Fresnel Documentation

Release 0.12.0

The Regents of the University of Michigan

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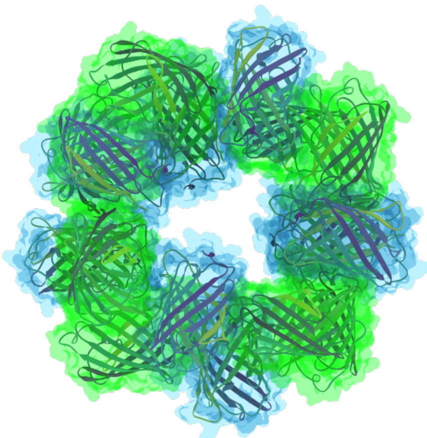
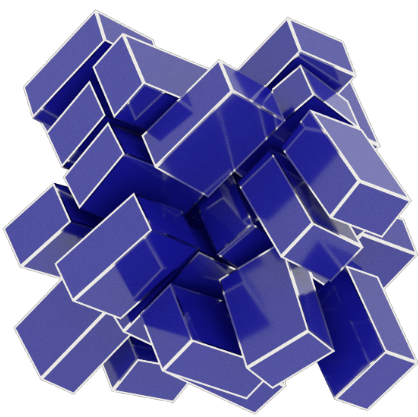
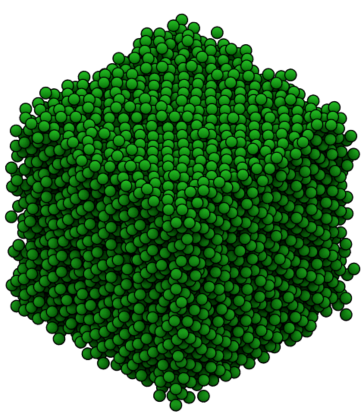
EXAMPLES

fresnel is a python library for path tracing publication quality images of soft matter simulations in real time. The fastest render performance is possible on NVIDIA GPUs using their OptiX ray tracing engine. **fresnel** also supports multi-core CPUs using Intel's Embree ray tracing kernels. Path tracing enables high quality global illumination and advanced rendering effects. **Fresnel** offers intuitive material parameters (like *roughness*, *specular*, and *metal*) and simple predefined lighting setups (like *cloudy* and *lightbox*).

Here are a few samples of what **fresnel** can do:



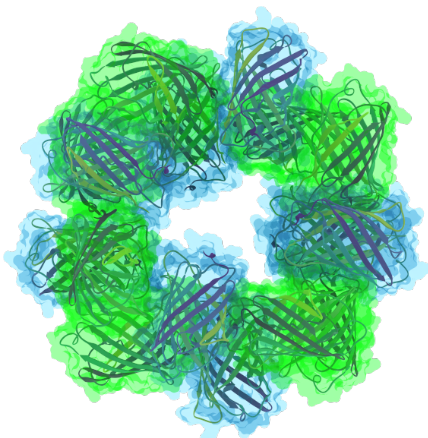


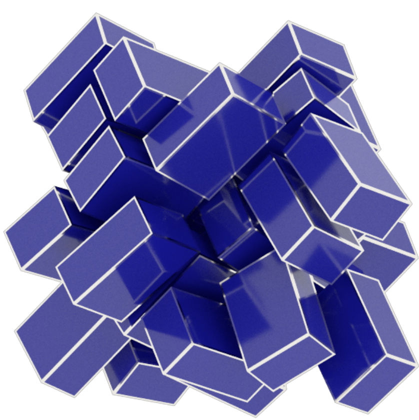


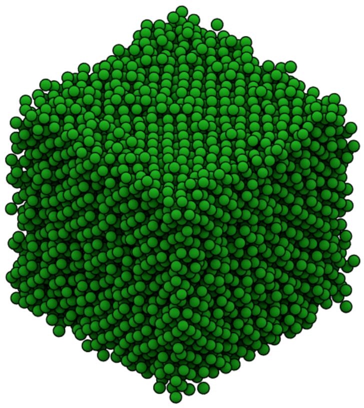
CHAPTER

ONE

GALLERY





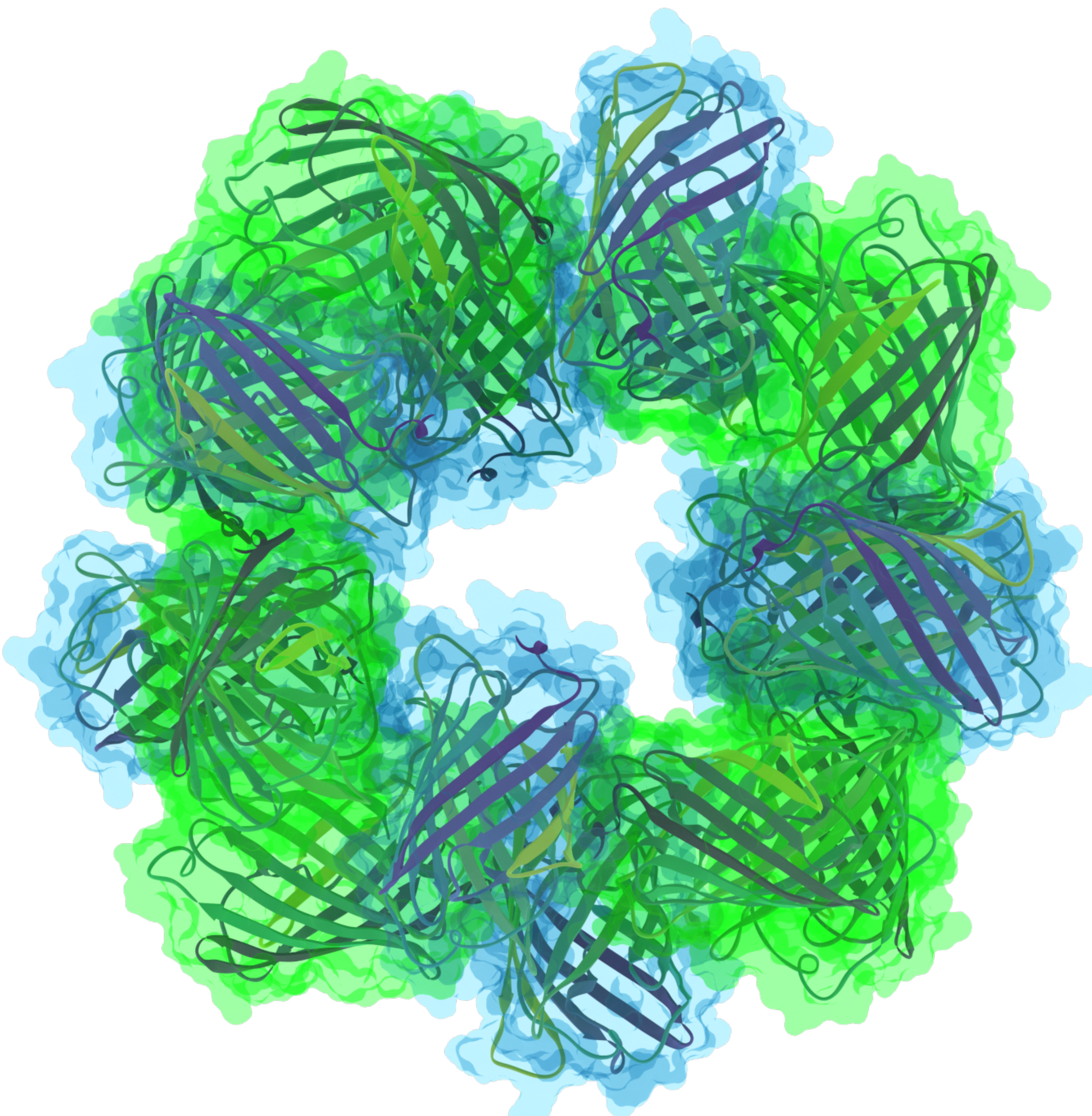


CHAPTER

TWO

RESEARCH

2.1 Protomer



Protomer on the cover of nature chemistry volume 11, issue 3:

- Ribbon geometry: `geometry.Mesh`
  - `material`: *roughness* = 1.0, *specular* = 1.0, *metal* = 0, *spec_trans* = 0
  - Generated with: ribbon
- Molecular surface: `geometry.Mesh`
  - `material`: *roughness* = 2.0, *specular* = 0.95, *metal* = 0, *spec_trans* = 0.95
  - Generated with MSMS
- Lighting: `light.lightbox` with background light
- Rendered with: `tracer.Path`: *samples* = 64, *light_samples* = 32 on the GPU

Author

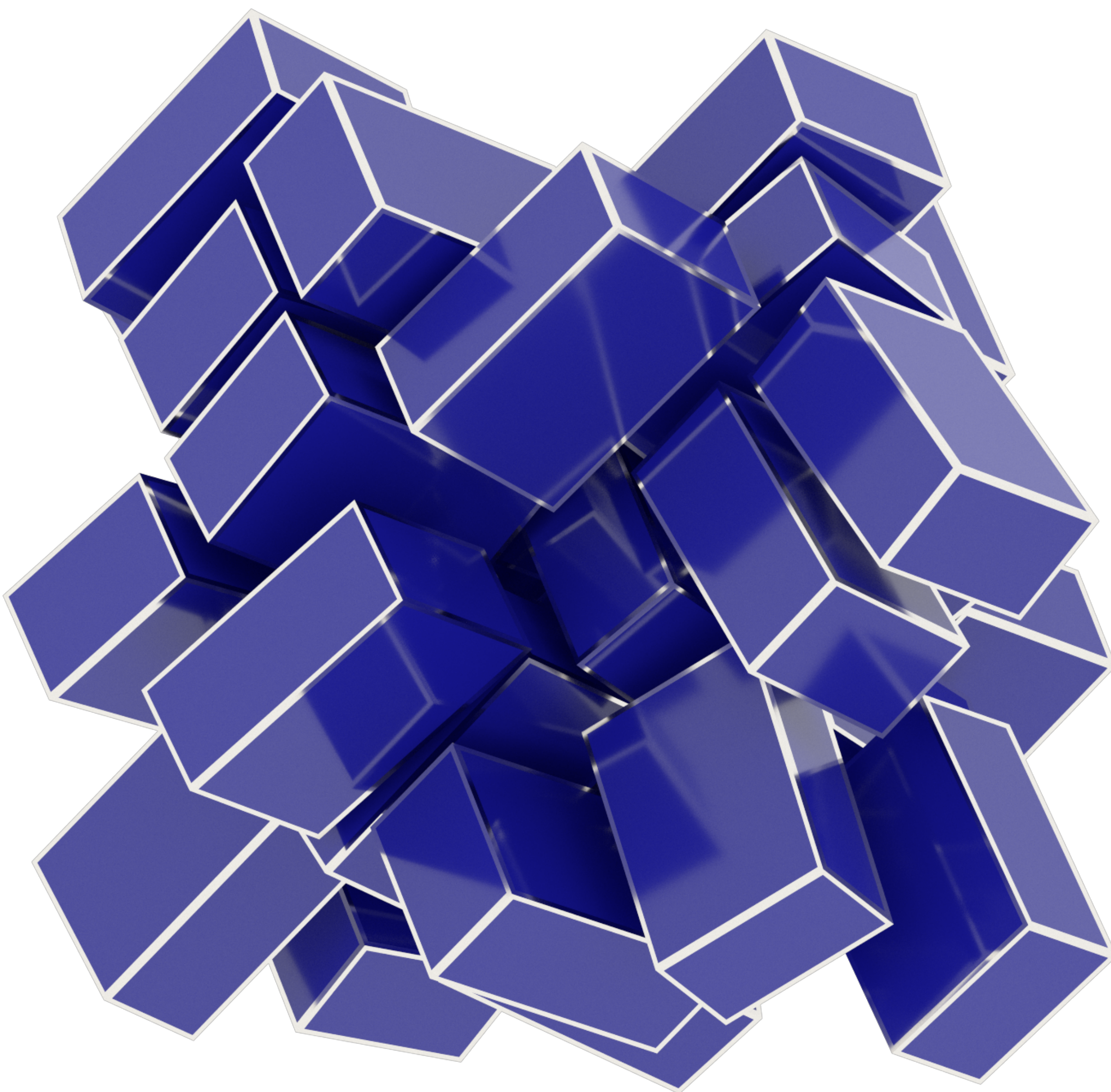
Jens Glaser

CHAPTER

THREE

FEATURES

3.1 Cuboids



Cuboid example script:

- Geometry: `geometry.ConvexPolyhedron`: *outline_width* = 0.015
  - `material`: *roughness* = 0.1, *specular* = 1, *metal* = 0, *spec_trans* = 0
  - `outline_material`: *roughness* = 0.1, *metal* = 1, *spec_trans* = 0, *color* = (0.95,0.93,0.88)
  - position, orientation: output of a HOOMD simulation
- Lighting: `light.lightbox`
- Rendered with: `tracer.Path`: *samples* = 256, *light_samples* = 16

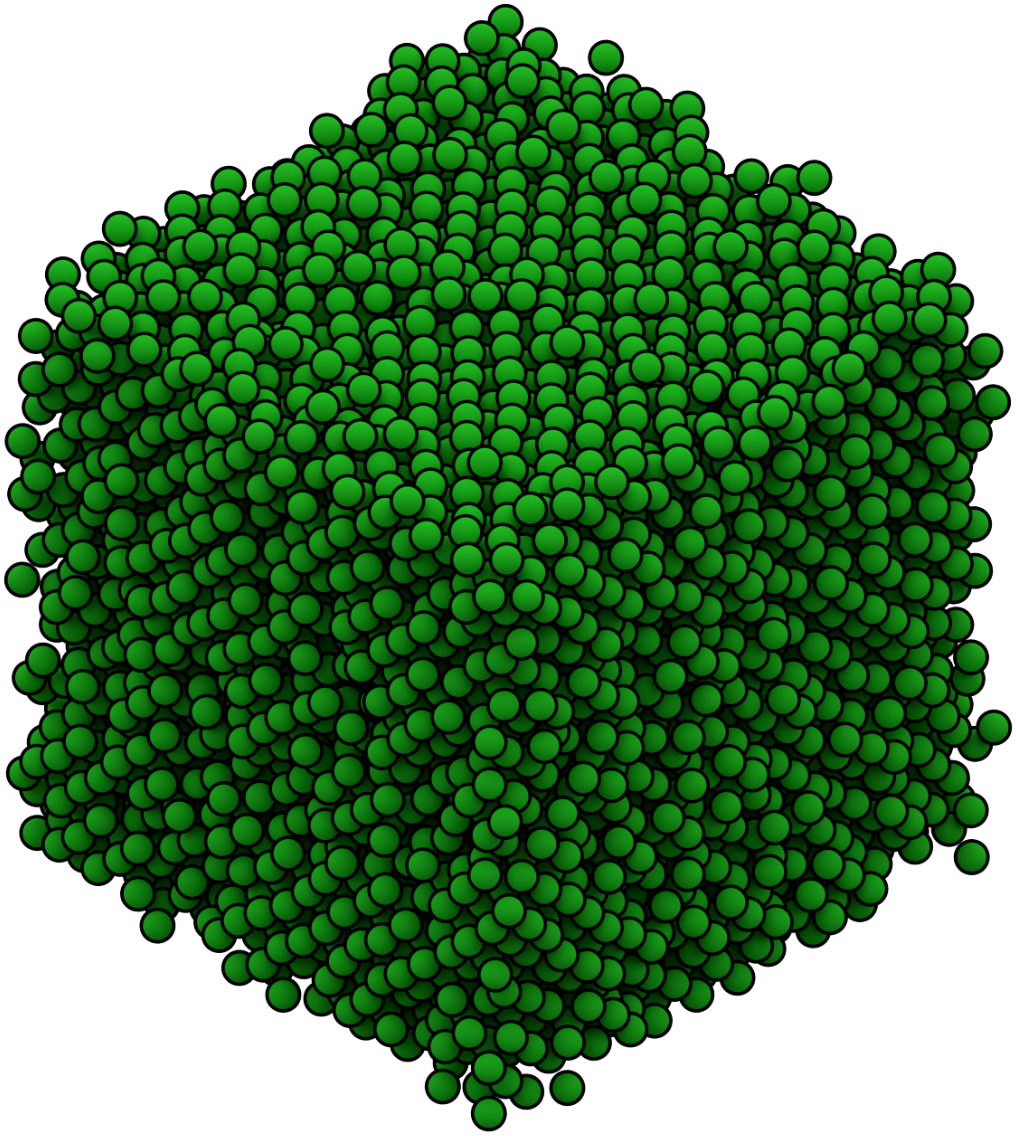
Source code

```
import PIL

data = numpy.load('cuboids.npz')

scene = fresnel.Scene(fresnel.Device(mode='cpu'))
scene.lights = fresnel.light.lightbox()
W, H, D = data['width']
poly_info = fresnel.util.convex_polyhedron_from_vertices(
    [[-W, -H, -D], [-W, -H, D], [-W, H, -D], [-W, H, D],
     [W, -H, -D], [W, -H, D], [W, H, -D], [W, H, D]])

geometry = fresnel.geometry.ConvexPolyhedron(
    scene, poly_info,
    position=data['position'],
    orientation=data['orientation'],
    outline_width=0.015)
geometry.material = fresnel.material.Material(
    color=fresnel.color.linear([0.1, 0.1, 0.6]),
    roughness=0.1,
    specular=1)
geometry.outline_material = fresnel.material.Material(
    color=(0.95, 0.93, 0.88),
    roughness=0.1,
    metal=1.0)

scene.camera = fresnel.camera.fit(scene, view='front')
out = fresnel.pathtrace(scene, samples=64,
```

Author

Joshua A. Anderson

3.2 Spheres



Spheres example script:

- Geometry: `geometry.Sphere`: *radius* = 0.5, *outline_width* = 0.1
  - `material`: *roughness* = 0.8, *specular* = 0.2, *metal* = 0, *spec_trans* = 0
  - `outline_material`: *solid* = 1, *color* = (0,0,0)
  - positions: output of a HOOMD simulation
- Lighting: `light.cloudy`
- Rendered with: `tracer.Path`: *samples* = 256, *light_samples* = 16

Source code

```
import PIL

data = numpy.load('spheres.npz')

scene = fresnel.Scene()
scene.lights = fresnel.light.cloudy()

geometry = fresnel.geometry.Sphere(
    scene,
    position=data['position'],
    radius=0.5,
    outline_width=0.1)

geometry.material = fresnel.material.Material(
    color=fresnel.color.linear([0.1, 0.8, 0.1]),
    roughness=0.8,
    specular=0.2)

out = fresnel.pathtrace(scene, samples=64,
```

Author

Joshua A. Anderson

CHAPTER

FOUR

INSTALLATION

Fresnel binaries are available in the glotzerlab-software Docker/Singularity images and in packages on conda-forge. You can also compile **fresnel** from source.

4.1 Binaries

4.1.1 Anaconda package

Fresnel is available on conda-forge. To install, first download and install miniconda. Then add the `conda-forge` channel and install **fresnel**:

```
conda config --add channels conda-forge
conda install fresnel
```

jupyter and **matplotlib** are required to execute the fresnel example notebooks:

```
conda install jupyter matplotlib
```

Note: The **fresnel** package on `conda-forge` does not support GPUs

4.1.2 Singularity / Docker images

See the glotzerlab-software documentation for container usage information and cluster specific instructions.

4.2 Compile from source

4.2.1 Obtain the source

Download source releases directly from the web: https://glotzerlab.engin.umich.edu/downloads/fresnel:

```
curl -O https://glotzerlab.engin.umich.edu/downloads/fresnel/fresnel-v0.12.0.tar.gz
```

Or, clone using git:

```
git clone --recursive  https://github.com/glotzerlab/fresnel
```

Fresnel uses git submodules. Either clone with the `--recursive` option, or execute `git submodule update --init` to fetch the submodules.

4.2.2 Configure a virtual environment

When using a shared Python installation, create a virtual environment where you can install **fresnel**:

```
python3 -m venv /path/to/virtual/environment --system-site-packages
```

Activate the environment before configuring and before executing **fresnel** scripts:

```
source /path/to/virtual/environment/bin/activate
```

Tell CMake to search in the virtual environment first:

```
export CMAKE_PREFIX_PATH=/path/to/virtual/environment
```

Note: Other types of virtual environments (such as *conda*) may work, but are not thoroughly tested.

4.2.3 Install Prerequisites

fresnel requires:

- C++11 capable compiler
- CMake >= 3.8
- pybind11 >= 2.2
- Python >= 3.6
- numpy
- Qhull >= 2015.2
- For CPU execution (required when `ENABLE_EMBREE=ON`):
  - Intel TBB >= 4.3.20150611
  - Intel Embree >= 3.0.0
- For GPU execution (required when `ENABLE_OPTIX=ON`):
  - OptiX >= 4.0
  - CUDA >= 7.5

`ENABLE_EMBREE` (*defaults ON*) and `ENABLE_OPTIX` (*defaults OFF*) are orthogonal settings, either or both may be enabled.

Additional packages may be needed:

- pyside2
  - Required t.o enable interactive widgets. (runtime)
- pillow
  - Required to display rendered output in Jupyter notebooks automatically. (runtime)
  - Required to execute unit tests.

- pytest
  - Required to execute unit tests.
- sphinx, sphinx_rtd_theme, and nbspinx
  - Required to build the user documentation.
- doxygen
  - Requited to build developer documentation.

Install these tools with your system or virtual environment package manager. **fresnel** developers have had success with `pacman` (arch linux), `apt-get` (ubuntu), Homebrew (macOS), and MacPorts (macOS):

```
your-package-manager install cmake doxygen embree pybind11 python python-pillow␣
↪python-pytest python-sphinx python-sphinx_rtd_theme python-nbsphinx intell-tbb qhull
```

Typical HPC cluster environments provide python, numpy, and cmake via a module system:

```
module load gcc python cmake
```

Note: Packages may be named differently, check your system's package list. Install any `-dev` packages as needed.

Tip: You can install numpy and other python packages into your virtual environment:

```
python3 -m pip install numpy
```

4.2.4 Compile

Configure with **cmake** and compile with **make**:

```
cd /path/to/fresnel
mkdir build
cd build
cmake ../
make install -j10
```

By default, **fresnel** builds the Embree (CPU) backend. Pass `-DENABLE_OPTIX=ON` to **cmake** to enable the GPU accelerated OptiX backend.

4.2.5 Run tests

To test **fresnel** builds without installing, add the build directory to your `PYTHONPATH`:

```
export PYTHONPATH=$PYTHONPATH:/path/to/fresnel/build
```

Execute `pytest` in the source directory to run all tests.

```
cd /path/to/fresnel
pytest
```

4.2.6 Build user documentation

Build the user documentation with **sphinx**:

```
cd /path/to/fresnel
cd doc
make html
open build/html/index.html
```

4.2.7 Build C++ Documentation

To build the developer documentation, execute `doxygen` in the repository root. It will write HTML output in `devdoc/html/index.html`.

CHAPTER

FIVE

CHANGE LOG

fresnel releases follow semantic versioning.

5.1 v0.x

5.1.1 v0.12.0 (2020-02-27)

Added

- `preview` and `tracer.Preview` accept a boolean flag `anti_alias` to enable or disable anti-aliasing.

Changed

- `preview` and `tracer.Preview` enable anti-alisasing by default.
- Python, Cython, and C code must follow strict style guidelines.
- Renamed `util.array` to `util.Array`
- Renamed `util.image_array` to `util.ImageArray`
- Converted `interact.SceneView.setScene` to a property: `scene`

Removed

- `preview` and `tracer.Preview` no longer accept the `aa_level` argument - use `anti_alias`.

5.1.2 v0.11.0 (2019-10-30)

Added

- Added box geometry convenience class `Box`.

Removed

- Support for **Python** 3.5.

Fixed

- Compile on systems where `libqhullcpp.a` is missing or broken.
- Find **Embree** headers when they are not in the same path as **TBB**.

5.1.3 v0.10.1 (2019-09-05)

Fixed

- Restore missing examples on readthedocs.

5.1.4 v0.10.0 (2019-08-19)

Changed

- **CMake** >= 3.8 is required at build time.
- **pybind11** >= 2.2 is required at build time.
- **qhull** >= 2015 is required.
- install to the **Python** `site-packages` directory by default.
- **CI** tests execute on Microsoft Azure Pipelines.

Fixed

- Improved installation documentation.

5.1.5 v0.9.0 (2019-04-30)

- Added support for linearizing colors of shape (4,).
- Improve examples.

