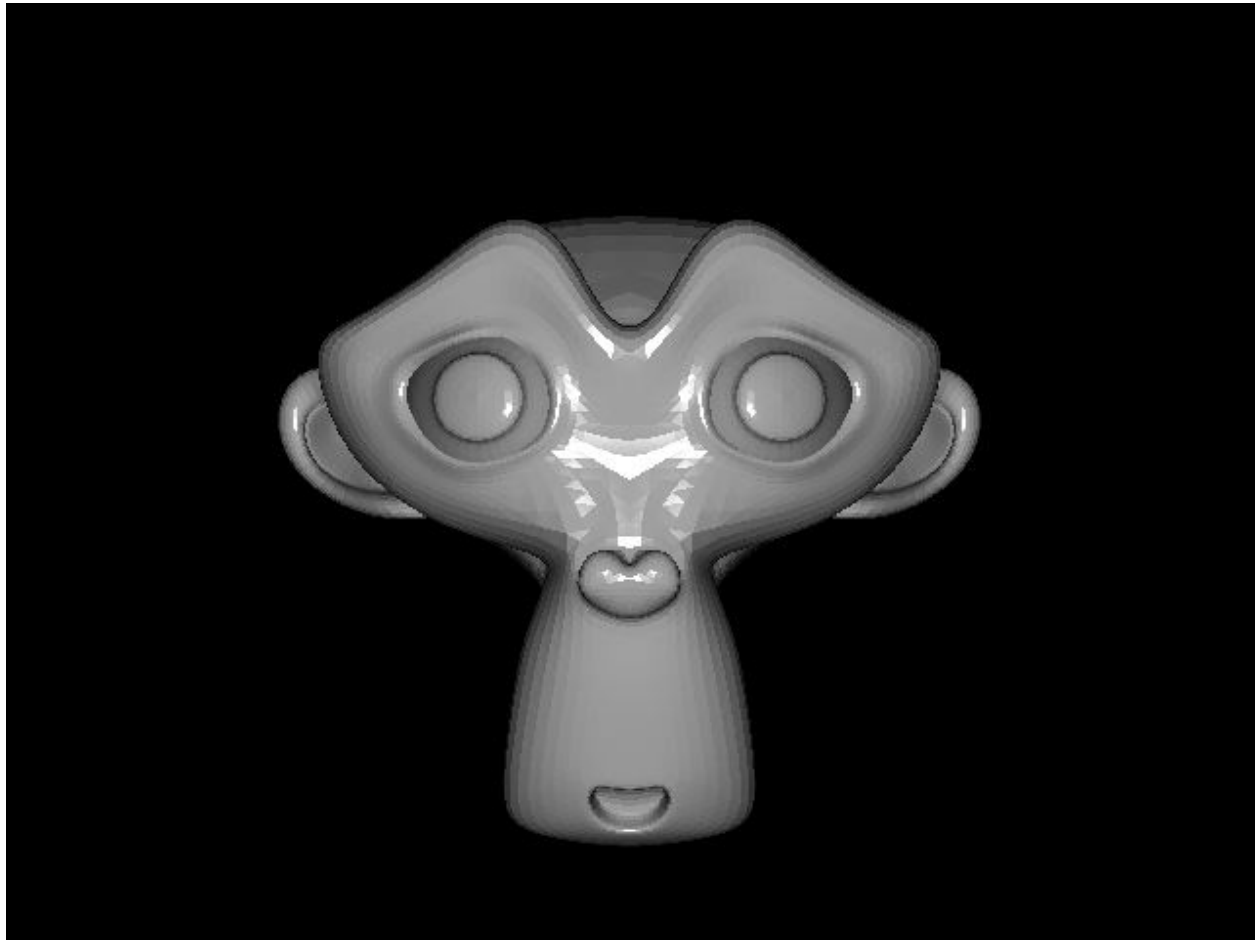
model_file = rc.resources.obj_primitives
monkey = rc.WavefrontReader(model_file).get_mesh('Monkey')
monkey.position.xyz = 0, 0, -2.5

camera = rc.Camera()