5.1.6 v0.8.0 (2019-03-05)

- Documentation improvements.
- Add `geometry.Polygon`: Simple and/or rounded polygons in the *z=0* plane.
- API breaking changes:
  - Remove: `geometry.Prism`

5.1.7 v0.7.1 (2019-02-05)

- Fix **conda-forge** build on mac

5.1.8 v0.7.0 (2019-02-05)

- Add `util.convex_polyhedron_from_vertices`: compute convex polyhedron plane origins and normals given a set of vertices
- Improve documentation
- Add `interact.SceneView`: **pyside2** widget for interactively rendering scenes with path tracing
- Add `geometry.Mesh`: Arbitrary triangular mesh geometry, instanced with N positions and orientations
- **fresnel** development is now hosted on github: https://github.com/glotzerlab/fresnel/
- Improve `light.lightbox` lighting setup

- API breaking changes:
  - geometry.ConvexPolyhedron arguments changed. It now accepts polyhedron information as a dictionary.

5.1.9 v0.6.0 (2018-07-06)

- Implement tracer.Path on the GPU.
- Implement ConvexPolyhedron geometry on the GPU.
- Improve path tracer performance with Russian roulette termination.
- Compile warning-free.
- Fix sphere intersection test bugs on the GPU.
- tracer.Path now correctly starts sampling over when resized.
- Wrap C++ code with **pybind** 2.2
- Make documentation available on readthedocs: http://fresnel.readthedocs.io
- Fresnel is now available on **conda-forge**: https://anaconda.org/conda-forge/fresnel
- embree >= 3.0 is now required for CPU support
- Improve documentation

5.1.10 v0.5.0 (2017-07-27)

- Add new lighting setups
  - lightbox
  - cloudy
  - ring
- Adjust brightness of lights in existing setups
- Remove clearcoat material parameter
- Add spec_trans material parameter
- Add Path tracer to render scenes with indirect lighting, reflections, and transparency (*CPU-only*)
- Add ConvexPolyhedron geometry (*CPU-only*, *beta API, subject to change*)
- Add fresnel.preview function to easily generate Preview traced renders with one line
- Add fresnel.pathtrace function to easily generate Path traced renders with one line
- Add anti-aliasing (always on for the Path tracer, set aa_level > 0 to enable for Preview)
- API breaking changes:
  - render no longer exists. Use preview or pathtrace.
  - tracer.Direct is now tracer.Preview.

CPU-only features will be implemented on the GPU in a future release.

5.1.11 v0.4.0 (2017-04-03)

- Enforce requirement: Embree >= 2.10.0
- Enforce requirement Pybind =1.8.1
- Enforce requirement TBB >= 4.3
- Rewrite camera API, add camera.fit to fit the scene
- scenes default to an automatic fit camera
- Implement area lights, add default lighting setups
- `Scene` now supports up to 4 lights, specified in camera space
- Implement Disney's principled BRDF
- `Tracer.histogram` computes a histogram of the rendered image
- `Tracer.enable_highlight_warning` highlights overexposed pixels with a given warning color
- `Device.available_modes` lists the available execution modes
- `Device.available_gpus` lists the available GPUs
- `Device` can now be limited to *n* GPUs
- API breaking changes:
  - `camera.Orthographic` is now `camera.orthographic`
  - `Device` now takes the argument *n* instead of *limit*
  - `Scene` no longer has a `light_direction` member

5.1.12 v0.3.0 (2017-03-09)

- Suppress "cannot import name" messages
- Support Nx3 and Nx4 inputs to `color.linear`

5.1.13 v0.2.0 (2017-03-03)

- Parallel rendering on the CPU
- Fix PTX file installation
- Fix python 2.7 support
- Unit tests
- Fix bug in sphere rendering on GPU

5.1.14 v0.1.0 (2017-02-02)

- Prototype API
- Sphere geometry
- Prism geometry
- outline materials
- diffuse materials
- Direct tracer

CHAPTER

SIX

USER COMMUNITY

6.1 fresnel-users mailing list

Subscribe to the fresnel-users mailing list to receive release announcements, post questions for advice on using the software, and discuss potential new features.

6.2 Issue tracker

File bug reports on fresnel's issue tracker.

6.3 Contribute

fresnel is an open source project. Contributions are accepted via pull request to fresnel's github repository. Please review `CONTRIBUTING.MD` in the repository before starting development. You are encouraged to discuss your proposed contribution with the **fresnel** user and developer community who can help you design your contribution to fit smoothly into the existing ecosystem.

CHAPTER

SEVEN

INTRODUCTION

Fresnel is a python library that can ray trace publication quality images in real time. It provides a simple python API to define a **scene** consisting of any number of **geometry** primitives and **render** it to an output image.

To start, import the `fresnel` python module.

[1]:
```
import fresnel
```

7.1 Define a scene

A **Scene** defines a coordinate system, the **camera** view, the **light sources**, and contains a number of **geometry** primitives. Create a new **Scene** class instance. Scenes come with a default automatic camera that fits the geometry and a default set of lights.

[2]:
```
scene = fresnel.Scene()
```

7.2 Add geometry to the scene

A **Scene** may consist of any number of **geometry** objects. Each **geometry** object consists of *N* primitives of the same type, and a **material** that describes how the primitives interact with light sources. Create 8 spheres with radius 1.0.

[3]:
```
geometry = fresnel.geometry.Sphere(scene, N=8, radius=1.0)
```

Geometry objects have a number of per-primitive attributes. These are exposed with an interface compatible with **numpy** arrays, and can copy data from **numpy** arrays efficiently. Set the positions of the spheres:

[4]:
```
geometry.position[:] = [[1,1,1],
                        [1,1,-1],
                        [1,-1,1],
                        [1,-1,-1],
                        [-1,1,1],
                        [-1,1,-1],
                        [-1,-1,1],
                        [-1,-1,-1]]
```

Set the **material** of the geometry object to a rough blue surface:

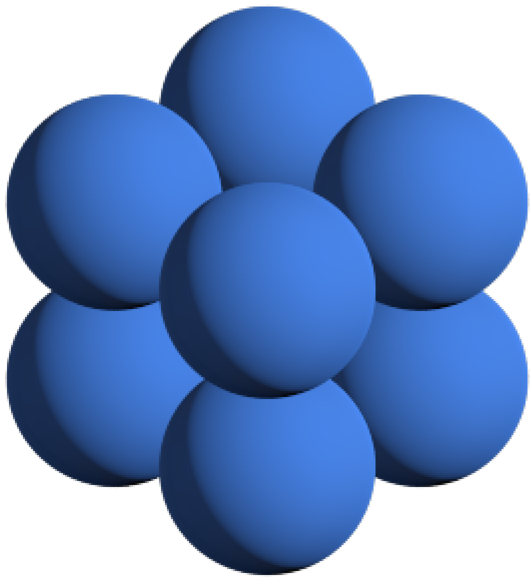
[5]:
```
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.
↪9]),
                                              roughness=0.8)
```

7.3 Render the scene

preview quickly renders the scene from the view point of the camera. Anti-aliasing is on by default to smooth edges in the image.

[6]:
```
fresnel.preview(scene)
```

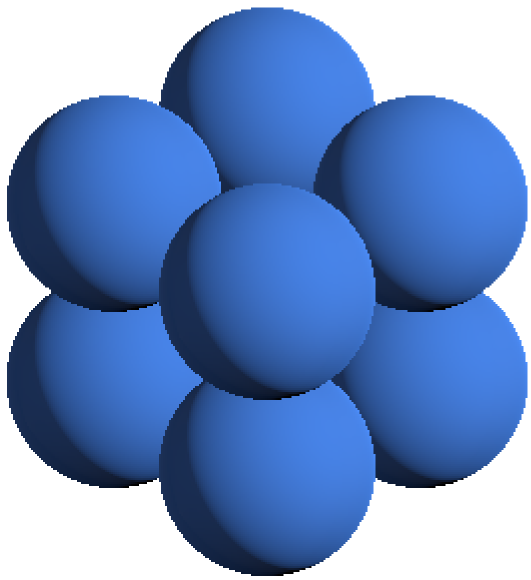
[6]:



Disable *anti-aliasing* if you desire a quicker render.

[7]:
```
fresnel.preview(scene, anti_alias=False)
```

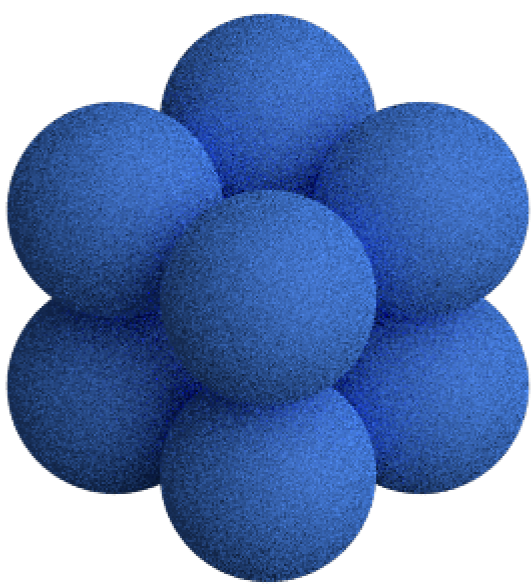
[7]:



preview only applies direct lighting. Use **pathtrace** to account for indirect lighting. (anti-aliasing is always enabled when path tracing).

[8]:
```
fresnel.pathtrace(scene)
```

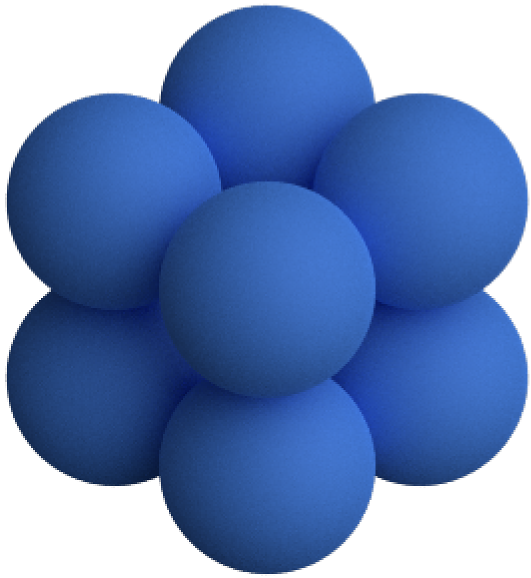
[8]:



The resulting image is noisy. Increase the number of *light samples* to obtain a clean image.

[9]:
```
fresnel.pathtrace(scene, light_samples=40)
```

[9]:



7.4 Save output

preview and *pathtrace* return output buffers that can be used like `HxWx4` RGBA **numpy** arrays. You can pass this standard format on to other python libraries that work images (e.g. matplotlib).

[10]:
```
out = fresnel.preview(scene)
print(out[:].shape)
print(out[:].dtype)
```

```
(370, 600, 4)
uint8
```

Use Pillow to save the rendered output to a png file with transparency.

[11]:
```
import PIL
```

[12]:
```
image = PIL.Image.fromarray(out[:], mode='RGBA')
image.save('output.png')
```

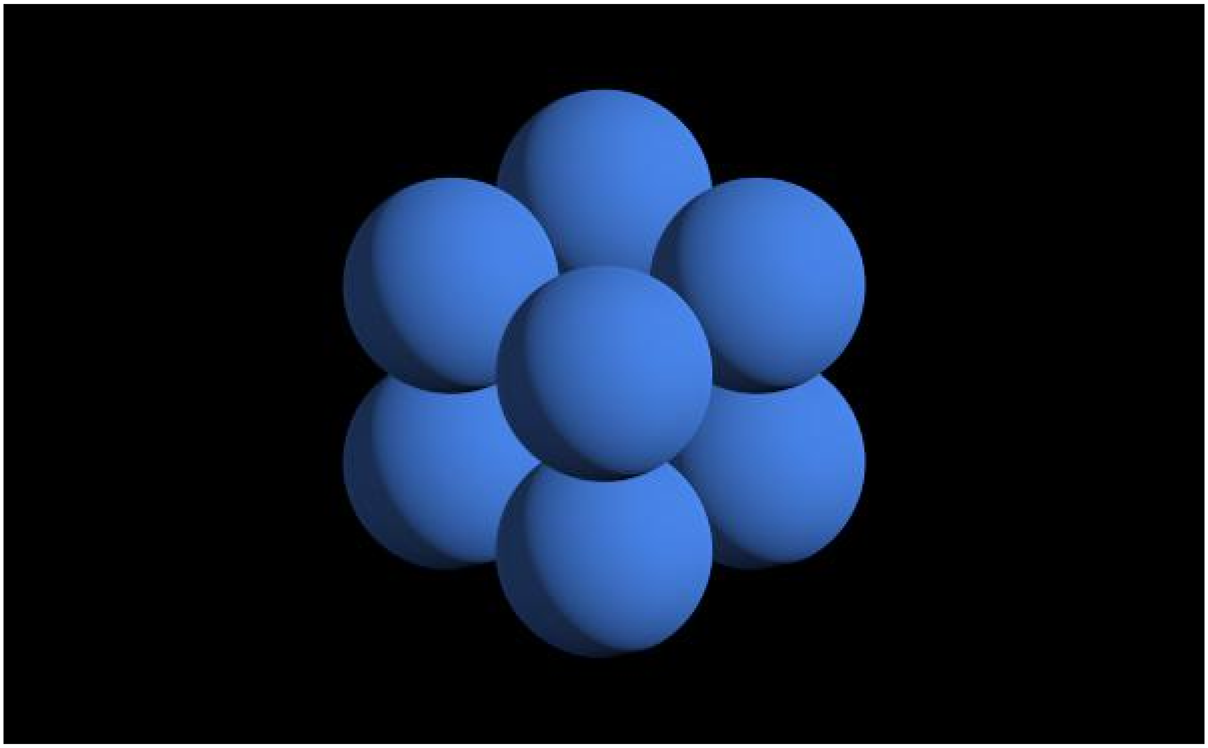
To save a JPEG, create an RGB image. This ignores the alpha channel, so the scene background color will show.

[13]:
```
image = PIL.Image.fromarray(out[:,:,0:3], mode='RGB')
image.save('output.jpeg')
```

This is what `output.jpeg` looks like (the default background color is black):

[14]:
```
import IPython.display
IPython.display.Image('output.jpeg')
```

[14]:



This page was generated from a jupyter notebook. You can download and run the notebook locally from the fresnel-examples repository.

CHAPTER

EIGHT

PRIMITIVE PROPERTIES

Each **geometry** type specifies a number of per-primitive properties. For example, the **Sphere** geometry has per-primitive *position*, *radius*, and *color*.

[1]:
```
import fresnel
scene = fresnel.Scene()
```

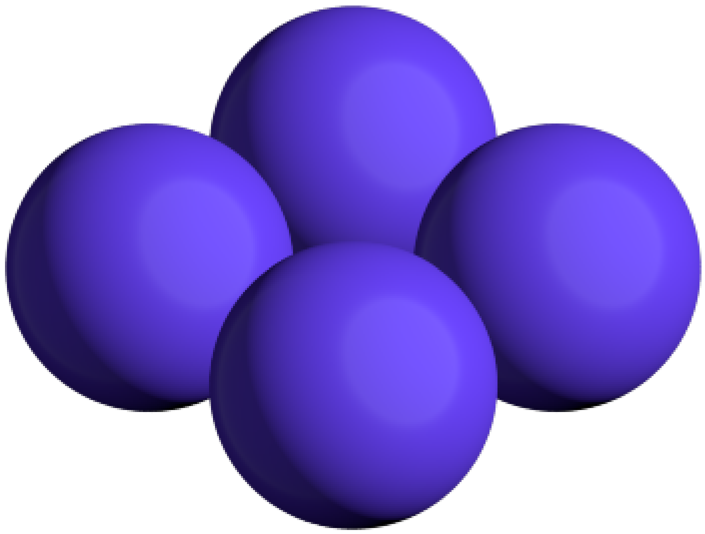
8.1 Setting properties when creating the geometry

Any of the properties may be set when the **geometry** is created, or they may be left as default values.

[2]:
```
geometry = fresnel.geometry.Sphere(scene,
                                   position = [[1,0,1],
                                               [1,0,-1],
                                               [-1,0,1],
                                               [-1,0,-1]],
                                   radius=1.0,
                                   material = fresnel.material.Material(color=fresnel.
↪color.linear([0.42,0.267,1]))
                                   # per-primitive color left default
                                   )
```

[3]:
```
fresnel.preview(scene)
```

[3]:



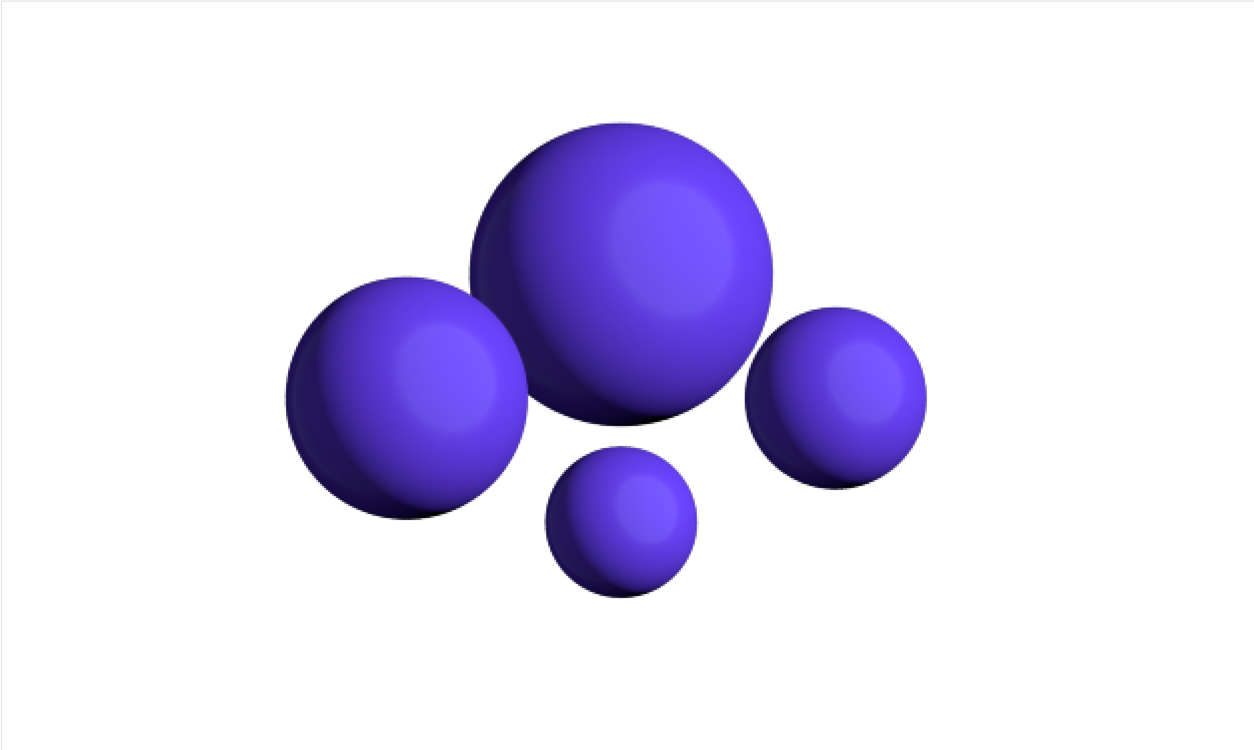
8.2 Changing properties after creation

Access the per-primitive properties as if they were **numpy** arrays. The *radius* property for the **Sphere geometry** sets the radius of each primitive.

[4]:
```
geometry.radius[:] = [0.5, 0.6, 0.8, 1.0]
```

[5]:
```
fresnel.preview(scene)
```

[5]:

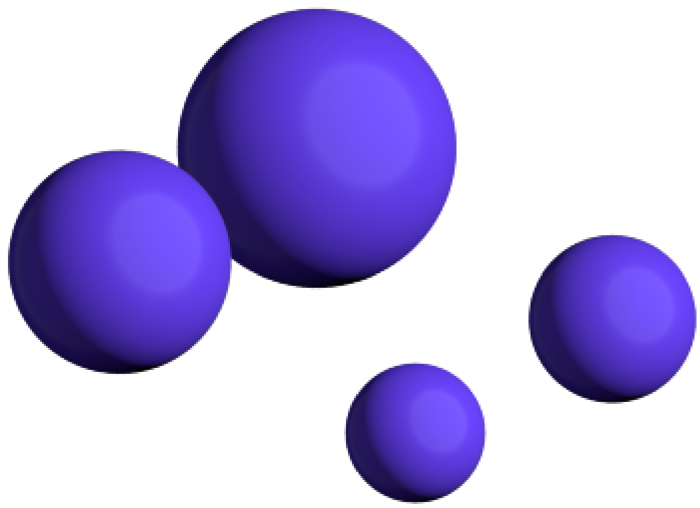


The *position* property sets the position of each sphere in the scene's coordinate system.

[6]:
```
geometry.position[:] = [[1.5,0,1],
                         [1.5,0,-1],
                         [-1.5,0,1],
                         [-1.5,0,-1]]
```

[7]:
```
fresnel.preview(scene)
```

[7]:

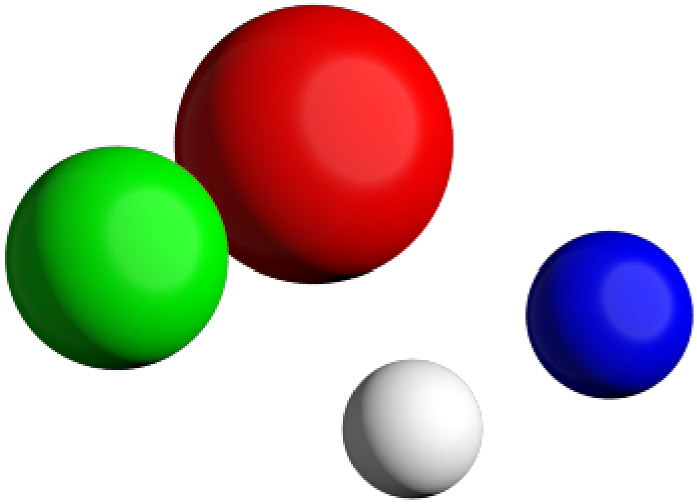


The *color* property sets a per primitive color. The geometry **material color** and the **primitive color** are mixed with fraction **primitive_color_mix**. A value of 1.0 selects the primitive color, 0.0 selects the *material* color and values in between mix the colors.

[8]:
```
geometry.material.primitive_color_mix = 1.0
geometry.color[:] = fresnel.color.linear([[1,1,1], [0,0,1], [0,1,0], [1,0,0]])
```

[9]:
```
fresnel.preview(scene)
```

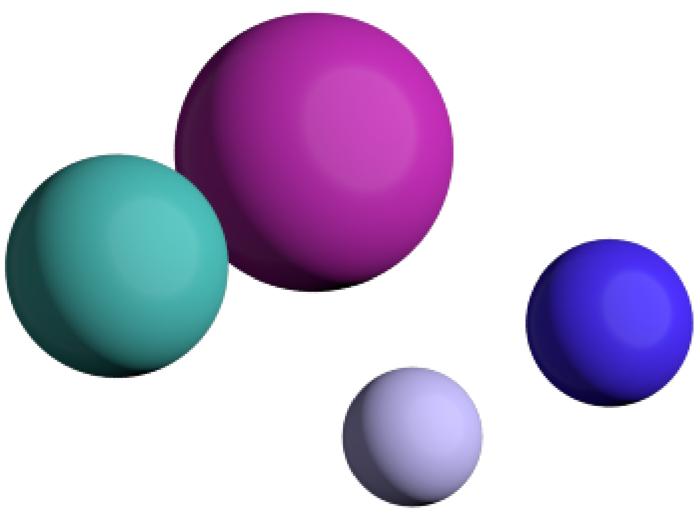
[9]:



[10]:
```
geometry.material.primitive_color_mix = 0.5
```

[11]:
```
fresnel.preview(scene)
```

[11]:



8.3 Reading primitive properties

Primitive properties may be read as well as written.

```
[12]: geometry.radius[:]
```

```
[12]: array([0.5, 0.6, 0.8, 1. ], dtype=float32)
```

```
[13]: geometry.position[:]
```

```
[13]: array([[ 1.5,  0. ,  1. ],
       [ 1.5,  0. , -1. ],
       [-1.5,  0. ,  1. ],
       [-1.5,  0. , -1. ]], dtype=float32)
```

```
[14]: geometry.color[:]
```

```
[14]: array([[1., 1., 1.],
       [0., 0., 1.],
       [0., 1., 0.],
       [1., 0., 0.]], dtype=float32)
```

8.4 Common errors

Primitive properties may be accessed like **numpy** arrays, but they may not be assigned directly.

```
[15]: geometry.radius = 1.0
```

```
---------------------------------------------------------------------------
AttributeError                            Traceback (most recent call last)
<ipython-input-15-020bd663bace> in <module>()
----> 1 geometry.radius = 1.0

AttributeError: can't set attribute
```

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CHAPTER

NINE

MATERIAL PROPERTIES

Each **geometry** has an associated **material**. The **material** is a set of parameters that defines how light interacts with the **geometry**. Here is a test scene to demonstrate these properties.

[1]:
```
import fresnel
import math
device = fresnel.Device()
scene = fresnel.Scene(device)
position = []
for k in range(5):
    for i in range(5):
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
```

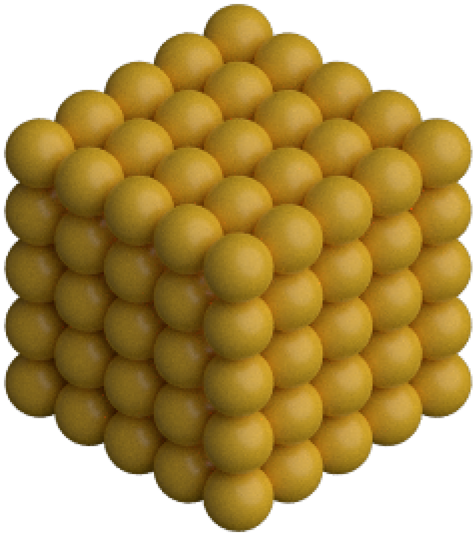
9.1 Material color

The **color** of a material sets its base color. Default material parameters set a primarily diffuse material with light specular highlights.

[2]:
```
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.9,0.714,0.
↪169]))
```

[3]:
```
fresnel.pathtrace(scene, w=300, h=300, light_samples=40)
```

[3]:



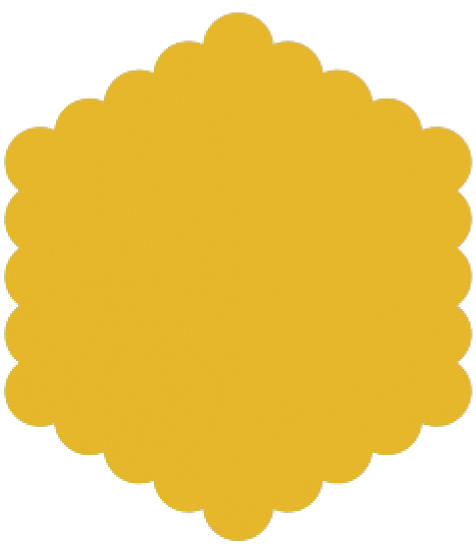
9.2 Solid color materials

Set the **solid** parameter to 1.0 to disable material interaction with light. A **solid** material has no shading applied and always displays as **color**.

[4]:
```
geometry.material.solid = 1.0
```

[5]:
```
fresnel.preview(scene, w=300, h=300)
```

[5]:



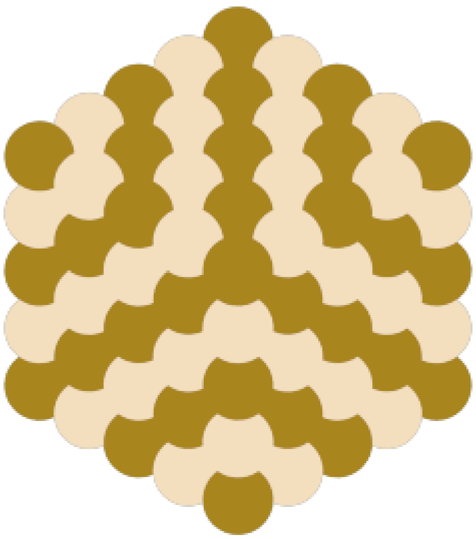
9.3 Geometry / primitive color mixing

Set **primitive_color_mix** to any value in the range 0.0 to 1.0 to control the amount that the per-primitive colors mix with the geometry color.

[6]:
```
geometry.material.primitive_color_mix = 0.5
geometry.color[::2] = fresnel.color.linear([0,0,0])
geometry.color[1::2] = fresnel.color.linear([1,1,1])
```

[7]:
```
fresnel.preview(scene, w=300, h=300)
```

[7]:



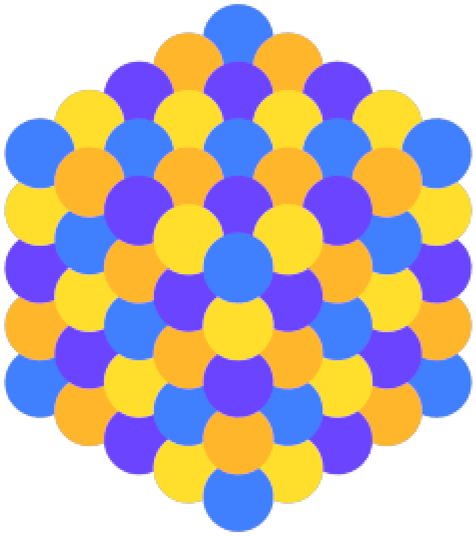
Typical use cases utilize values of either 0.0 (force a single color defined by the material) or 1.0 (force the per primitive color.)

[8]:
```
geometry.material.primitive_color_mix = 1.0

geometry.color[::4] = fresnel.color.linear([0.25,0.5,1])
geometry.color[1::4] = fresnel.color.linear([1,0.714,0.169])
geometry.color[2::4] = fresnel.color.linear([0.42,0.267,1])
geometry.color[3::4] = fresnel.color.linear([1,0.874,0.169])
```

[9]:
```
fresnel.preview(scene, w=300, h=300)
```

[9]:



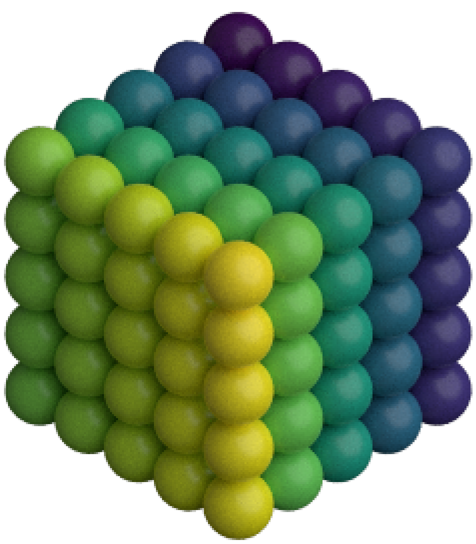
To use a **matplotlib** color map, pass the output of the color map to `fresnel.color.linear` so the output colors appear as intended.

[10]:
```
import matplotlib, matplotlib.cm
import numpy
geometry.material.solid = 0.0
mapper = matplotlib.cm.ScalarMappable(norm = matplotlib.colors.Normalize(vmin=0,␣
↪vmax=1, clip=True),
                                      cmap = matplotlib.cm.get_cmap(name='viridis'))

v = numpy.linspace(0,1,len(position))
geometry.color[:] = fresnel.color.linear(mapper.to_rgba(v))
```

[11]:
```
fresnel.pathtrace(scene, w=300, h=300, light_samples=40)
```

[11]:



9.4 All properties

Materials have a number of intuitive properties. All are defined in a nominal range from 0 to 1, though some values can be pushed past 1 for extremely strong effects.

- roughness - Set the roughness of the material. Recommend values >= 0.1.
- specular - Control the strength of the specular highlights
- metal - 0: dielectric materials (plastic, glass, etc...). 1: pure metals.
- spec_trans - Set the fraction of light that passes through the material.

Here are some examples of different material parameters.

[12]:
```
scene2 = fresnel.Scene(device)
spheres = []
for i in range(11):
    spheres.append(fresnel.geometry.Sphere(scene2, position = (i, 0, 0), radius=0.4))
    spheres[i].material = fresnel.material.Material(color=(.1,.7,.1))

tracer = fresnel.tracer.Path(device=device, w=1000, h=75)

scene2.lights = [fresnel.light.Light(direction=(1,1,-1), color=(0.5, 0.5, 0.5)),
                 fresnel.light.Light(direction=(-1,-1,1), color=(0.5, 0.5, 0.5))]
```

9.4.1 Examples

These examples are front lit from the lower left and back lit from the upper right.

Vary roughness in a specular material from 0.1 to 1.1

[13]:
```
for i in range(11):
    spheres[i].material.specular = 1.0
    spheres[i].material.roughness = i/10+0.1

tracer.sample(scene2, samples=64, light_samples=40)
```

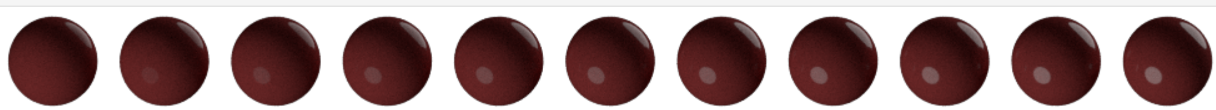
[13]:

Vary specular from 0 to 1 with constant roughness.

[14]:
```
for i in range(11):
    spheres[i].material.specular = i/10
    spheres[i].material.roughness = 0.1
    spheres[i].material.color=(.7,.1,.1)

tracer.sample(scene2, samples=64, light_samples=40)
```

[14]:



The following examples use cloudy lighting which places a bright hemisphere of light above the scene and a dim hemisphere of light below the scene.

Vary metal from 0 to 1 with a rough material. (metal materials look best when there is other geometry to reflect from the surface)

[15]:
```
for i in range(11):
    spheres[i].material.specular = 1.0
    spheres[i].material.color=(.7,.7,.7)
    spheres[i].material.metal = i/10

scene2.lights = fresnel.light.cloudy()
tracer.sample(scene2, samples=64, light_samples=40)
```

[15]:

Vary spec_trans from 0 to 1 with all other quantities constant.

[ ]:
```
for i in range(11):
    spheres[i].material.metal = 0.0
    spheres[i].material.spec_trans = i/10
    spheres[i].material.color=(.1,.1,.7)

tracer.sample(scene2, samples=64, light_samples=40)
```

Execute this notebook with **ipywidgets** installed and use the panel below to explore the material parameters and how they react to different lighting angles.

[ ]:
```
import ipywidgets

tracer.resize(450,450)

@ipywidgets.interact(color=ipywidgets.ColorPicker(value='#1c1c7f'),
                     primitive_color_mix=ipywidgets.FloatSlider(value=0.0, min=0.0,␣
↪max=1.0, step=0.1, continuous_update=False),
                     roughness=ipywidgets.FloatSlider(value=0.3, min=0.1, max=1.0,␣
↪step=0.1, continuous_update=False),
                     specular=ipywidgets.FloatSlider(value=0.5, min=0.0, max=1.0,␣
↪step=0.1, continuous_update=False),
                     spec_trans=ipywidgets.FloatSlider(value=0.0, min=0.0, max=1.0,␣
↪step=0.1, continuous_update=False),
                     metal=ipywidgets.FloatSlider(value=0, min=0.0, max=1.0, step=1.0,
↪ continuous_update=False),
                     light_theta=ipywidgets.FloatSlider(value=5.5, min=0.0,␣
↪max=2*math.pi, step=0.1, continuous_update=False),
                     light_phi=ipywidgets.FloatSlider(value=0.8, min=0.0, max=math.pi,
↪ step=0.1, continuous_update=False))
def test(color, primitive_color_mix, roughness, specular, spec_trans, metal, light_
↪theta, light_phi):
    r = int(color[1:3], 16)/255;
    g = int(color[3:5], 16)/255;
    b = int(color[5:7], 16)/255;
    scene.lights[0].direction = (math.sin(light_phi)*math.cos(-light_theta),
                                 math.cos(light_phi),
                                 math.sin(light_phi)*math.sin(-light_theta))

    scene.lights[1].theta = math.pi
    geometry.material = fresnel.material.Material(color=fresnel.color.linear([r,g,b]),
                                                  primitive_color_mix=primitive_color_
↪mix,
```

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```
                                                    roughness=roughness,
                                                    metal=metal,
                                                    specular=specular,
                                                    spec_trans=spec_trans
                                                   )
    return tracer.sample(scene, samples=64, light_samples=1)
```

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CHAPTER TEN

OUTLINE MATERIALS

Each **geometry** has an associated **outline material** and an **outline width**. The **outline material** has all the same attributes as a normal material, but it is only applied in a thin line around each geometry primitive. The width of that line is the **outline width**.

[1]:
```
import fresnel
import math
scene = fresnel.Scene()
position = []
for k in range(5):
    for i in range(5):
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.color[::4] = fresnel.color.linear([0.25,0.5,1])
geometry.color[1::4] = fresnel.color.linear([1,0.714,0.169])
geometry.color[2::4] = fresnel.color.linear([0.42,0.267,1])
geometry.color[3::4] = fresnel.color.linear([1,0.874,0.169])
geometry.material = fresnel.material.Material(solid=0.0, primitive_color_mix=1.0,␣
↪color=fresnel.color.linear([0,0,0]))
fresnel.light.cloudy();
```

10.1 Enabling outlines

The default **outline width** is 0. Set a non-zero outline width to enable the outlines.

[2]:
```
geometry.outline_width
```

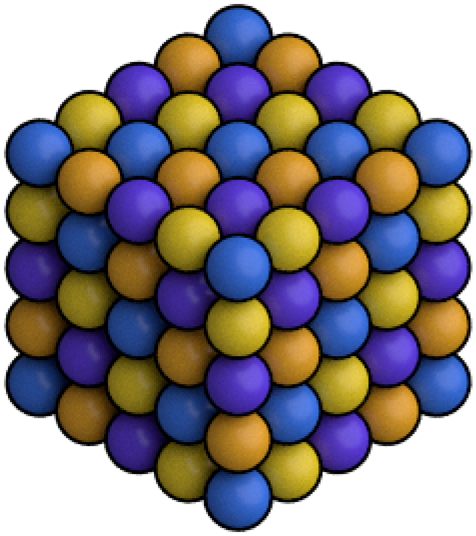
[2]:
```
0.0
```

The **outline width** is in distance units in the same coordinate system as scene. The is *width* units wide perpendicular to the view direction. Outlines enhance the separation between primitives visually. They work well with diffuse and solid colored primitives.

[3]:
```
geometry.outline_width = 0.12
```

[4]:
```
fresnel.pathtrace(scene, w=300, h=300,light_samples=40)
```

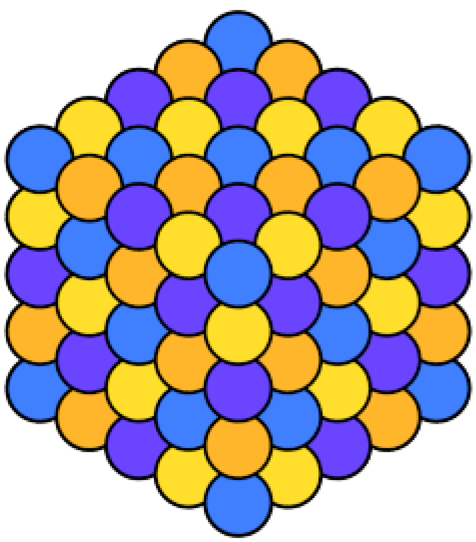
[4]:



[5]:
```
geometry.material.solid = 1.0
```

[6]:
```
fresnel.preview(scene, w=300, h=300)
```

[6]:



10.2 Outline material properties

The default **outline material** is a solid black.

[7]:
```
geometry.outline_material.color
```

[7]:
```
(0.0, 0.0, 0.0)
```

[8]:
```
geometry.outline_material.solid
```

[8]:
```
1.0
```

[9]:
```
geometry.outline_material.primitive_color_mix
```

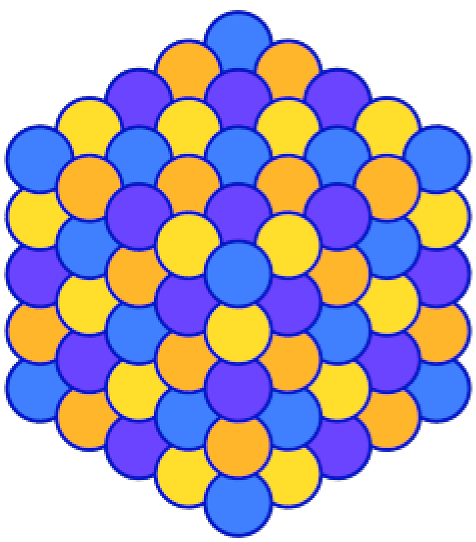
[9]:
```
0.0
```

The **outline material** has all the same properties as a normal material.

[10]:
```
geometry.outline_material.color = fresnel.color.linear(fresnel.color.linear([0.08,0.
↪341,0.9]))
```

[11]:
```
fresnel.preview(scene, w=300, h=300)
```

[11]:

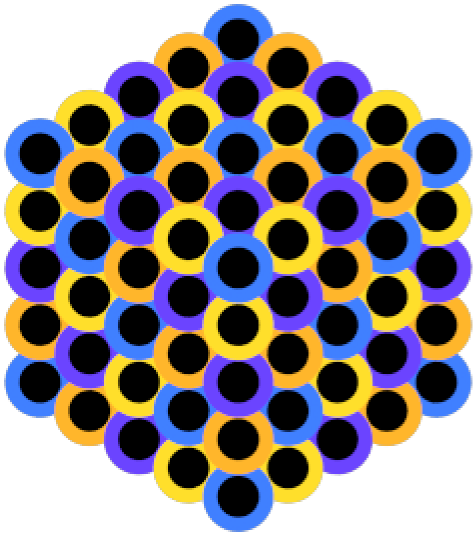


Outlines may be colored by the primitives:

[12]:
```
geometry.material.primitive_color_mix = 0.0
geometry.outline_material.primitive_color_mix = 1.0
geometry.outline_width = 0.4
```

[13]:
```
fresnel.preview(scene, w=300, h=300)
```

[13]:

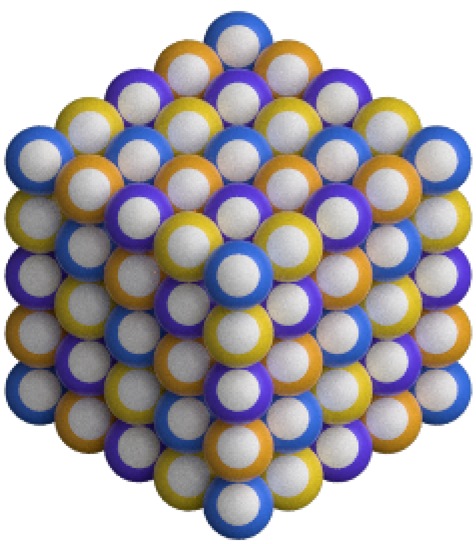


Outlines may have diffuse shading:

[14]:
```
geometry.material.color = fresnel.color.linear([1,1,1])
geometry.material.solid = 0
geometry.outline_material.solid = 0
```

[15]:
```
fresnel.pathtrace(scene, w=300, h=300,light_samples=40)
```

[15]:



Or be metallic:

[16]:
```
geometry.material.color = fresnel.color.linear([0.08,0.341,0.9])

geometry.outline_material.solid = 0
geometry.outline_material.color = [0.95,0.95,0.95]
```

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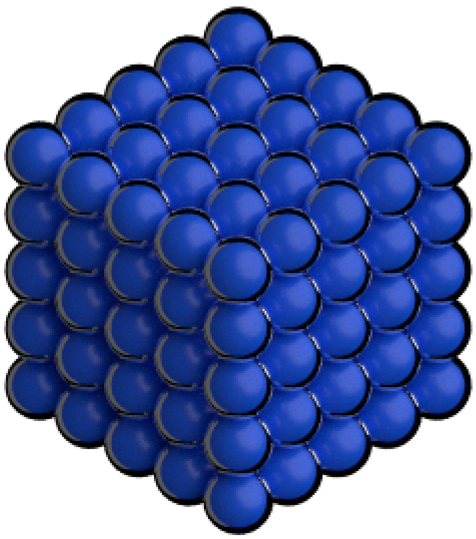
```
geometry.outline_material.roughness = 0.1
geometry.outline_material.metal = 1
geometry.outline_material.primitive_color_mix = 0.0
geometry.outline_width = 0.2
```

[17]:
```
fresnel.pathtrace(scene, w=300, h=300,light_samples=40)
```

[17]:



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CHAPTER

ELEVEN

SCENE PROPERTIES

Each **Scene** has a **background color** and **alpha**, **lights**, and a **camera**.

```
[1]: import fresnel
import math
scene = fresnel.Scene()
position = []
for i in range(6):
    position.append([2*math.cos(i*2*math.pi / 6), 2*math.sin(i*2*math.pi / 6), 0])

geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.material = fresnel.material.Material(solid=0.0, color=fresnel.color.
↪linear([1,0.874,0.169]))
geometry.outline_width = 0.12
```

11.1 Background color and alpha

The default **background color** is black (0,0,0) and the **background alpha** is 0 (transparent).

```
[2]: scene.background_color
```

```
[2]: (0.0, 0.0, 0.0)
```

```
[3]: scene.background_alpha
```

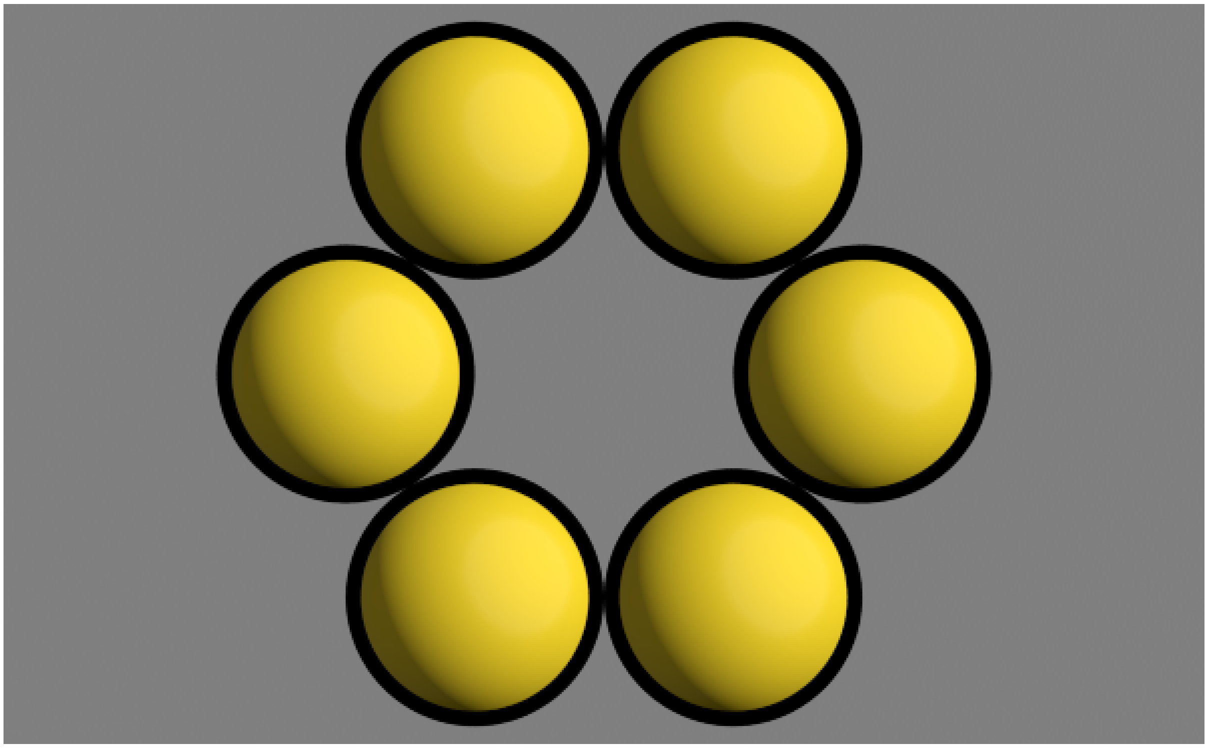
```
[3]: 0.0
```

The background color is applied to any pixel in the output image where no object is present. Change the **background alpha** to only partially transparent:

```
[4]: scene.background_alpha = 0.5
```

```
[5]: fresnel.preview(scene)
```

[5]:

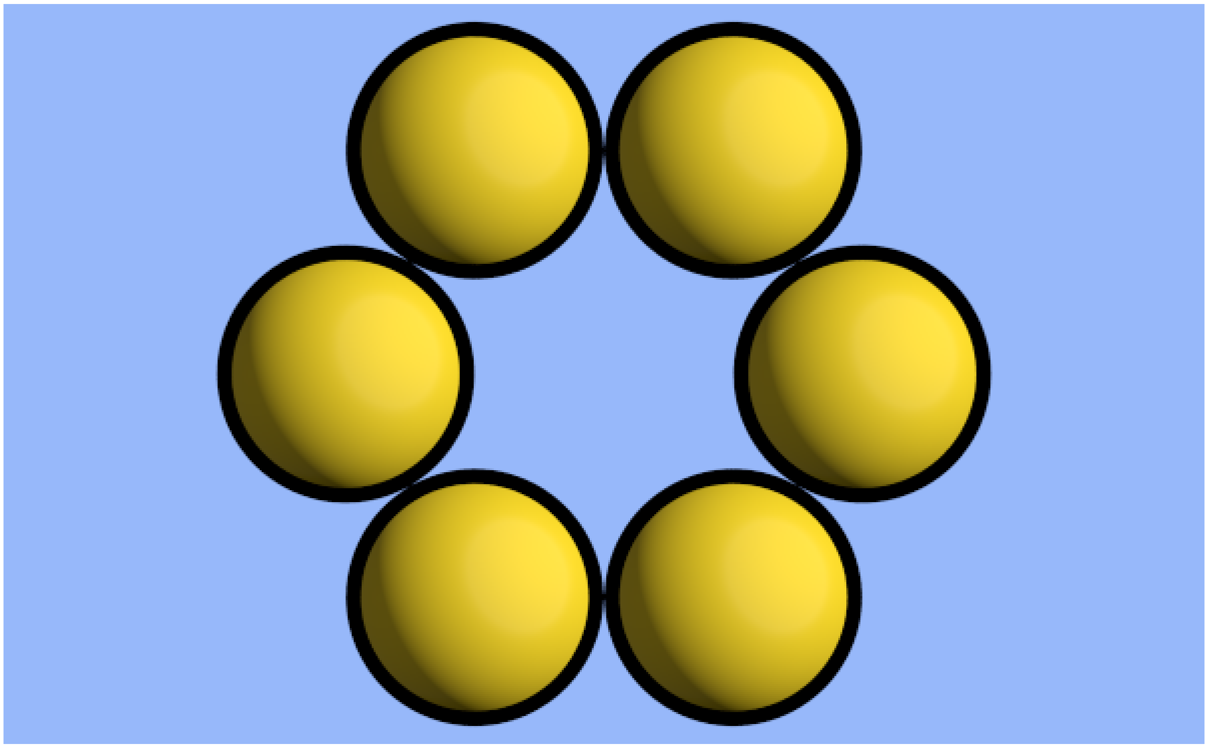


Set a solid background color:

[6]:
```
scene.background_alpha = 1.0
scene.background_color = fresnel.color.linear([0.592, 0.722, 0.98])
```

[7]:
```
fresnel.preview(scene)
```

[7]:



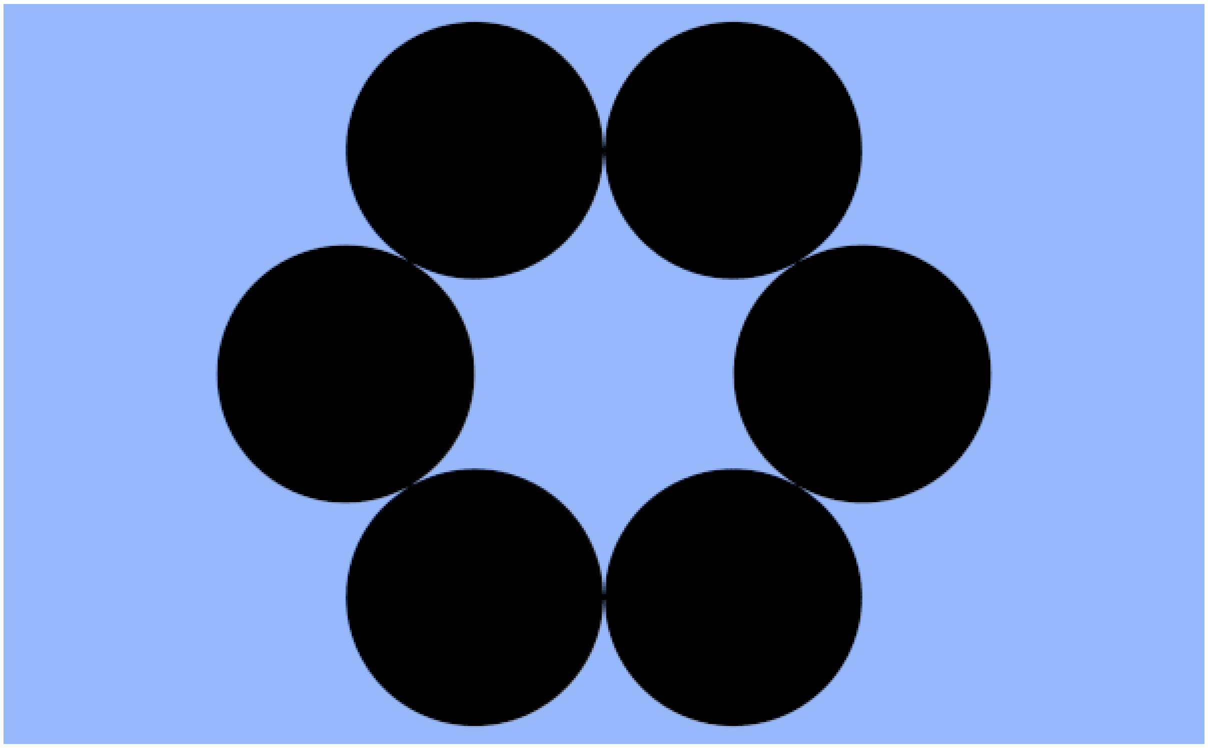
11.2 Light sources

Light sources light the objects in the scene. Without lights, all objects are black.

[8]:
```
scene.lights.clear()
```

[9]:
```
fresnel.preview(scene)
```

[9]:

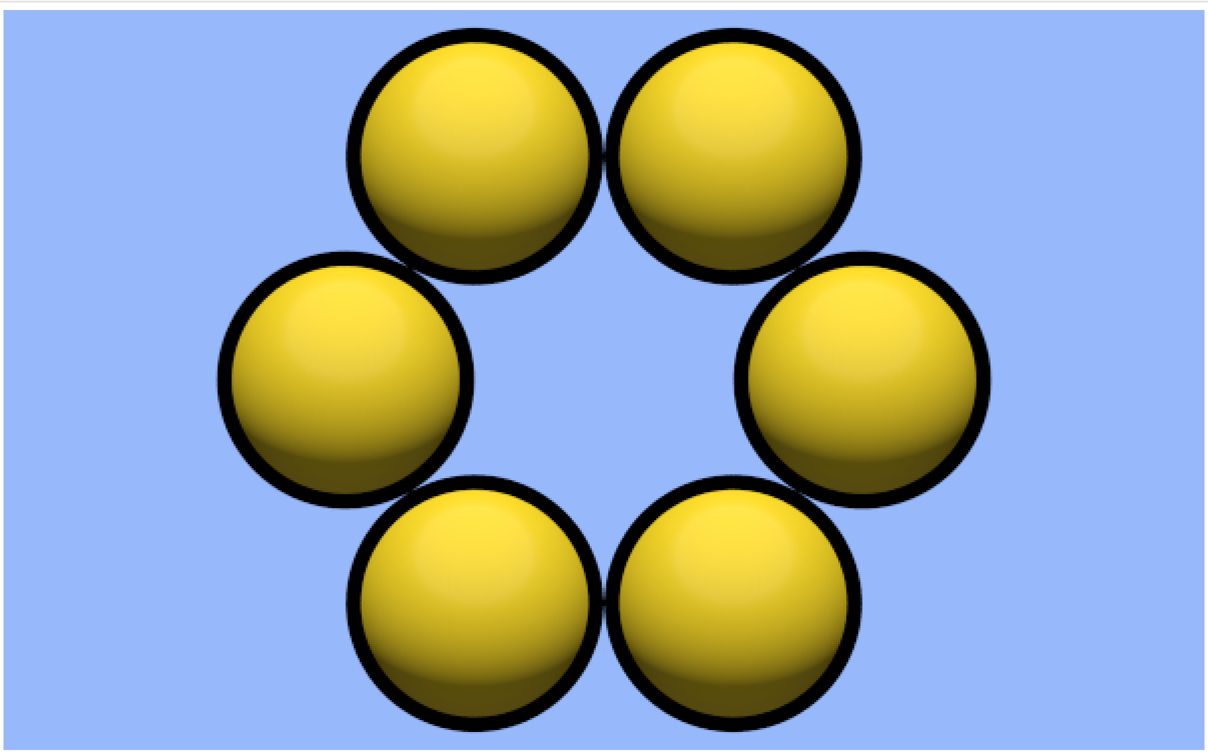


Fresnel defines several standard lighting setups that may be easily applied.

[10]:
```
scene.lights = fresnel.light.butterfly()
```

[11]:
```
fresnel.preview(scene)
```

[11]:

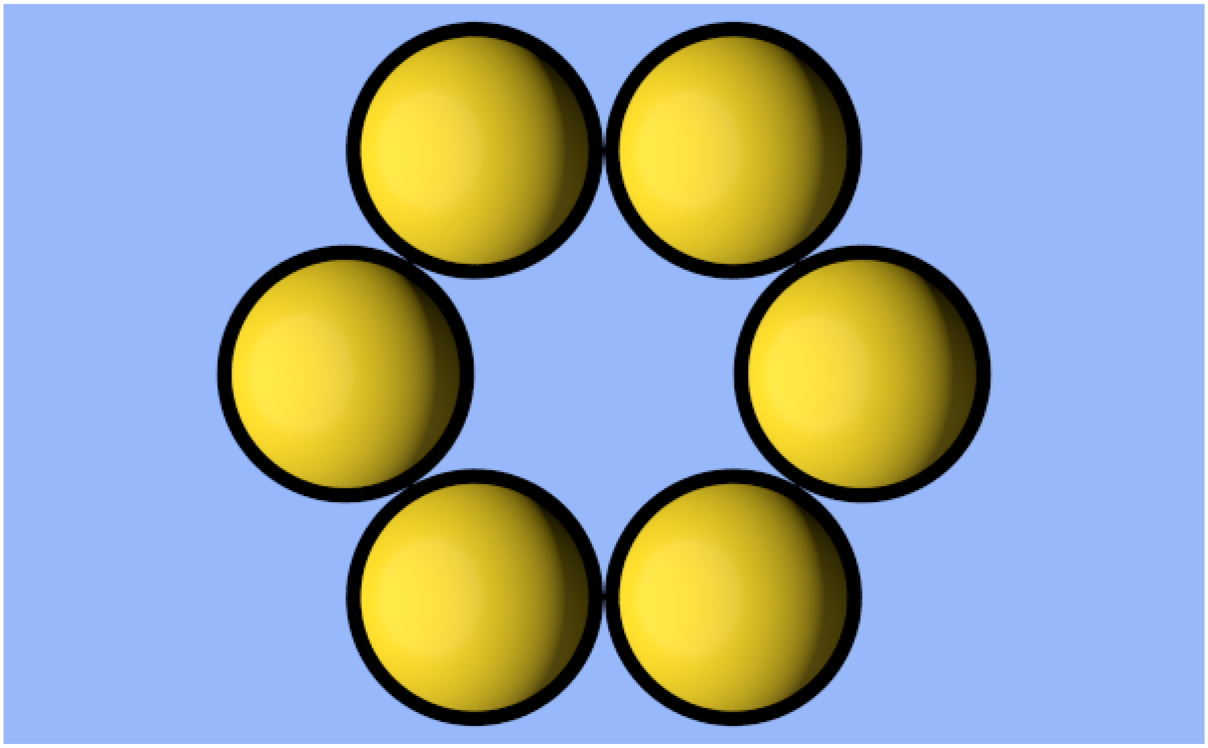


You can modify individual lights.

[12]:
```
scene.lights[0].direction = (-1, 0, 1)
```

[13]:
```
fresnel.preview(scene)
```

[13]:



11.3 Camera

The camera defines the view to render into the scene. By default, the camera is `auto` and the camera is automatically selected to fit the scene every time it is rendered.

[14]:
```
print(scene.camera)
```

```
auto
```

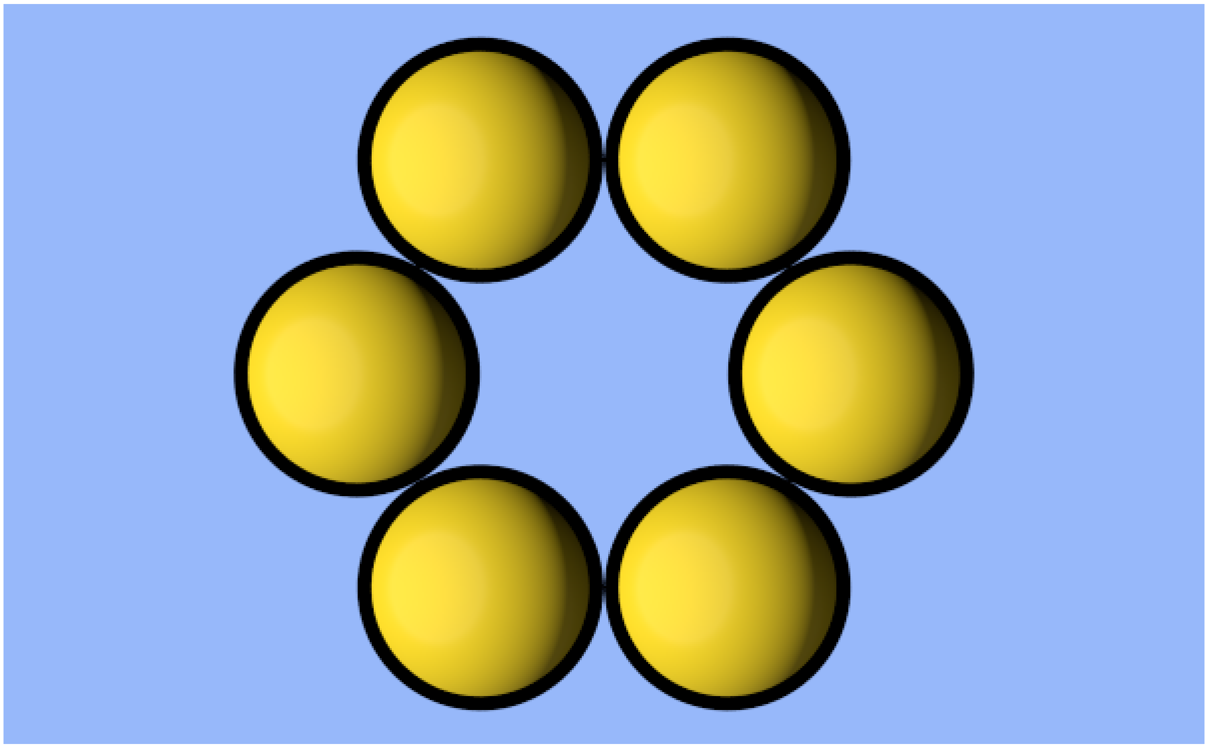
You can obtain the same camera explicitly with `camera.fit`. Call it **after** defining all of the geometry in your scene.

[15]:
```
scene.camera = fresnel.camera.fit(scene)
```

A **camera** is defined by its *position*, *look-at point*, *up vector* and *height* of the view into the scene. All of these quantities are in scene coordinates.

[16]:
```
scene.camera = fresnel.camera.orthographic(position=(0,0,2), look_at=(0,0,0), up=(0,1,
↪0), height=6)
fresnel.preview(scene)
```

[16]:



You can modify these parameters individually.

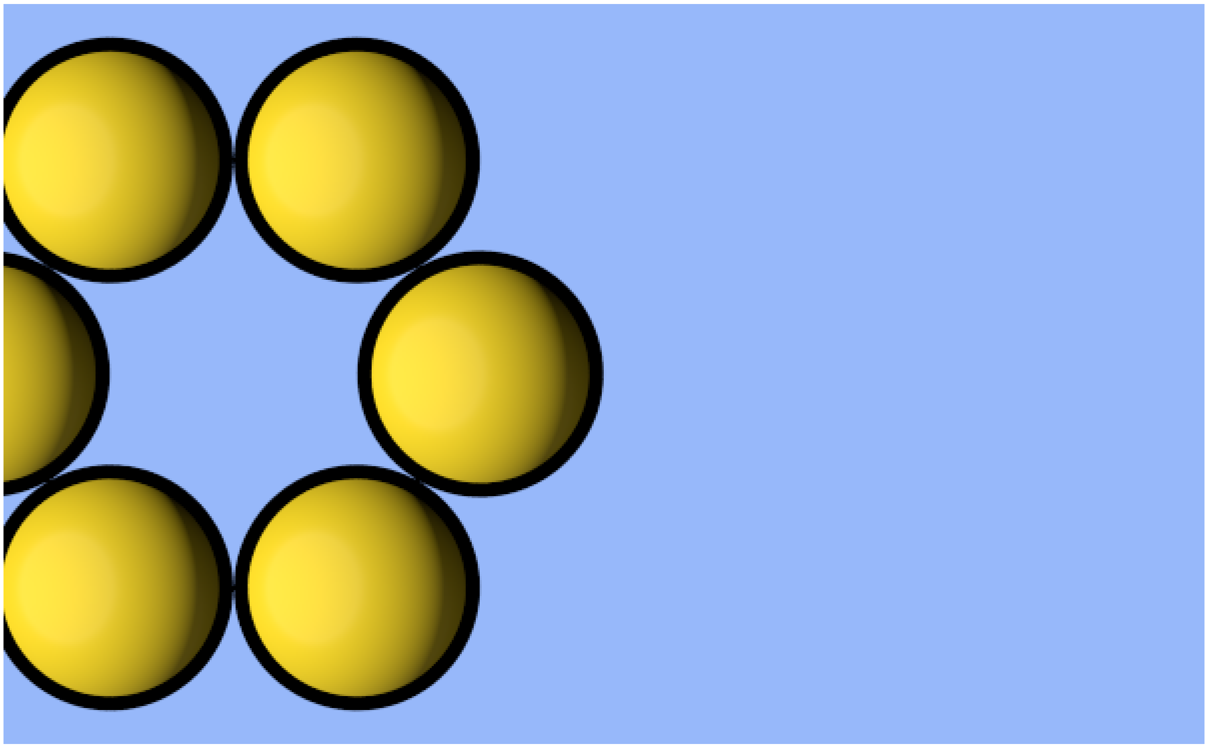
[17]:

```
scene.camera.position = (3, 0, 10)
scene.camera.look_at=(3,0,0)
```

[18]:

```
fresnel.preview(scene)
```

[18]:



Print the full representation of the camera.

[19]:
```
print(repr(scene.camera))
```

```
fresnel.camera.orthographic(position=(3.0, 0.0, 10.0), look_at=(3.0, 0.0, 0.0), up=(0.
↪0, 1.0, 0.0), height=6.0)
```

You can copy and paste this text to reproduce the same camera elsewhere.

[20]:
```
scene.camera = fresnel.camera.orthographic(position=(3.0, 0.0, 10.0),
                                           look_at=(3.0, 0.0, 0.0),
                                           up=(0.0, 1.0, 0.0),
                                           height=6.0)
```

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CHAPTER

TWELVE

LIGHTING SETUPS

Each **Scene** has associated **lights**. The lights control how the objects in a scene is lit.

[1]:
```
import fresnel
import math
import matplotlib, matplotlib.cm
from matplotlib import pyplot
%matplotlib inline
import numpy

device = fresnel.Device()
scene = fresnel.Scene(device)
position = []
for k in range(5):
    for i in range(5):
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.material = fresnel.material.Material(primitive_color_mix=1.0, color=(1,1,1))
mapper = matplotlib.cm.ScalarMappable(norm = matplotlib.colors.Normalize(vmin=0,␣
↪vmax=1, clip=True),
                                       cmap = matplotlib.cm.get_cmap(name='viridis'))

v = numpy.linspace(0,1,len(position))
geometry.color[:] = fresnel.color.linear(mapper.to_rgba(v))
scene.camera = fresnel.camera.fit(scene, view='isometric')
tracer = fresnel.tracer.Path(device, w=450, h=450)
```

12.1 Lighting presets

Fresnel defines many lighting presets that use classic photography techniques to light the scene. Create a setup and assign it to the Scene's lights.

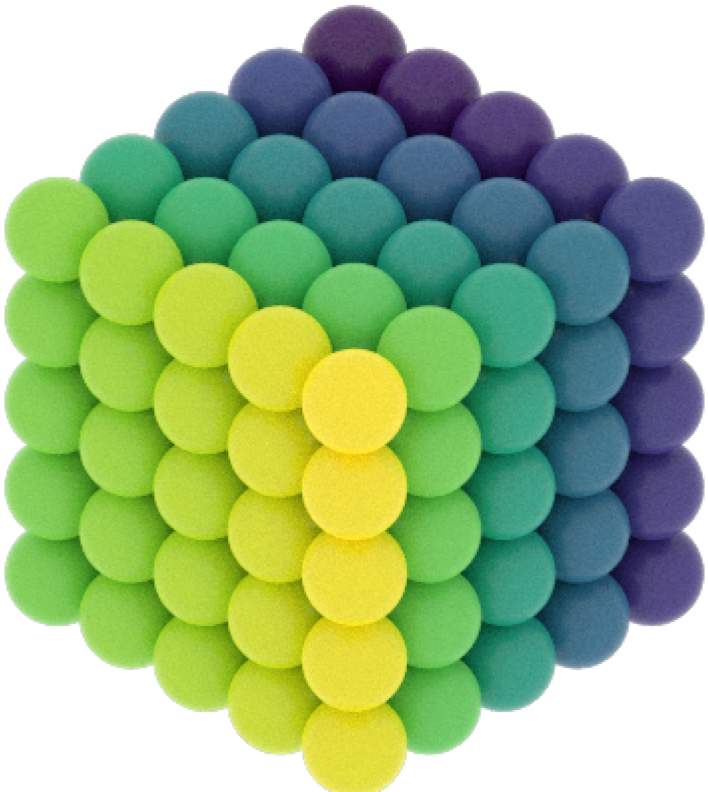
The images in these examples are noisy because of the small number of samples. Increase the number of samples to obtain less noisy images.

12.1.1 Light box

A light box lights the scene equally from all sides. This type of lighting is commonly used product photography.

[2]:
```
scene.lights = fresnel.light.lightbox()
tracer.sample(scene, samples=64, light_samples=10)
```

[2]:

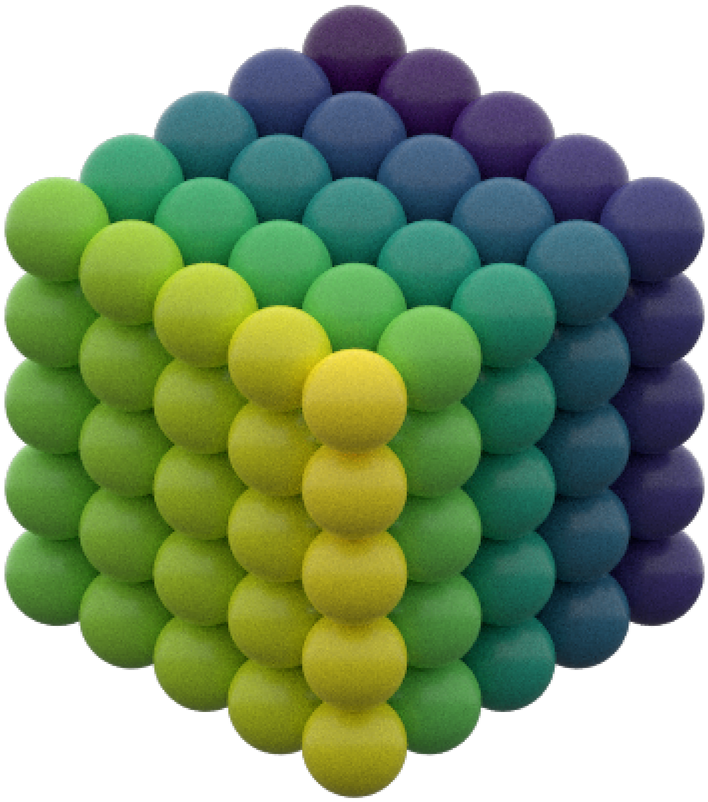


12.1.2 Cloudy

Cloudy lighting mimics a cloudy day. Strong light comes from all directions above, while weak light comes from below.

[3]:
```
scene.lights = fresnel.light.cloudy()
tracer.sample(scene, samples=64, light_samples=10)
```

[3]:



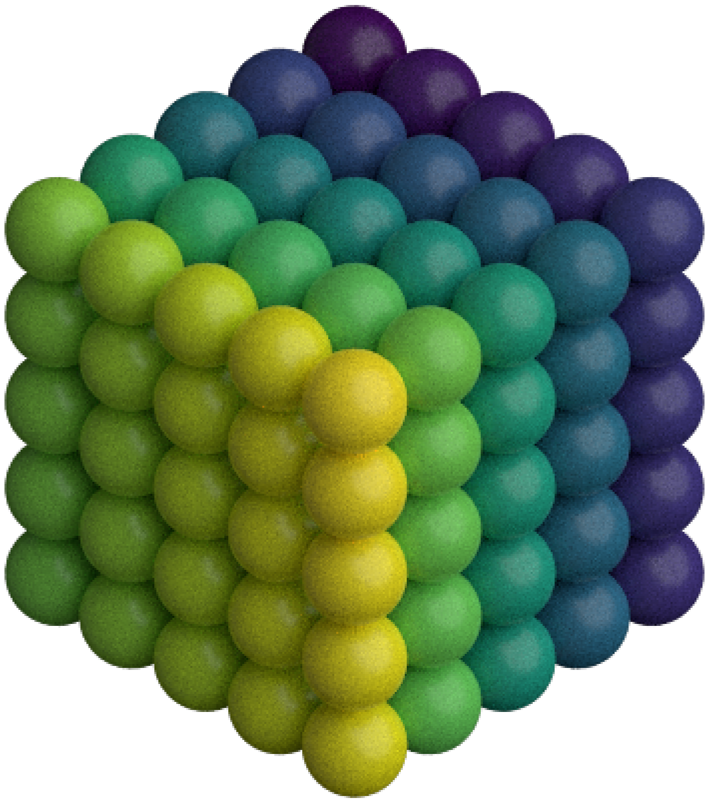
12.1.3 Rembrandt

Rembrandt lighting places the key light 45 degrees to one side and slightly up.

[4]:

```
scene.lights = fresnel.light.rembrandt()
tracer.sample(scene, samples=64, light_samples=10)
```

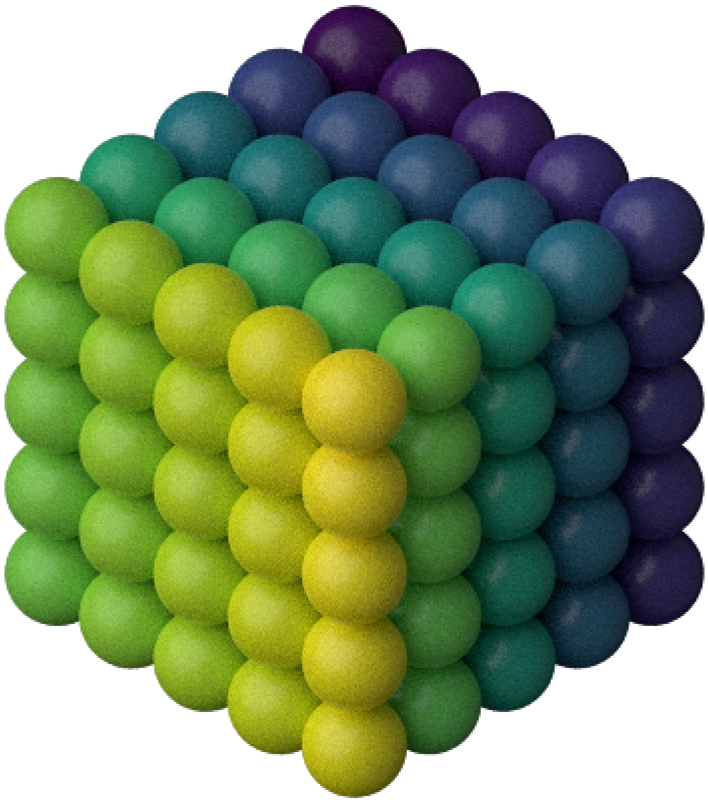
[4]:



Use the *side* argument specify which side to place the key light on.

[5]:
```
scene.lights = fresnel.light.rembrandt(side='left')
tracer.sample(scene, samples=64, light_samples=10)
```

[5]:



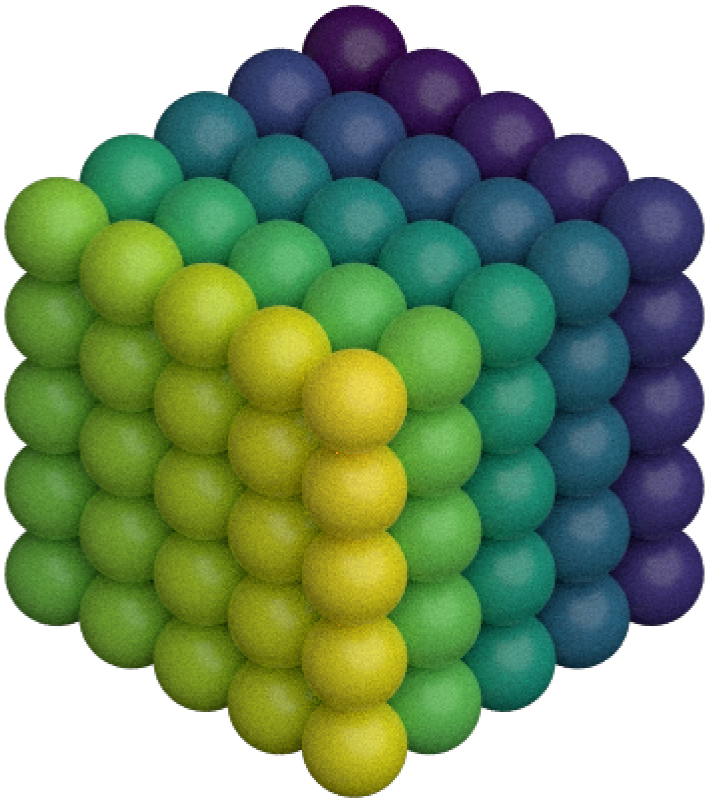
12.1.4 Loop lighting

Loop lighting places the key light slightly to one side and slightly up.

[6]:

```
scene.lights = fresnel.light.loop()
tracer.sample(scene, samples=64, light_samples=10)
```

[6]:

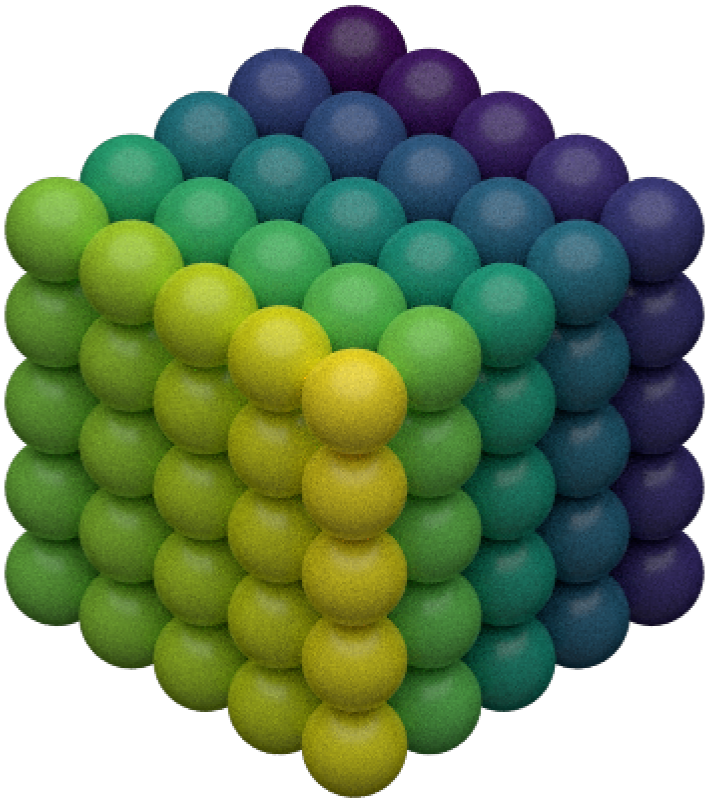


12.1.5 Butterfly lighting

Butterfly lighting places the key light high above the camera.

[7]:
```
scene.lights = fresnel.light.butterfly()
tracer.sample(scene, samples=64, light_samples=10)
```

[7]:



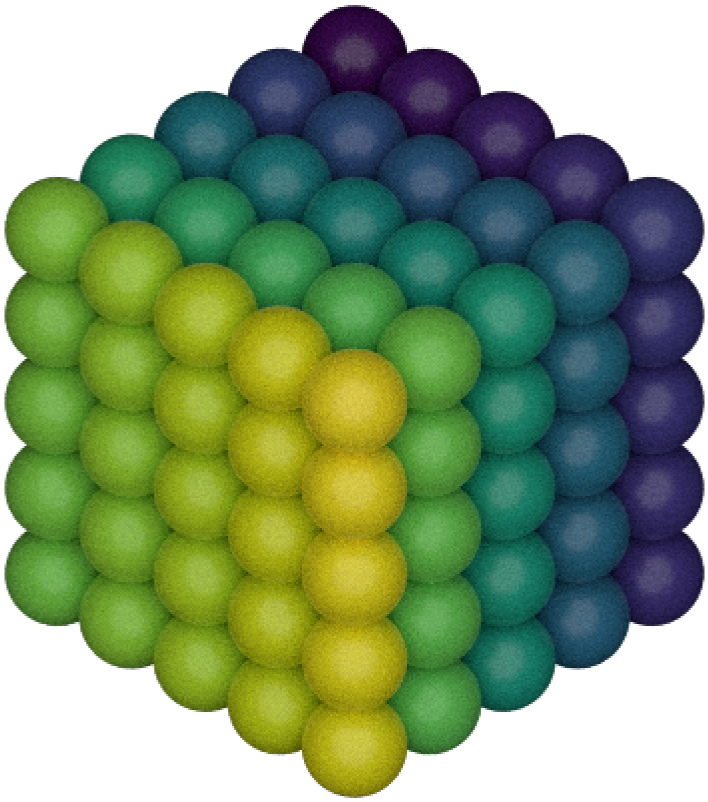
12.1.6 Ring lighting

The ring lighting setup provides a strong front area light. This type of lighting is common in fashion photography.

[8]:

```
scene.lights = fresnel.light.ring()
tracer.sample(scene, samples=64, light_samples=10)
```

[8]:



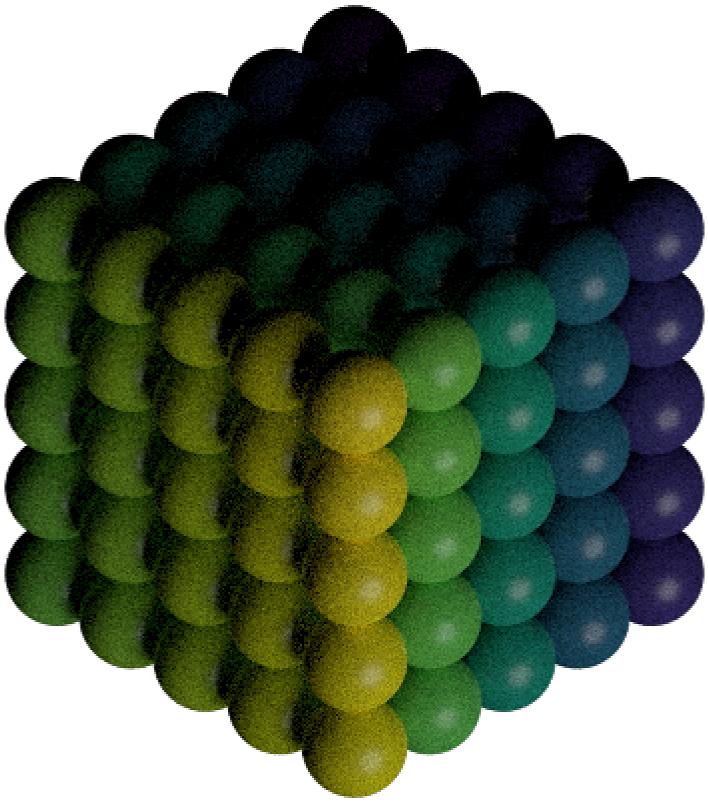
12.2 Custom lights

You can define your own custom lights. Provide a *direction* vector pointing to the light in the coordinate system of the camera (+x points to the right, +y points up, and +z points out of the screen). The light color defines both the color (RGB) and the intensity of the light in a linear sRGB color space.

[9]:
```
my_lights = [fresnel.light.Light(direction=(1,-1,1), color=(1,1,1))]
scene.lights = my_lights
```

[10]:
```
tracer.sample(scene, samples=64, light_samples=10)
```

[10]:

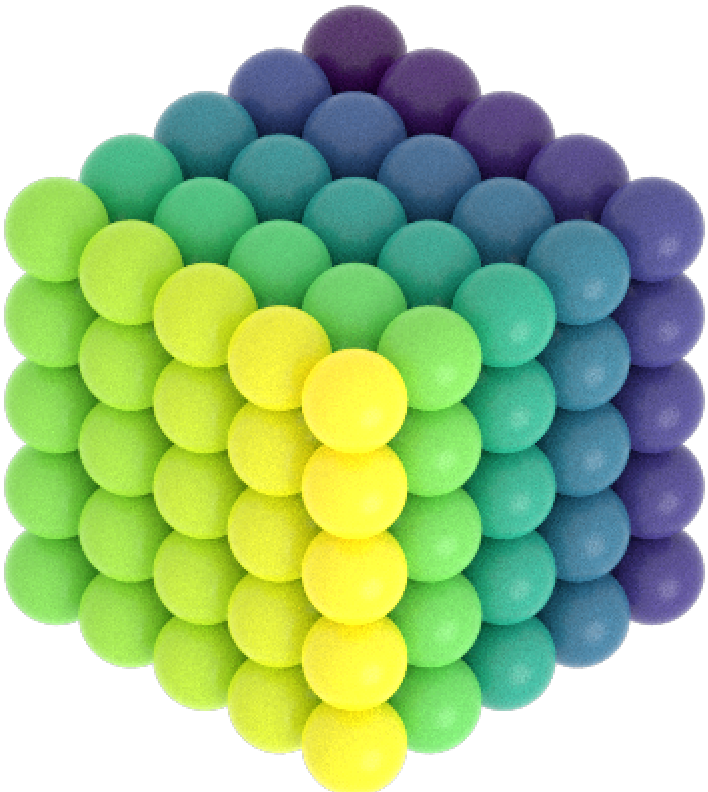


The shadows are very dark. Add another light to fill them in. You can access the scene's lights directly. The value *theta* defines the half angle width of the light source. Large lights provide soft shadows.

[11]:

```
scene.lights.append(fresnel.light.Light(direction=(0,0,1), color=(1,1,1), theta=3.14))
tracer.sample(scene, samples=64, light_samples=10)
```

[11]:

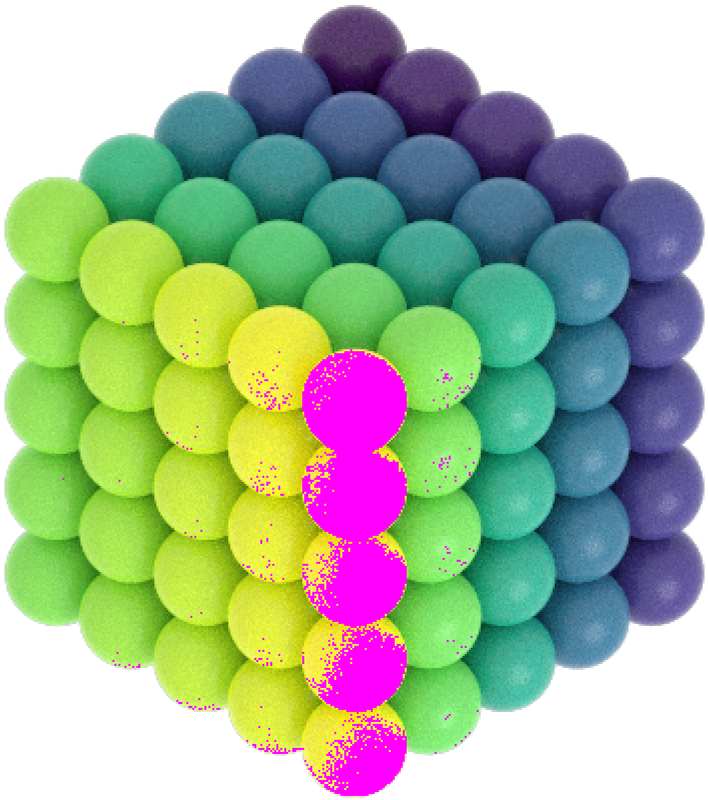


This image is overexposed.

Highlight warnings show overexposed areas of the image as a special color (default: magenta).

[12]:
```
tracer.enable_highlight_warning()
tracer.render(scene)
```

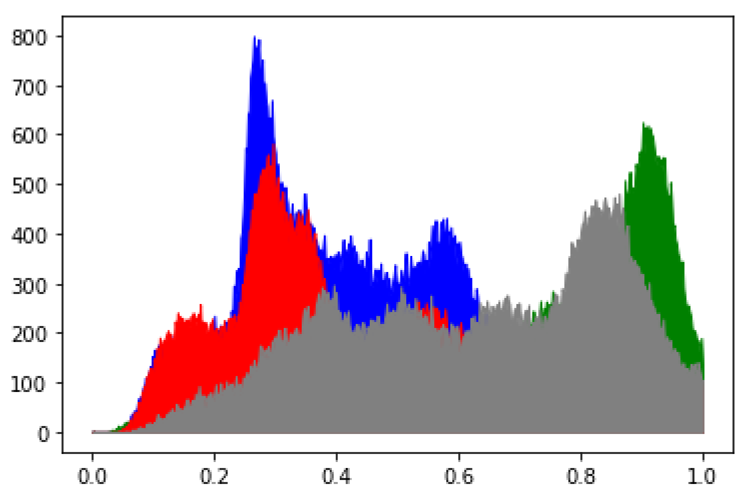
[12]:



If the histogram is blocking up at 1.0, there are overexposed highlights.

[13]:

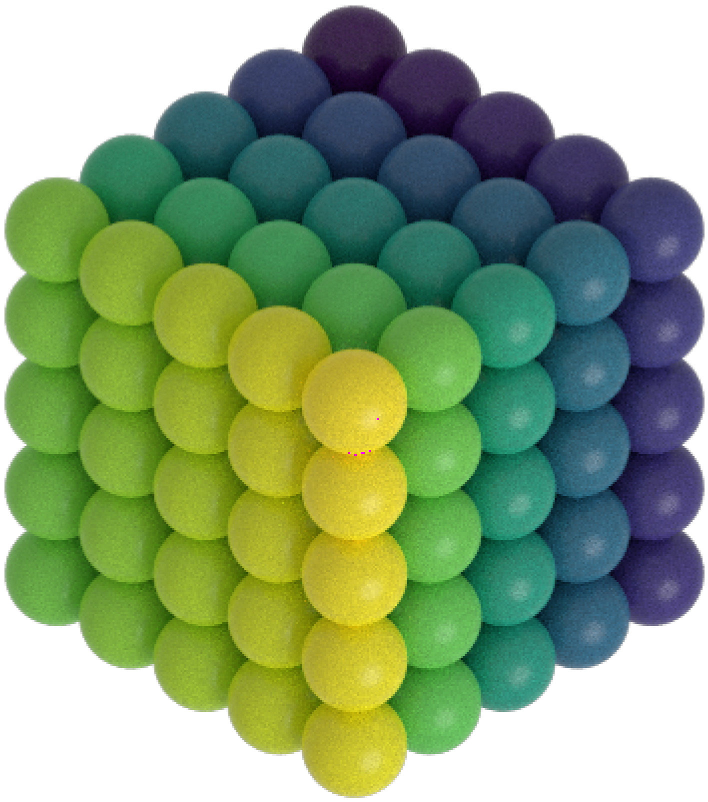
```
L, bins = tracer.histogram()
pyplot.fill_between(bins, L[:,3], color='blue');
pyplot.fill_between(bins, L[:,2], color='green');
pyplot.fill_between(bins, L[:,1], color='red');
pyplot.fill_between(bins, L[:,0], color='gray');
```



Reduce the intensity of the light to correctly expose the image.

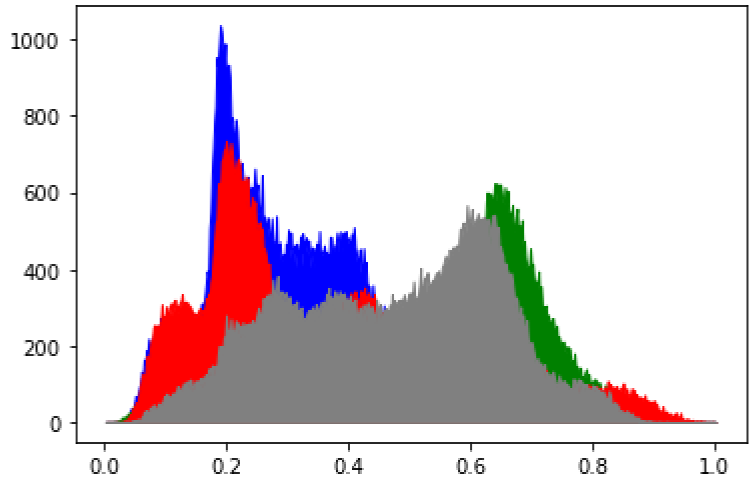
[14]:
```
scene.lights[1].color=(0.45,0.45,0.45)
tracer.sample(scene, samples=64, light_samples=10)
```

[14]:



Now there are no clipping warnings and the histogram shows a perfectly exposed image.

[15]:
```
L, bins = tracer.histogram()
pyplot.fill_between(bins, L[:,3], color='blue');
pyplot.fill_between(bins, L[:,2], color='green');
pyplot.fill_between(bins, L[:,1], color='red');
pyplot.fill_between(bins, L[:,0], color='gray');
```

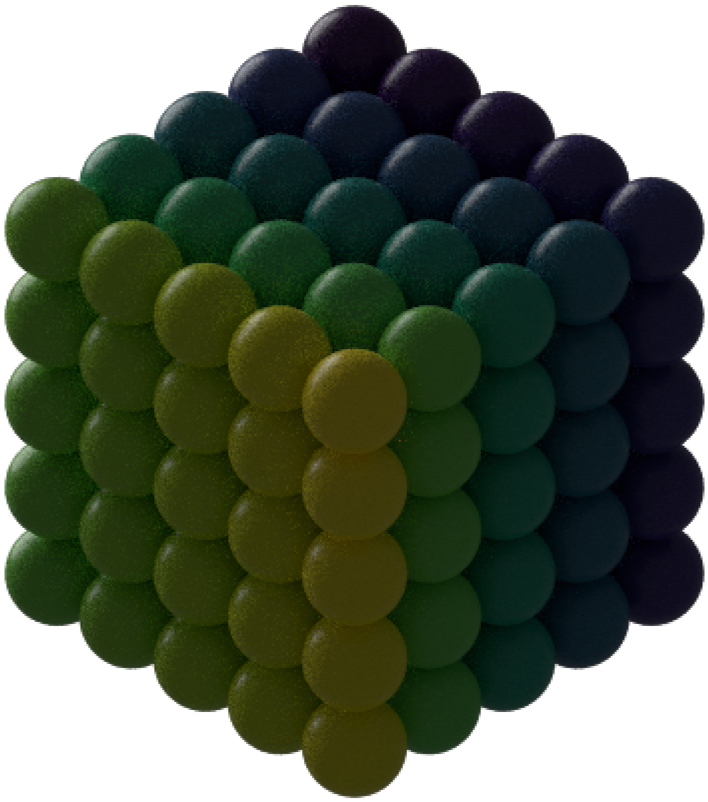


`scene.lights` has typical sequence like behavior. You can assign a sequence of Light objects to it, append lights to it, and loop over the lights in it. For example, reverse the direction of every light:

[16]:
```
for l in scene.lights:
    d = l.direction;
    l.direction = (-d[0], -d[1], -d[2])
```

[17]:
```
scene.lights[1].color=(0.05,0.05,0.05)
tracer.disable_highlight_warning()
tracer.sample(scene, samples=64, light_samples=10)
```

[17]:



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CHAPTER

THIRTEEN

SPHERE

```
[1]: import fresnel
scene = fresnel.Scene()
```

The **sphere geometry** defines a set of *N* spheres. Each sphere has its own *position*, *radius*, and *color*.