@window.event
def on_draw():
    window.clear()
    with rc.default_shader, rc.default_states, camera:
        monkey.draw()

def update(dt):
    pass
pyglet.clock.schedule(update)

pyglet.app.run()
```



When the light is reflected from the monkey's face we get a feeling that the monkey is a 3D object. But are we seeing

3D? No.

StereoCameraGroup

Earlier we talked about stereopsis - having two different images for each eye to perceive depth. Therefore, the first step is to actually have two eyes. The “eye” in our virtual scene is the camera. We can create a StereoCameraGroup object which creates those two cameras automatically for us. We simply replace Camera() with StereoCameraGroup():

```
import pyglet
import ratcave as rc

window = pyglet.window.Window(resizable=True)

model_file = rc.resources.obj_primitives
monkey = rc.WavefrontReader(model_file).get_mesh('Monkey')
monkey.position.xyz = 0, 0, -2.5

camera = rc.StereoCameraGroup()
```

At this point we have a camera group that with a little bit more work can give us depth.

3D Display Mode

Due to different hardware solutions, there are two modes that stereopsis can be implemented on your screen:

- Anaglyph (red and blue)
- Active mode

Anaglyph mode is the simplest one. In this mode, we apply a color filter to the image that is seen by the camera. That is, for instance, we filter red color for right camera (right eye), and filter the cyan for the left camera (left eye).

The other mode is the active mode which utilizes active shutter 3D glasses. This mode requires your graphics card to support 3D displays. We will go through implementation of anaglyph 3D mode in this tutorial and to see 3D at the end of this tutorial, all you need is an anaglyph glasses.

Switching between cameras

After creating a StereoCameraGroup object, we have two cameras: camera.left and camera.right:

```
@window.event
def on_draw():
    window.clear()
    with rc.default_shader, rc.default_states:

        with camera.right:
            monkey.draw()

        with camera.left:
            monkey.draw()
```

When you run the above code, you should be able to see two overlapping monkeys. However, this is still not useful with the anaglyph glasses - we need to apply a color filter. To do that, we can use OpenGL glColorMask() provided by pyglet.gl class. with this function we can activate or deactivate color channels on our scene. For instance, to deactivate red channel:

```
from pyglet.gl import gl

gl.glColorMask(True, False, False, True)
```

Now if we apply this color filter with its corresponding camera, the `on_draw()` changes to:

```
@window.event
def on_draw():
    gl.glColorMask(True, True, True, True)
    window.clear()

    with rc.default_shader, rc.default_states:
        with camera.right:
            gl.glColorMask(False, True, True, True)
            monkey.draw()

    gl.glClear(gl.GL_DEPTH_BUFFER_BIT)

    with camera.left:
        gl.glColorMask(True, False, False, True)
        monkey.draw()
```

Make sure to add `glClear(gl.GL_DEPTH_BUFFER_BIT)` before drawing the scene of the second camera. This ensures that the depth information of the previously drawn object is removed and the color information of both camera scenes are drawn on the screen without the interruption of depth testing.

Now you can use your anaglyph glasses and enjoy the 3D view. Here is the complete code, and its output:

```
import pyglet
import ratcave as rc
from pyglet.gl import gl
from pyglet.window import key

window = pyglet.window.Window(resizable=True)
keys = key.KeyStateHandler()
window.push_handlers(keys)

# get an object
model_file = rc.resources.obj_primitives
monkey = rc.WavefrontReader(model_file).get_mesh('Monkey')
monkey.position.xyz = 0, 0, -2.5

camera = rc.StereoCameraGroup()