```
[2]: geometry = fresnel.geometry.Sphere(scene, N=3)
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.
↪9]),
                                              roughness=0.8)
```

13.1 Geometric properties

position defines the position of each sphere.

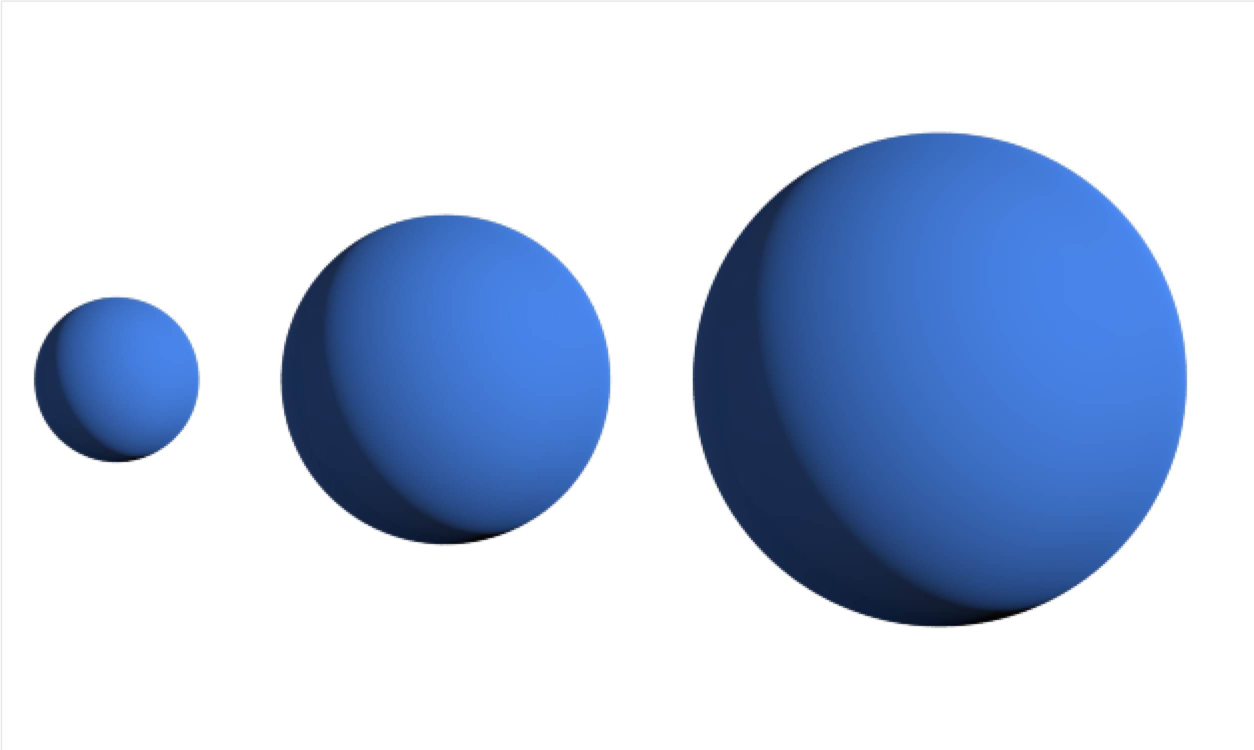
```
[3]: geometry.position[:] = [[-2,0,0], [0, 0, 0], [3, 0, 0]]
```

radius sets the radius of each sphere.

```
[4]: geometry.radius[:] = [0.5, 1.0, 1.5]
```

```
[5]: scene.camera = fresnel.camera.fit(scene, view='front', margin=0.5)
fresnel.preview(scene)
```

[5]:



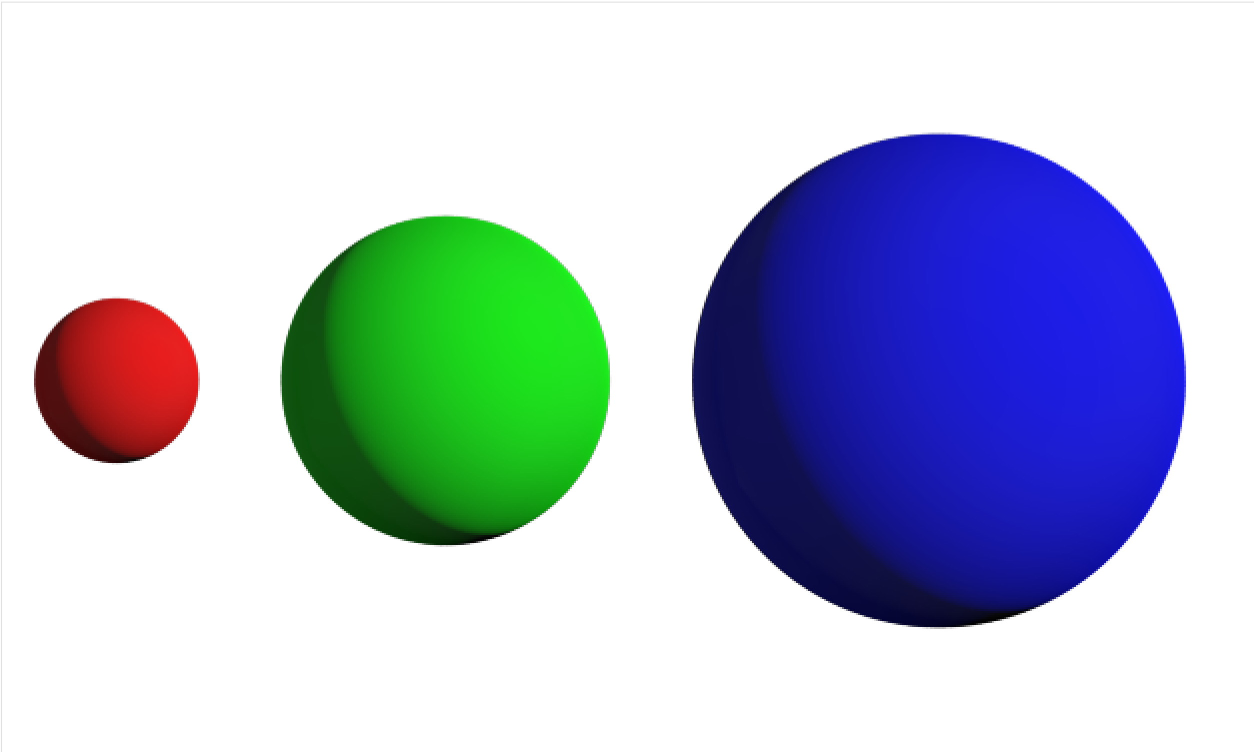
13.2 Color

color sets the color of each sphere (when when *primitive_color_mix > 0*)

[6]:
```
geometry.color[:] = fresnel.color.linear([[0.9,0,0], [0, 0.9, 0], [0, 0, 0.9]])
geometry.material.primitive_color_mix = 1.0
```

[7]:
```
fresnel.preview(scene)
```

[7]:



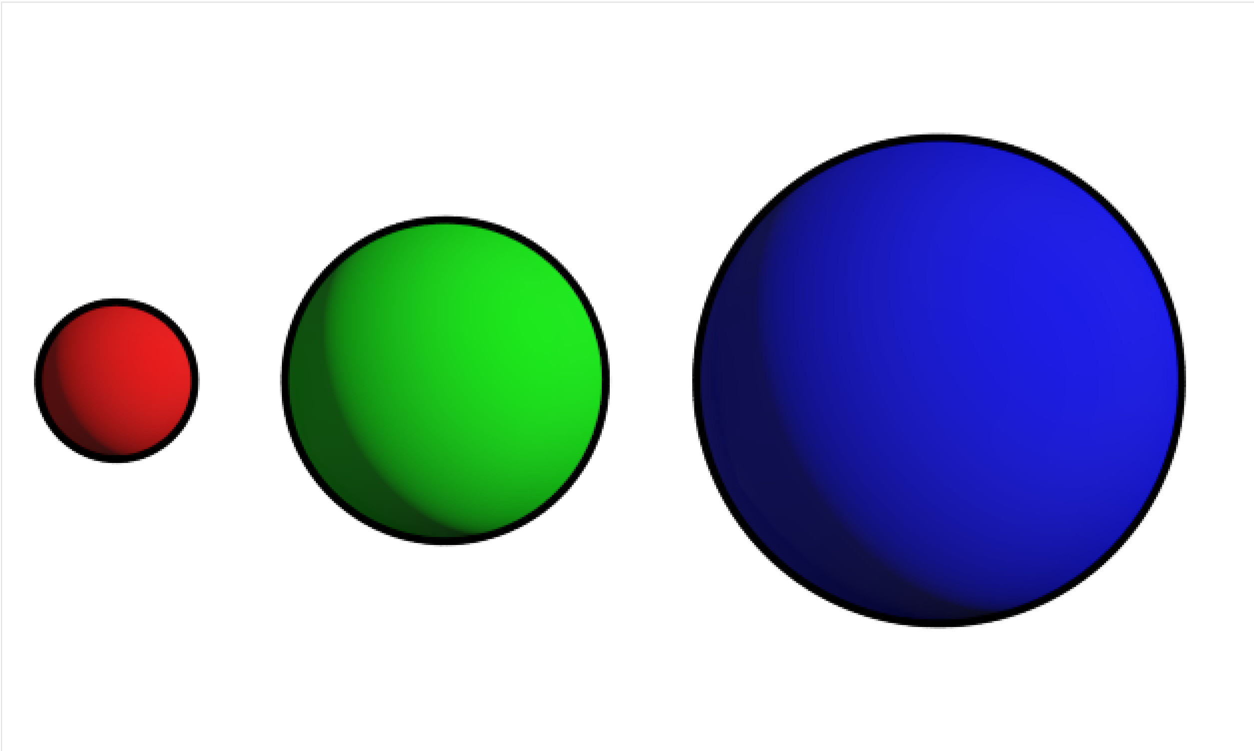
13.3 Outlines

Outlines are applied on the outer edge of the sphere in the view plane.

[8]:
```
geometry.outline_width = 0.05
```

[9]:
```
fresnel.preview(scene)
```

[9]:



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CHAPTER FOURTEEN

CYLINDER

[1]:
```python
import fresnel
scene = fresnel.Scene()
```

The **cylinder geometry** defines a set of *N* spherocylinders. Each spherocylinder is defined by two end points and has its own *radius*, and end point *colors*.

[2]:
```python
geometry = fresnel.geometry.Cylinder(scene, N=3)
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.
↪9]),
                                              roughness=0.8)
```

14.1 Geometric properties

points defines the end points of each cylinder.

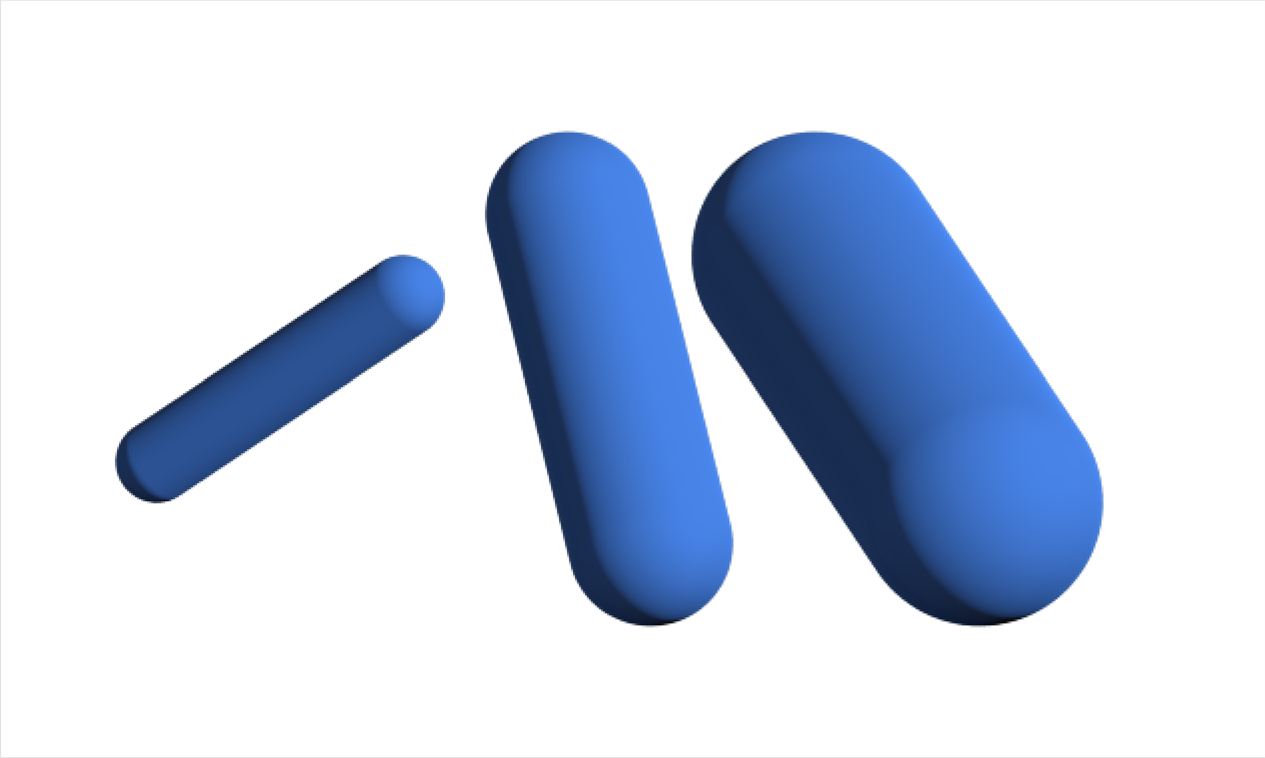
[3]:
```python
geometry.points[:] = [[[-5,-1,-1], [-2, 1, 1]],
                      [[1, -2, 1],[0, 2, -1]],
                      [[5, -1.5, 2], [3, 1.5, -2]]]
```

radius sets the radius of each spherocylinder.

[4]:
```python
geometry.radius[:] = [0.5, 1.0, 1.5]
```

[5]:
```python
scene.camera = fresnel.camera.fit(scene, view='front', margin=0.5)
fresnel.preview(scene)
```

[5]:



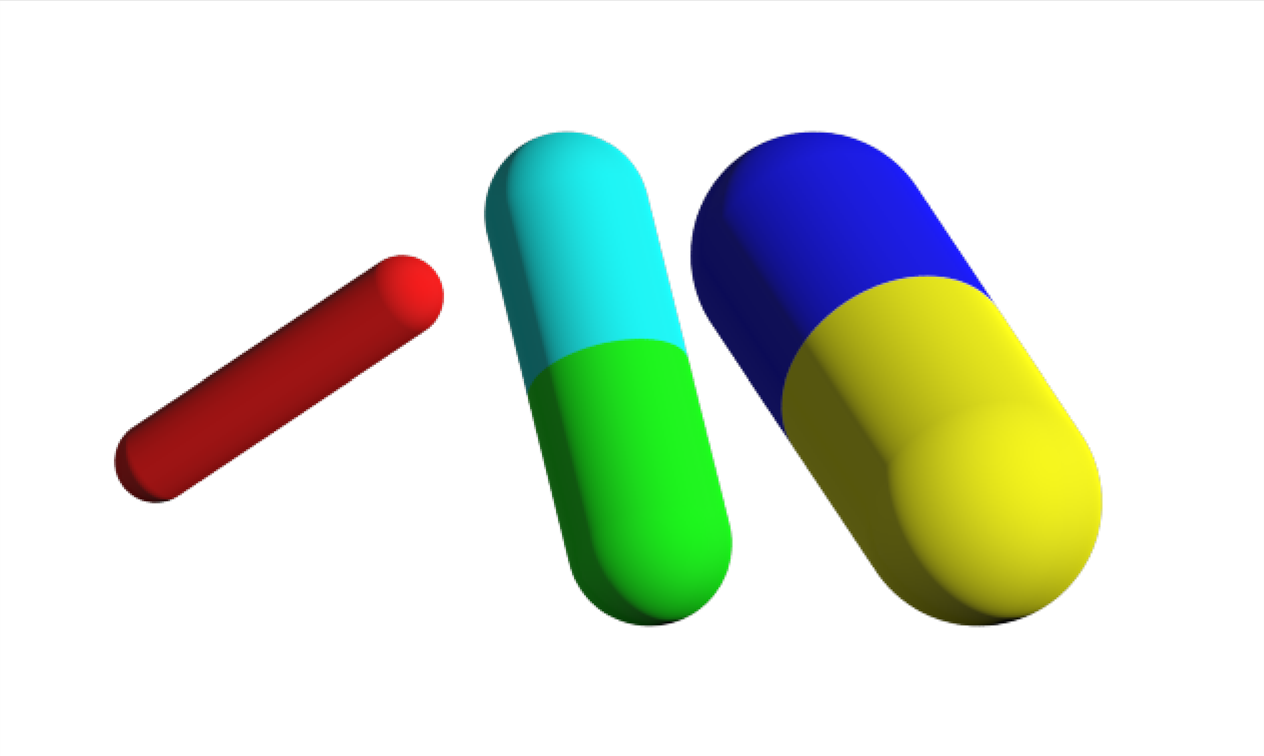
14.2 Color

color sets the color of the end points of each cylinder (when *primitive_color_mix > 0*). The color transitions at the midpoint.

[6]:
```
geometry.color[:] = [[[0.9,0,0], [0.9, 0, 0]],
                      [[0, 0.9, 0], [0, 0.9, 0.9]],
                     [[0.9, 0.9, 0], [0, 0, 0.9]]]
geometry.material.primitive_color_mix = 1.0
```

[7]:
```
fresnel.preview(scene)
```

[7]:



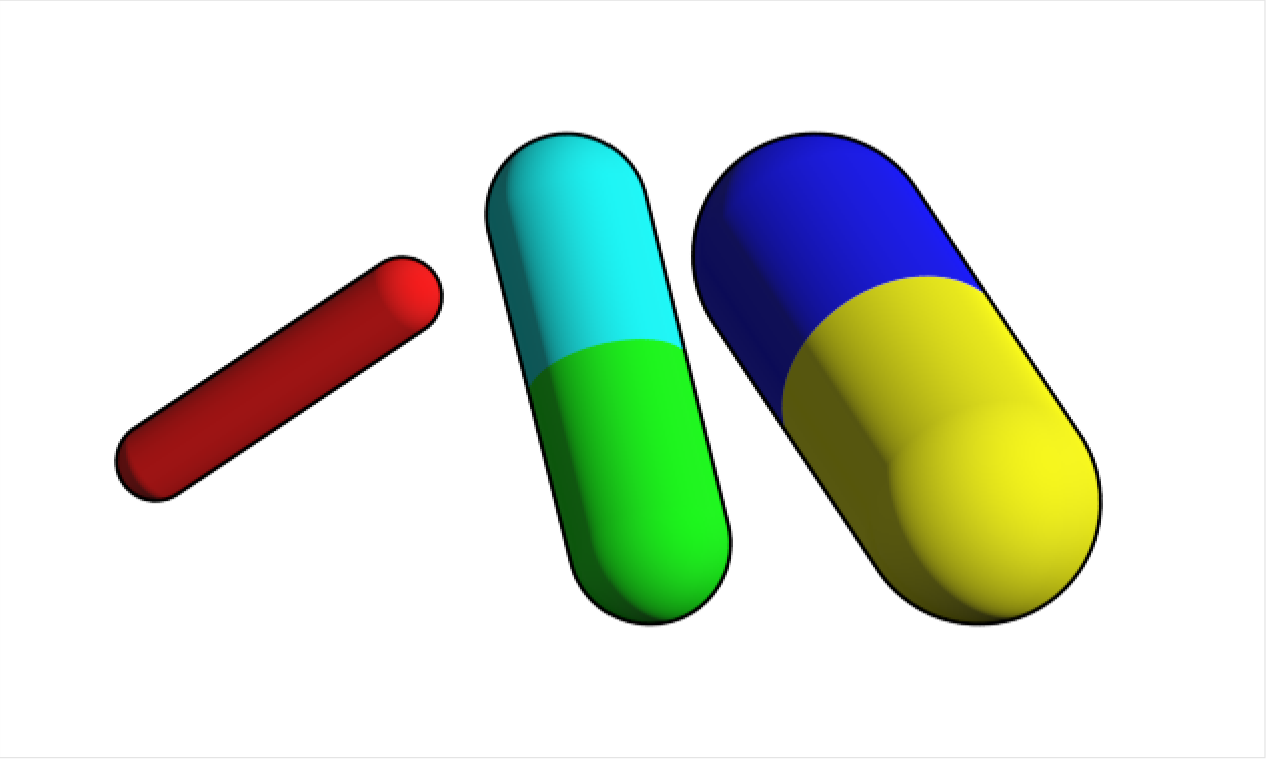
14.3 Outlines

Outlines are applied on the outer edge of the cylinder in the view plane.

[8]:
```
geometry.outline_width = 0.05
```

[9]:
```
fresnel.preview(scene)
```

[9]:



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CHAPTER

FIFTEEN

CONVEX POLYHEDRON

[1]:
```python
import fresnel
import itertools
import math
import numpy as np
device = fresnel.Device()
scene = fresnel.Scene(device)
```

The **convex polyhedron geometry** defines a set of *N* convex polyhedra. The shape of all *N* polyhedra is identical and defined by *P* planes. Each polyhedron has its own *position*, *orientation*, and *color*. You must also specify the circumsphere radius *r*. Note that the information used to draw a convex polyhedron is easily obtained from it's vertices via the `util.convex_polyhedron_from_vertices()` utility function.

To construct a truncated cube:

[2]:
```python
# first get cube verts
pm = [-1, 1]
cube_verts = list(itertools.product(pm, repeat=3))
trunc_cube_verts = []
# truncate by removing corners and adding vertices to edges
for p1, p2 in itertools.combinations(cube_verts, 2):
    # don't add points along any diagonals
    match = (p1[0]==p2[0], p1[1]==p2[1], p1[2]==p2[2])
    if match.count(False) == 1: # only 1 coordinate changes, not a diagonal
        p1, p2 = np.array(p1), np.array(p2)
        vec = p2 - p1
        trunc_cube_verts.append(p1 + vec/3)
        trunc_cube_verts.append(p1 + 2*vec/3)
```

[3]:
```python
c1 = fresnel.color.linear([0.70, 0.87, 0.54])*0.8
c2 = fresnel.color.linear([0.65,0.81,0.89])*0.8
colors = {8: c1, 3: c2}
poly_info = fresnel.util.convex_polyhedron_from_vertices(trunc_cube_verts)
for idx, fs in enumerate(poly_info['face_sides']):
    poly_info['face_color'][idx] = colors[fs]
geometry = fresnel.geometry.ConvexPolyhedron(scene,
                                             poly_info,
                                             N=3
                                            )
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.
↪9]),
                                              roughness=0.8)
```

15.1 Geometric properties

position defines the position of the center of each convex polyhedron.

```
[4]: geometry.position[:] = [[-3,0,0], [0, 0, 0], [3, 0, 0]]
```

orientation sets the orientation of each convex polyhedron as a quaternion

```
[5]: geometry.orientation[:] = [[1, 0, 0, 0],
                               [0.80777943,  0.41672122,  0.00255412,  0.41692838],
                               [0.0347298, 0.0801457, 0.98045, 0.176321]]
```

```
[6]: scene.camera = fresnel.camera.fit(scene, view='front', margin=0.8)
     fresnel.preview(scene)
```

[6]:

15.2 Color

color sets the color of each individual convex polyhedron (when *primitive_color_mix > 0* and *color_by_face < 1*)

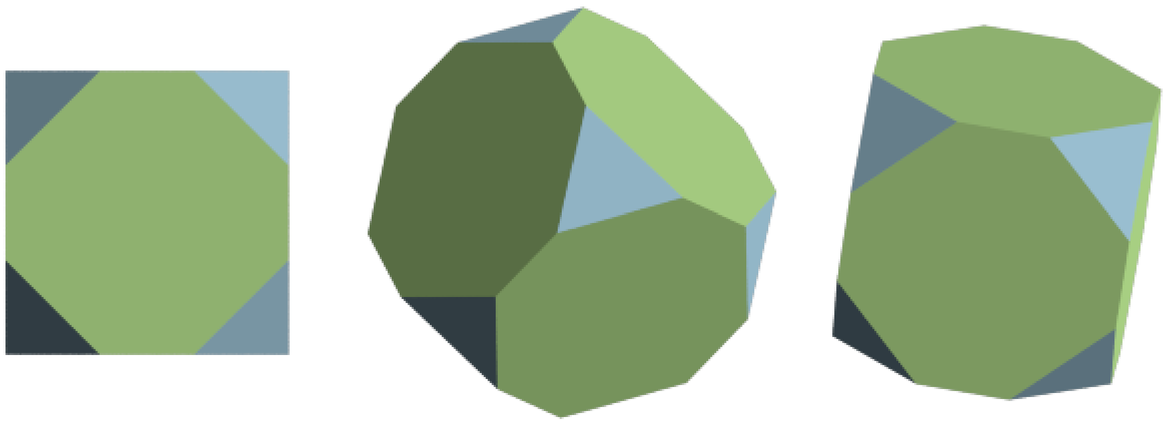
```
[7]: geometry.color[:] = fresnel.color.linear([[0.9,0,0], [0, 0.9, 0], [0, 0, 0.9]])
     geometry.material.primitive_color_mix = 1.0
     fresnel.preview(scene)
```

[7]:

Set **color_by_face** > 0 to color the faces of the polyhedra independently. `poly_info['face_colors']` (i.e., the output of convex_polyhedron_from_vertices, which we modified above) sets the color of each face. Above, we set the color of the each face based on number of sides it has.

[8]:
```
geometry.color_by_face = 1.0
fresnel.preview(scene)
```

[8]:

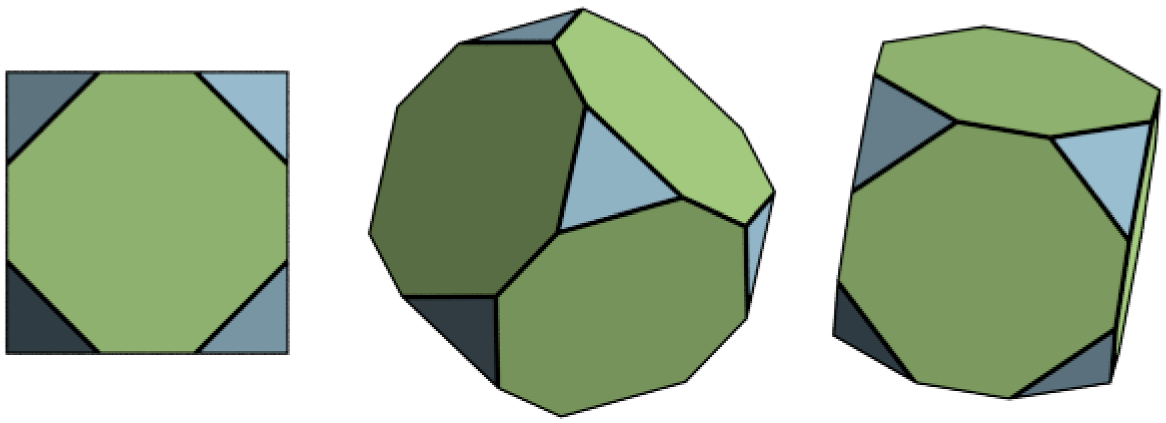


15.3 Outlines

Outlines are applied at the outer edge of each face.

[9]:
```
geometry.outline_width = 0.02
fresnel.preview(scene)
```

[9]:



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[1]:
```
import fresnel
import numpy
import matplotlib, matplotlib.cm
```

CHAPTER SIXTEEN

MESH

The **mesh geometry** defines a generic triangle mesh. Define a mesh with an 3Tx3 array where T is the number of triangles. Triangles must be specified with a counter clockwise winding. Here is the Standford bunny as an example:

[2]:
```
# https://graphics.stanford.edu/~mdfisher/Data/Meshes/bunny.obj
verts = numpy.load('bunny.npy')
```

16.1 Geometric properties

Pass the vertices to the mesh geometry.

[3]:
```
scene1 = fresnel.Scene()
bunny = fresnel.geometry.Mesh(scene1,vertices=verts,N=1)
```

[4]:
```
bunny.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.9]),
↪ roughness=0.6)
scene1.camera = fresnel.camera.fit(scene1,margin=0)
scene1.lights = fresnel.light.cloudy()
fresnel.pathtrace(scene1, samples=200)
```

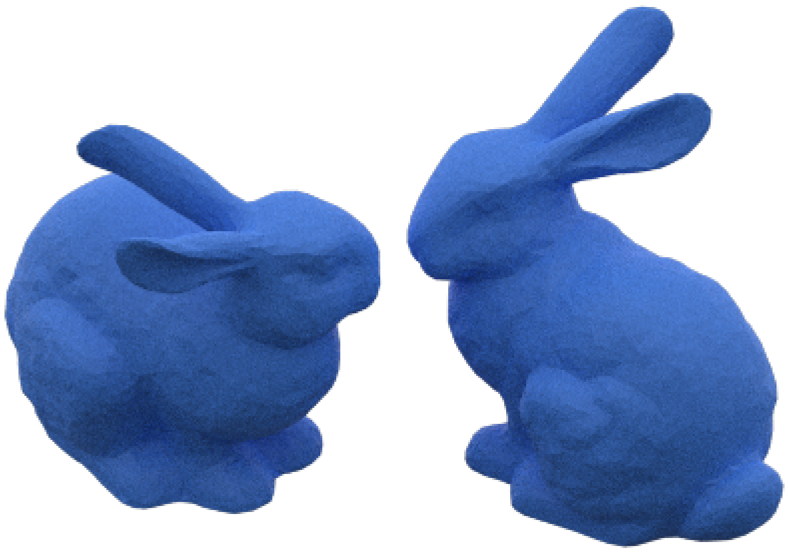
[4]:

Specify position and orientation to instantiate the mesh many times.

[5]:
```
scene2 = fresnel.Scene()
bunnies = fresnel.geometry.Mesh(scene2,vertices=verts,N=2)
bunnies.position[:] = [[0,0,0], [-0.11,0,0.1]]
bunnies.orientation[:] = [[1,0,0,0], [0,0,1,0]]
```

[6]:
```
bunnies.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.5,0.
↪9]), roughness=0.6)
scene2.camera = fresnel.camera.fit(scene1,margin=0)
scene2.lights = fresnel.light.cloudy()
fresnel.pathtrace(scene2, samples=200)
```

[6]:



16.2 Color

Specify per vertex colors. These colors are smoothly interpolated across the triangles. Set `primitive_color_mix=1` to choose the per-vertex colors.

Color the bunny based on the y-coordinate of the mesh:

[7]:
```
mapper = matplotlib.cm.ScalarMappable(norm = matplotlib.colors.Normalize(vmin=-0.08,␣
↪vmax=0.05, clip=True),
                                      cmap = matplotlib.cm.get_cmap(name='viridis'))

bunny.color[:] = fresnel.color.linear(mapper.to_rgba(verts[:,1]))
bunny.material.primitive_color_mix = 1.0
```

[8]:
```
fresnel.pathtrace(scene1, samples=200)
```

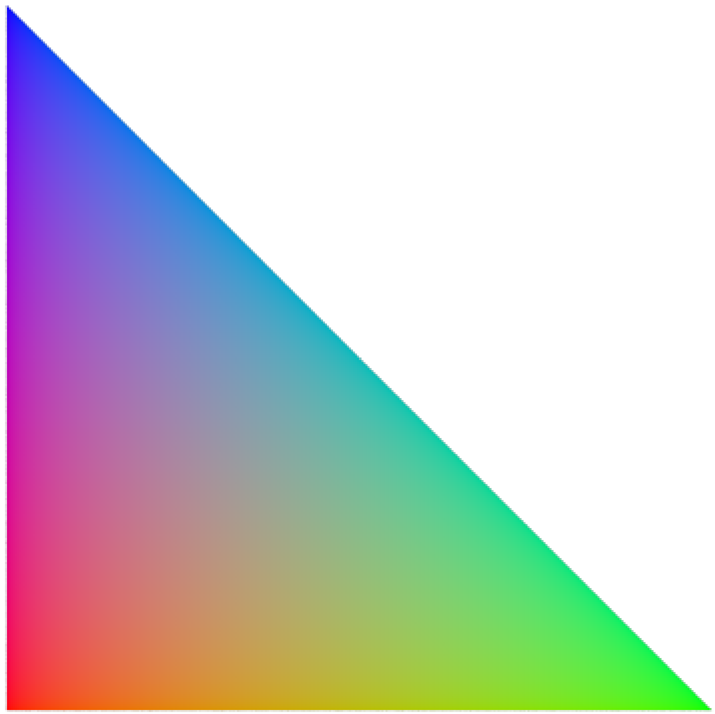
[8]:

Here is a single triangle demo to demonstrate the interpolation:

[9]:
```
scene3 = fresnel.Scene()
triangle = fresnel.geometry.Mesh(scene3,vertices=[[0,0,0],[1,0,0],[0,1,0]],N=1)
triangle.material.solid = 1
triangle.material.primitive_color_mix = 1.0
triangle.color[:] = [[1,0,0], [0,1,0], [0,0,1]]
```

[10]:
```
scene3.camera = fresnel.camera.fit(scene3, view='front')
fresnel.preview(scene3)
```

[10]:



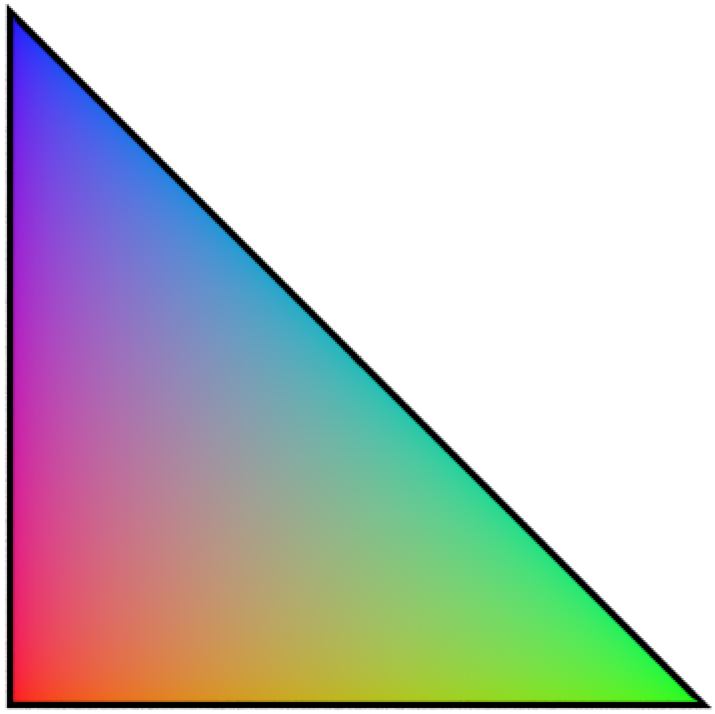
16.3 Outlines

Outlines are placed on the outer edge of each triangle in the mesh.

[11]:

```
triangle.outline_width=0.01
fresnel.preview(scene3)
```

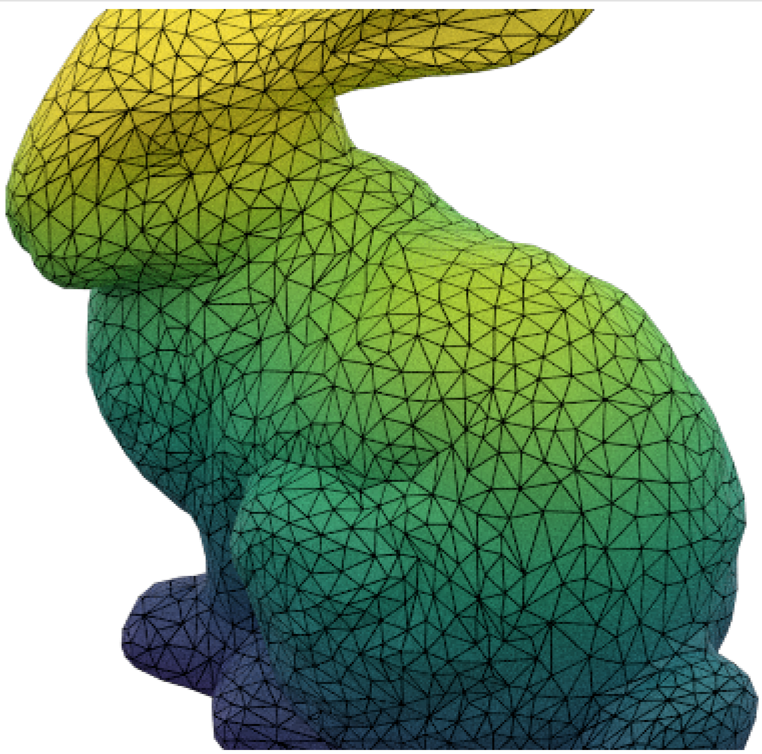
[11]:



[12]:

```
bunny.outline_width=0.0002
scene1.camera.height *= 0.5
fresnel.pathtrace(scene1, samples=200)
```

[12]:



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CHAPTER SEVENTEEN

POLYGON

[1]:
```
import fresnel
scene = fresnel.Scene()
```

The **polygon geometry** defines a set of N simple polygons in two dimensions. All polygons in the geometry have the same vertices. Each polygon has a separate *position*, orientation *angle*, and *color*.

[2]:
```
geometry = fresnel.geometry.Polygon(scene,
                                    N=2,
                                    vertices = [[0, -1], [1, 1],
                                                [0, 0.5], [-1, 1]])
geometry.material.color = fresnel.color.linear([0.20,0.64,0.58])
geometry.material.solid=1
```

17.1 Geometric properties

position defines the position of each polygon in the *z=0* plane.

[3]:
```
geometry.position[:] = [[-1,0],
                        [1, 0]]
```

angle defines the rotation angle of each polygon

[4]:
```
geometry.angle[:] = [0.1, -1.0]
```

[5]:
```
fresnel.preview(scene)
```

[5]:

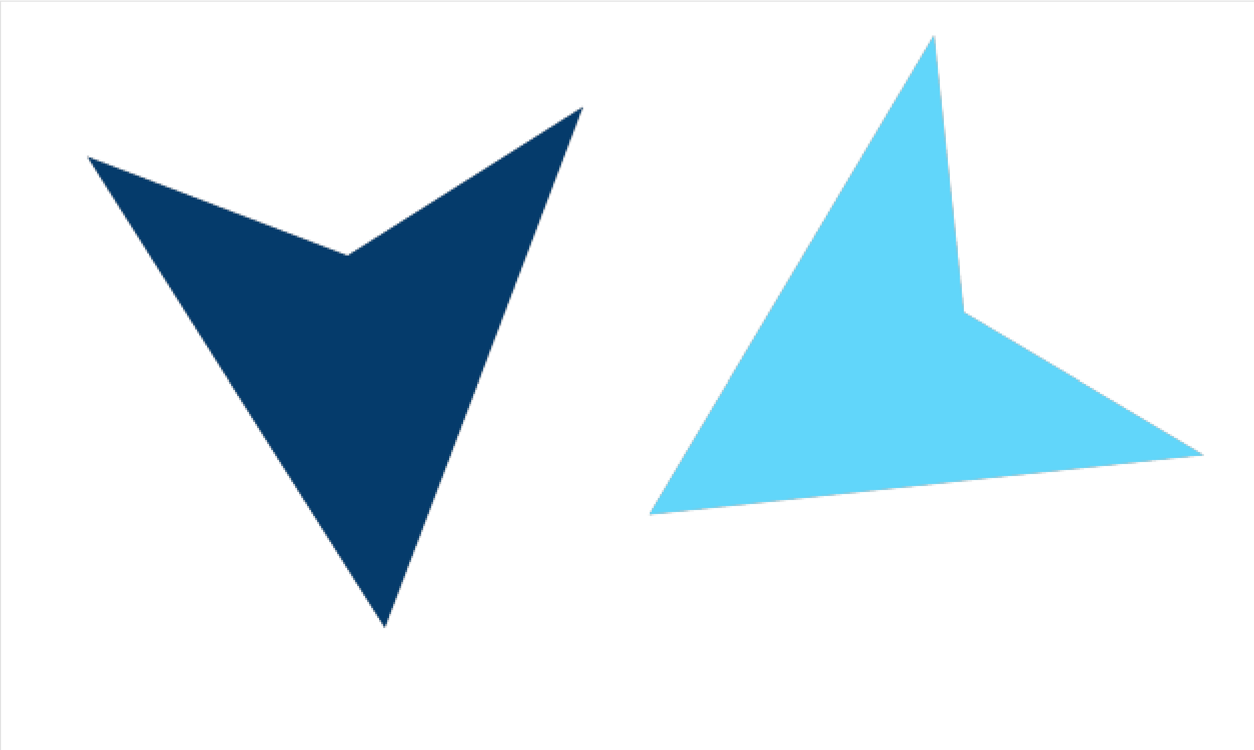
17.2 Color

color sets the color of each polygon (when *primitive_color_mix* > *0*).

[6]:
```
geometry.color[:] = [fresnel.color.linear([0.02,0.23,0.42]),
                     fresnel.color.linear([0.38,0.84,0.98])];
geometry.material.primitive_color_mix = 1.0
```

[7]:
```
fresnel.preview(scene)
```

[7]:



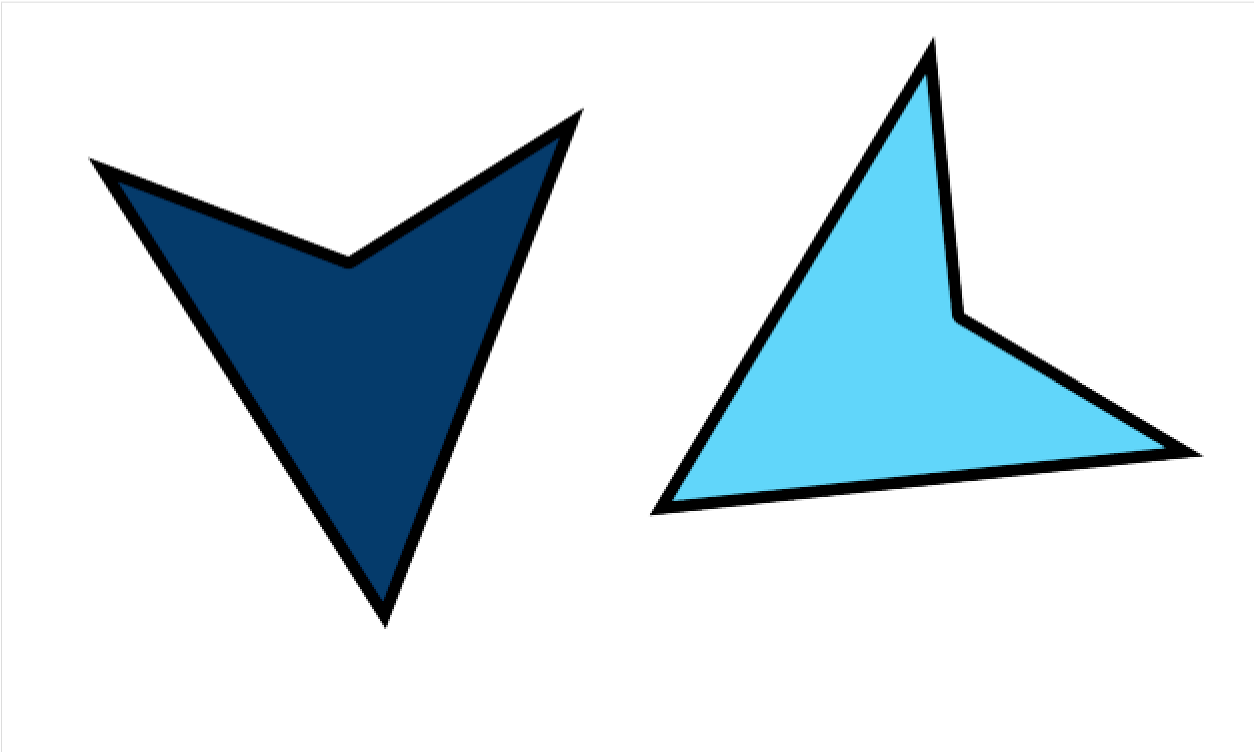
17.3 Outlines

Outlines are applied inside the outer edge of the polygon in the z=0 plane.

[8]:
```
geometry.outline_width = 0.05
```

[9]:
```
fresnel.preview(scene)
```

[9]:



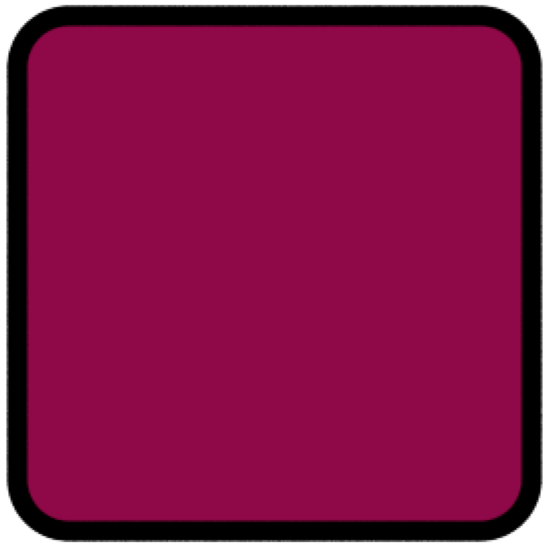
17.4 Rounded polygons

Specify *rounding_radius* to round the edges of the polygon.

[10]:
```
scene2 = fresnel.Scene()
geometry2 = fresnel.geometry.Polygon(scene2,
                                     rounding_radius=0.3,
                                     N=1,
                                     vertices = [[-1, -1], [1, -1],
                                                 [1, 1], [-1, 1]],
                                     outline_width=0.1)
geometry2.material.color=fresnel.color.linear([0.56,0.03,0.28])
geometry2.material.solid=1
```

[11]:
```
fresnel.preview(scene2)
```

[11]:



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CHAPTER EIGHTEEN

BOX

[1]:
```
import sys