@window.event
def on_draw():
    gl.glColorMask(True, True, True, True)
    window.clear()

    with rc.default_shader, rc.default_states:
        with camera.right:
            gl.glColorMask(False, True, True, True)
            monkey.draw()

    gl.glClear(gl.GL_DEPTH_BUFFER_BIT)

    with camera.left:
```

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```

        gl.glColorMask(True, False, False, True)
        monkey.draw()

t = 0
def update(dt):
    if keys[key.UP]:
        monkey.position.z -= .01
    elif keys[key.DOWN]:
        monkey.position.z += .01

    global t
    t += .5
    monkey.rotation.y = t
    for cam in camera.cameras:
        cam.uniforms['projection_matrix'] = cam.projection_matrix

pyglet.clock.schedule(update)

pyglet.app.run()
```

1.6 CAVE Virtual Reality

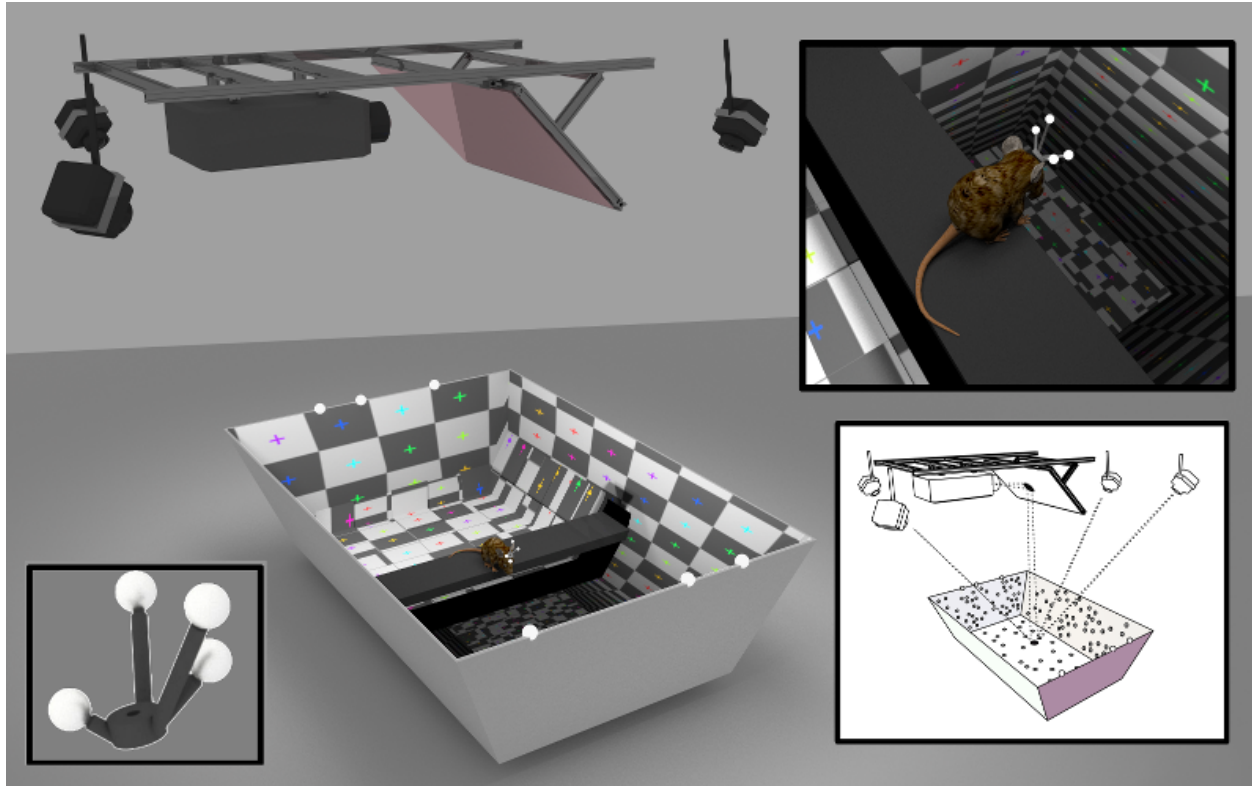
Building your own virtual reality setup requires several parts:

- A 3D Graphics Engine (to render the virtual environment)
- Video Displays (to show the environment to the user). Ideally, these should be large enough to allow the user to see a large amount of the virtual environment! This means you'll either want something that is: - Head-fixed (the display is attached to the user's head, so that they can always see a virtual space, no matter where they turn) - Projected on surfaces all around the user. If there are screens in a 360-degree arc around the user, you get a CAVE system!
- A head tracking system, to update the virtual environment when the user moves their head. This is one of the things that gives such a strong immersive sense to virtual reality.

1.6.1 Our Setup

The VR setup we made is intended for use by rats, mice, and gerbils for cognitive neuroscience experiments, which is why we call this python package ratcave! In selecting our components, we were both limited by and helped by the small sizes of our users:

- We use a simplified 3D graphics engine, to make our experiment scripts small and simple to deploy (python, with pyglet or psychopy + ratcave)
- Head-mounting a display on mice wasn't an option because of their small size, so we use a single wide-lens video projector, which front-projects onto the walls and floor of the rodent's arena. This gives them a 360-degree view of the virtual environment, while reducing the computational demands of our setup.
- We use an optical tracking system for measuring the rodent's head space via data collected from camera arrays. We use _NaturalPoint's Optitrack System: <http://www.optitrack.com/> - To control this tracking system from Python, we wrote a Python package called MotivePy, available here: <https://github.com/neuroneuro15/motivepy> - To access the data from the tracking system on a remote client in our experiment scripts, we wrote another Python client called NatNetClient, available here: <https://github.com/neuroneuro15/natnetclient>



1.6.2 Example VR Experiment Script

Writing a VR Script is relatively straightforward, and involves three main components:

- 1) Connect to your tracking system
- 2) Render your 3D environment
- 3) In a loop, re-render the 3D environment, setting the camera position at the new eye position of your user.

In Pyglet, ratcave, and NatNetClient, this would something like this:

```
import pyglet
import ratcave as rc
import natnetclient

# Connect to Tracking System
client = natnetclient.NatClient(ip='197.0.0.10', port=5023)
user = client.rigid_bodies['User']

# Create Scene and put in a draw loop
window = pyglet.window.Window()
reader = rc.WavefrontReader(rc.resources.obj_primitives)
scene = rc.scene(meshes=[reader.get_mesh('Sphere', position=(0, 1, -2))])

@window.event()
def on_draw():
    scene.draw()

# Update camera position, based on user's position
```

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```
def update(dt):
    scene.camera.position = user.position
pyglet.clock.schedule()

# Start App
pyglet.app.run()
```

In Psychopy, which is written in a more imperative format, it looks like this:

```
from psychopy import visual, event
import ratcave as rc
import natnetclient

# Connect to Tracking System
client = natnetclient.NatClient(ip='197.0.0.10', port=5023)
user = client.rigid_bodies['User']

window = visual.Window()

# Main Loop
while 'escape' not in event.getKeys():

    # Create Scene
    reader = rc.WavefrontReader(rc.resources.obj_primitives)
    scene = rc.scene(meshes=[reader.get_mesh('Sphere', position=(0, 1, -2))

    # Update Camera position, based on user's position
    scene.camera.position = user.position

    # Draw
    scene.draw()
    window.flip()
```

1.6.3 Modular Nature of VR

At its core, VR does not stand for any one technology. Whether you are using head-mounted screens or projector, optical camera array tracking systems or treadmills, or any sort of graphics engine out there, the key is that you are changing the camera position on a loop, based on some user movement. Hopefully, this description has given you some ideas for how you can set up your own VR system!

1.7 API Documentation

1.7.1 Main Modules Contents

Mesh

Camera

Texture

Scene

Shader

1.7.2 Main Topic Details

Meshes

`mesh.py`

`wavefront.py`

Cameras

`camera.py`

`light.py`

Textures

`texture.py`

Relationships

`scene.py`

`scenegraph.py`

`physical.py`

`coordinates.py`

Shader

`shader.py`

Other classes

`vertex.py`

`experimental.py`

- `genindex`