import fresnel

scene = fresnel.Scene()
```

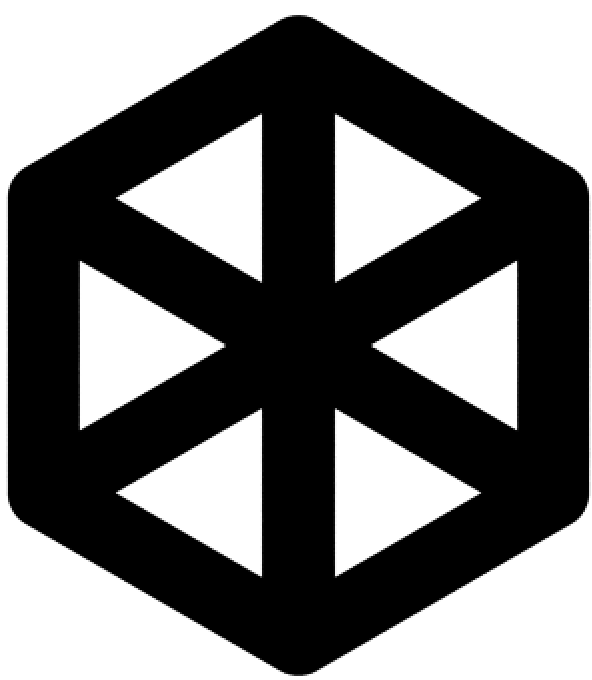
The Box geometry is a convenience class that uses the Cylinder geometry to draw a box. The Box geometry supports triclinic boxes and follows hoomd-blue box conventions. For cubic boxes, only one length is needed.

[2]:
```
my_box = [5]
```

[3]:
```
scene = fresnel.Scene()
geometry = fresnel.geometry.Box(scene, my_box)
```

[4]:
```
fresnel.preview(scene)
```

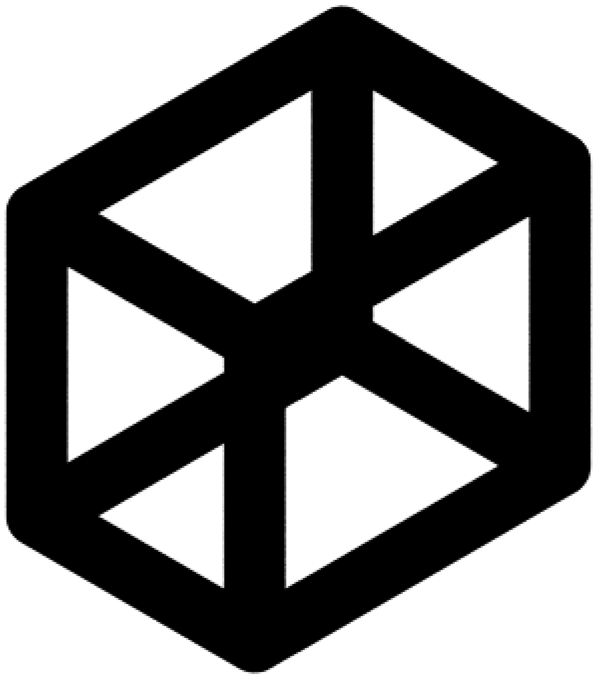
[4]:



Orthorhombic boxes require an Lx, Ly, and Lz

[5]:
```
my_box = [5,6,7]
scene = fresnel.Scene()
geometry = fresnel.geometry.Box(scene, my_box)
fresnel.preview(scene)
```

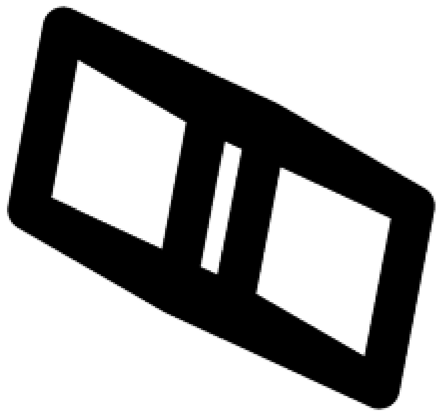
[5]:



Triclinic boxes are supported by using 6 terms, Lx, Ly, Lz, xy, xz, yz.

[6]:
```
my_box = [5,6,7, .2, 0, .9]
scene = fresnel.Scene()
geometry = fresnel.geometry.Box(scene, my_box)
fresnel.preview(scene)
```

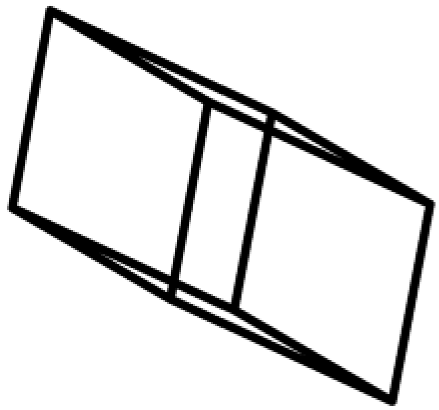
[6]:



The radius defaults to 0.5 but can be specifed when the box is created

[7]:
```
my_box = [5,6,7, .2, 0, .9]
scene = fresnel.Scene()
geometry = fresnel.geometry.Box(scene, my_box, box_radius=.1)
fresnel.preview(scene)
```

[7]:



Or changed later

[8]:
```
geometry.box_radius = 1
fresnel.preview(scene)
```

[8]:

The box color can also be set on initialization.

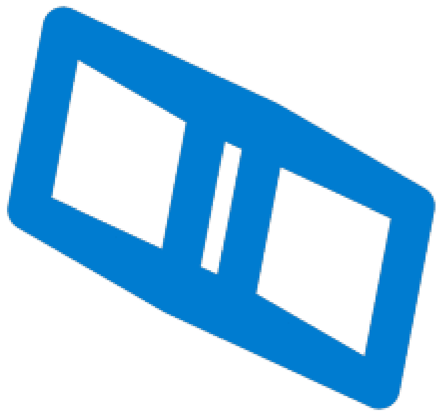
[9]:
```
my_box = [5, 6, 7, 0.2, 0, 0.9]
scene = fresnel.Scene()
geometry = fresnel.geometry.Box(scene, my_box, box_color=[214 / 255, 67 / 255, 9 /␣
↪255])
fresnel.preview(scene)
```

[9]:

Or changed later.

[10]:
```
geometry.box_color = [0, 51 / 255, 160 / 255]
fresnel.preview(scene)
```

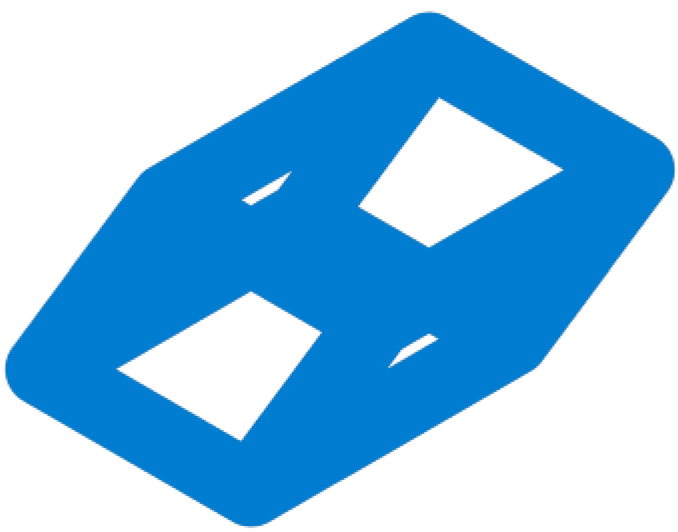
[10]:



The box size and shape can also be updated.

[11]:
```
geometry.box = [4, 4, 5, 0.6, 0,0]
fresnel.preview(scene)
```

[11]:



CHAPTER

NINETEEN

MULTIPLE GEOMETRIES

A **Scene** may consist of more than one geometry object. For fast performance, try to condense the scene down to as few geometries with as many primitives as possible. Multiple geometries allow for different materials to be applied to the same type of geometry and for different types of geometry in the same scene.

[1]:
```
import fresnel
scene = fresnel.Scene()
```

19.1 Create multiple geometries

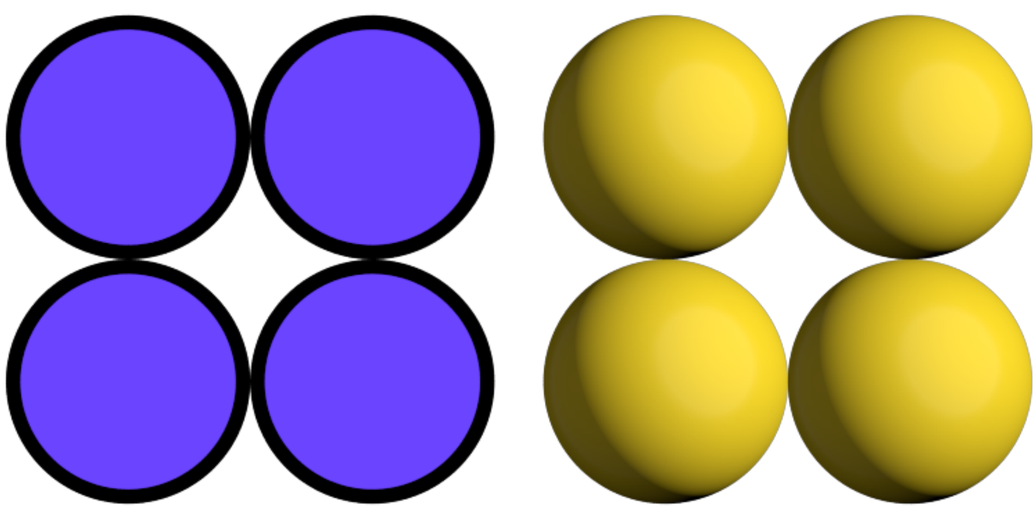
To create multiple geometries, instantiate several instances of the geometry class.

[2]:
```
geom1 = fresnel.geometry.Sphere(scene, position = [[-3.2, 1, 0], [-3.2, -1, 0], [-1.2,
↪ 1, 0], [-1.2, -1, 0]], radius=1.0)
geom1.material = fresnel.material.Material(solid=1.0, color=fresnel.color.linear([0.
↪42,0.267,1]))
geom1.outline_width = 0.12
```

[3]:
```
geom2 = fresnel.geometry.Sphere(scene, position = [[3.2, 1, 0], [3.2, -1, 0], [1.2, 1,
↪ 0], [1.2, -1, 0]], radius=1.0)
geom2.material = fresnel.material.Material(solid=0.0, color=fresnel.color.linear([1,0.
↪874,0.169]))
```

[4]:
```
fresnel.preview(scene, w=900, h=370)
```

[4]:



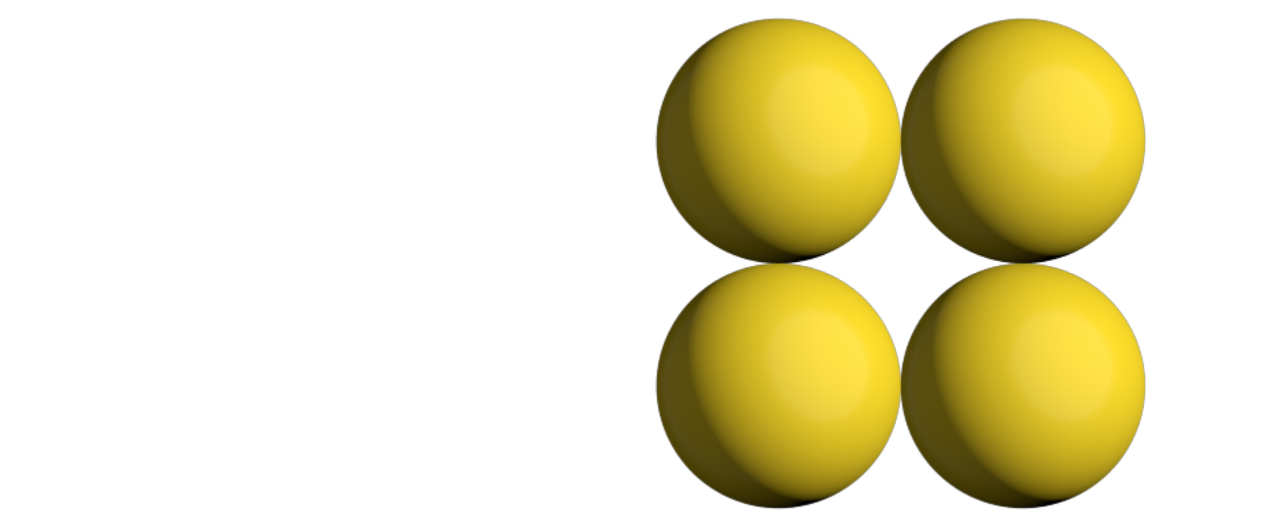
19.2 Disable geometries

disable a geometry to prevent it from appearing in the scene.

[5]:
```
geom1.disable()
```

[6]:
```
fresnel.preview(scene, w=900, h=370)
```

[6]:

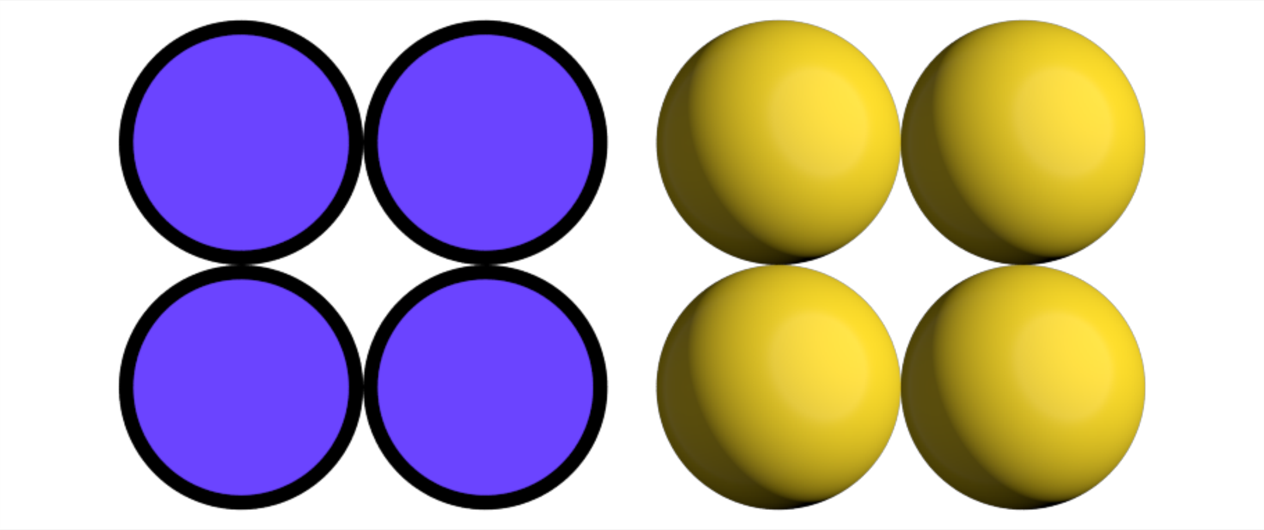


enable the geometry to make it appear again.

[7]:
```
geom1.enable()
```

[8]:
```
fresnel.preview(scene, w=900, h=370)
```

[8]:



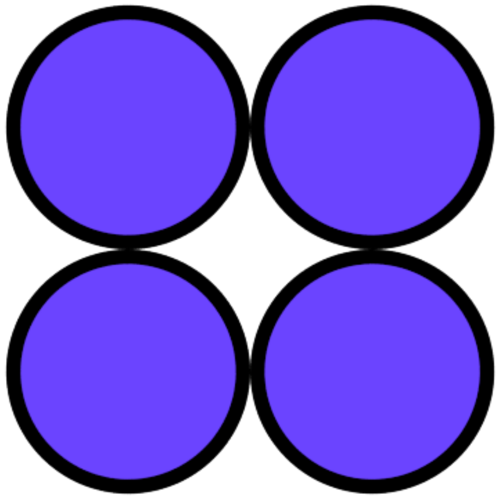
19.3 Remove geometry

Call **remove** to completely remove a geometry instance from the scene. It cannot be added back.

[9]:
```
geom2.remove()
```

[10]:
```
fresnel.preview(scene, w=900, h=370)
```

[10]:



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CHAPTER

TWENTY

DEVICES

Each **Scene** is attached to a specific **Device**. The **Device** controls what hardware the ray tracing executes on. **Scene** implicitly creates a default **Device** when you do not specify one.

20.1 The default device

The default device automatically selects **GPU ray tracing** if the *gpu module is compiled* and *there is at least one gpu present in the system* - otherwise it selects **CPU ray tracing**.

[1]:
```
import fresnel
device = fresnel.Device()
```

20.2 Query available execution modes

The `available_modes` static variable lists which execution modes are available. This will vary based on compile time options and whether there is a GPU present in the system.

[2]:
```
print(fresnel.Device.available_modes)
```

```
['gpu', 'cpu', 'auto']
```

`available_gpus` lists the GPUs available for rendering in the system.

[3]:
```
for g in fresnel.Device.available_gpus:
    print(g)
```

```
 [0]:                    TITAN V   80 SM_7.0 @ 1.46 GHz,   6135 MiB DRAM
 [1]:                    TITAN V   80 SM_7.0 @ 1.46 GHz,   6135 MiB DRAM
```

20.3 Choose execution hardware

Explicitly manage a **Device** to control what hardware the ray tracing executes on. Converting the device to a string provides a short summary of the device configuration.

[4]:
```
gpu = fresnel.Device(mode='gpu')
print(gpu)
```

```
<fresnel.Device: Enabled OptiX devices:
 [0]:                TITAN V   80 SM_7.0 @ 1.46 GHz,   6135 MiB DRAM
 [1]:                TITAN V   80 SM_7.0 @ 1.46 GHz,   6135 MiB DRAM
>
```

[5]:
```
cpu = fresnel.Device(mode='cpu')
print(cpu)
```

```
<fresnel.Device: All available CPU threads>
```

Set `n` to specify how many CPU threads or GPUs to use in parallel. By default, a device will use all available CPU cores or GPUs in the system.

[6]:
```
cpu_limit = fresnel.Device(mode='cpu', n=6)
print(cpu_limit)
```

```
<fresnel.Device: 6 CPU threads>
```

20.4 Attach a scene to a device

Each **Scene** must be attached to a device when created.

[7]:
```
scene_gpu = fresnel.Scene(device=gpu)
```

[8]:
```
scene_cpu = fresnel.Scene(device=cpu)
```

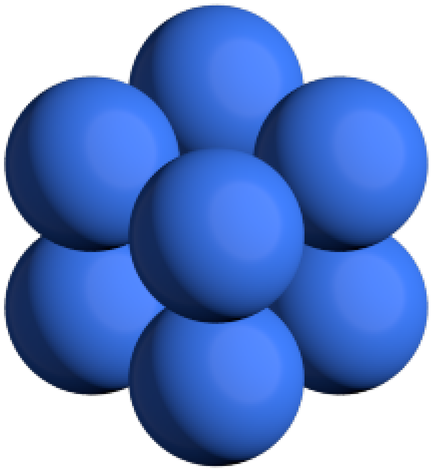
These two scenes have the same API, but different implementations.

[9]:
```
for scene in [scene_cpu, scene_gpu]:
    geometry = fresnel.geometry.Sphere(scene, N=8, radius=1.0)
    geometry.position[:] = [[1,1,1],
                        [1,1,-1],
                        [1,-1,1],
                        [1,-1,-1],
                        [-1,1,1],
                        [-1,1,-1],
                        [-1,-1,1],
                        [-1,-1,-1]]
    geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.25,0.
↪5,1]))
```

Rendered output is essentially identical from the two devices.

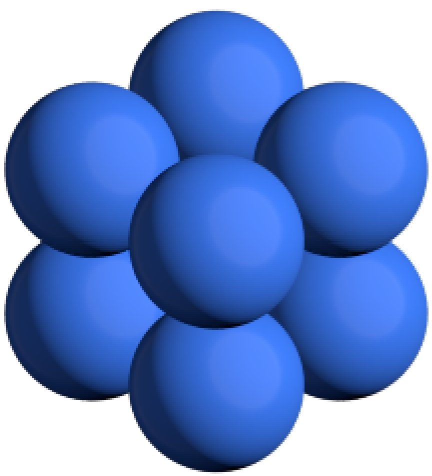
[10]:
```
fresnel.preview(scene_gpu, w=300, h=300)
```

[10]:



[11]:
```
fresnel.preview(scene_cpu, w=300, h=300)
```

[11]:



20.5 Memory consumption

Each **Device** consumes memory by itself. When maintaining multiple scenes, attach them all to the same device to reduce memory consumption.

[12]:
```
import math
scene2_gpu = fresnel.Scene(device=gpu)
position = []
for k in range(5):
    for i in range(5):
```

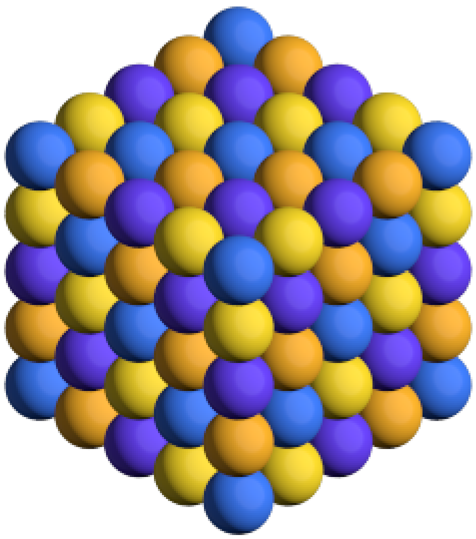
(continues on next page)

(continued from previous page)

```
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
geometry = fresnel.geometry.Sphere(scene2_gpu, position = position, radius=1.0)
geometry.color[::4] = fresnel.color.linear([0.25,0.5,1])
geometry.color[1::4] = fresnel.color.linear([1,0.714,0.169])
geometry.color[2::4] = fresnel.color.linear([0.42,0.267,1])
geometry.color[3::4] = fresnel.color.linear([1,0.874,0.169])
geometry.material = fresnel.material.Material(solid=0.0, primitive_color_mix=1.0)
```

[13]:
```
fresnel.preview(scene2_gpu, w=300, h=300)
```

[13]:



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CHAPTER

TWENTYONE

TRACER METHODS

Most of the tutorials use **fresnel.preview()** and **fresnel.pathtrace()** to render output images. This is a convenience API, and there are cases where it is not appropriate. To render many frames, such as in a movie or interactive visualization, use a **Tracer** directly to avoid overhead.

[1]:
```
import fresnel
import math
from matplotlib import pyplot
%matplotlib inline
device = fresnel.Device()
scene = fresnel.Scene(device=device)
position = []
for i in range(6):
    position.append([2*math.cos(i*2*math.pi / 6), 2*math.sin(i*2*math.pi / 6), 0])

geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.material = fresnel.material.Material(solid=0.0, color=fresnel.color.
↪linear([1,0.874,0.169])*0.9)
geometry.outline_width = 0.12
scene.camera = fresnel.camera.fit(scene, view='front', margin=0.2)
```

21.1 Common Tracer operations

The **Tracer** must use the same device as the **Scenes** it renders. Each **Tracer** maintains an output image, and the width **w** and height **h** must be defined when the tracer is created.

[2]:
```
tracer = fresnel.tracer.Preview(device=device, w=300, h=300)
```

21.1.1 Rendering and accessing output images

The **render** method renders the output.

[3]:
```
out = tracer.render(scene)
```

The return value of **render** is a proxy reference to the internal image buffer of the **Tracer**. You can access with a **numpy** array like interface.

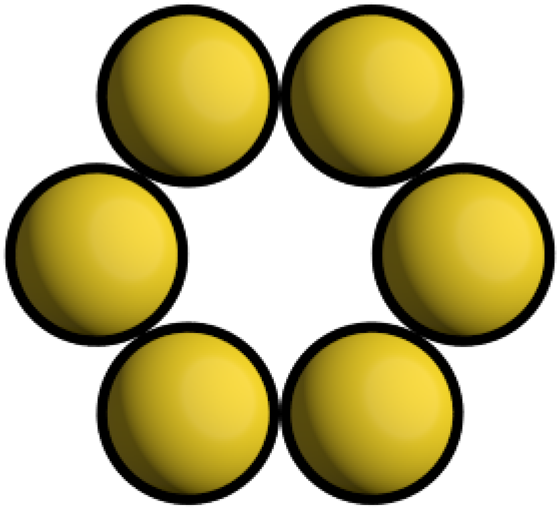
[4]:
```
out[100,100]
```

[4]:
```
array([139, 121,  21, 255], dtype=uint8)
```

The output object also provides an interface for **jupyter** to display the image.

[5]:
```
out
```

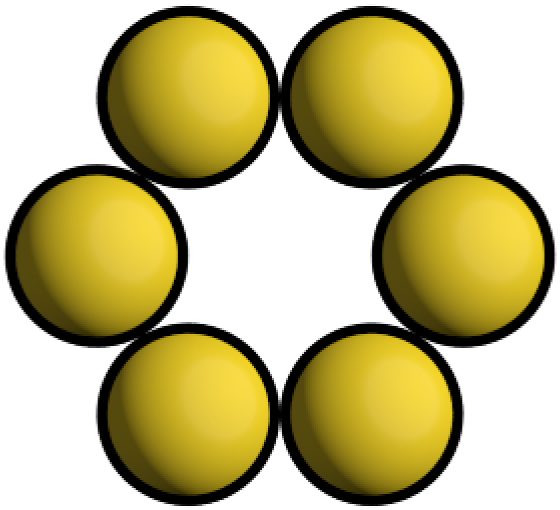
[5]:



tracer.output also accesses the output buffer.

[6]:
```
tracer.output
```

[6]:



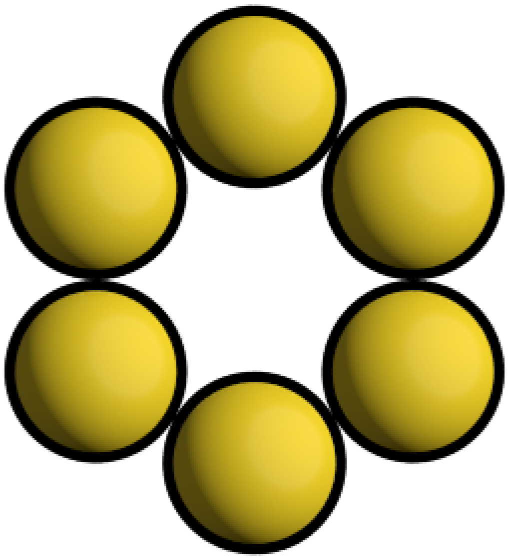
The tracer can render a modified scene without the initialization overhead.

[7]:
```
scene.camera.up = (1,0,0)
tracer.render(scene);
```

After rendering, existing references to the output buffer will access the newly rendered image.

[8]:
```
out
```

[8]:



21.1.2 Evaluate image exposure

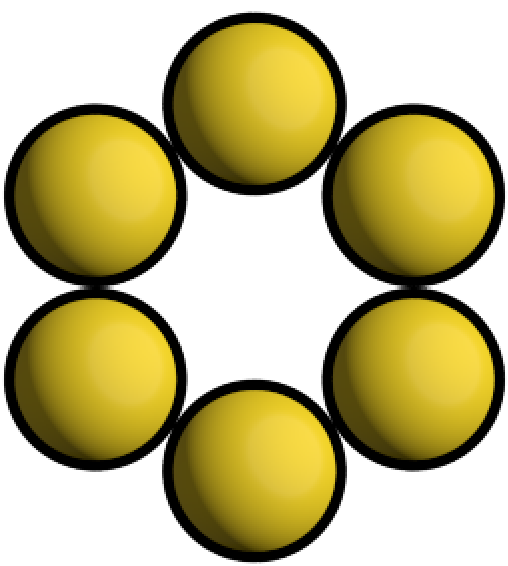
Tracer provides several methods to evaluate image exposure. Enable highlight warnings to flag overexposed pixels in the output image.

[9]:
```
tracer.enable_highlight_warning()
```

The test image is exposed correctly, there are no warning pixels.

[10]:
```
tracer.render(scene)
```

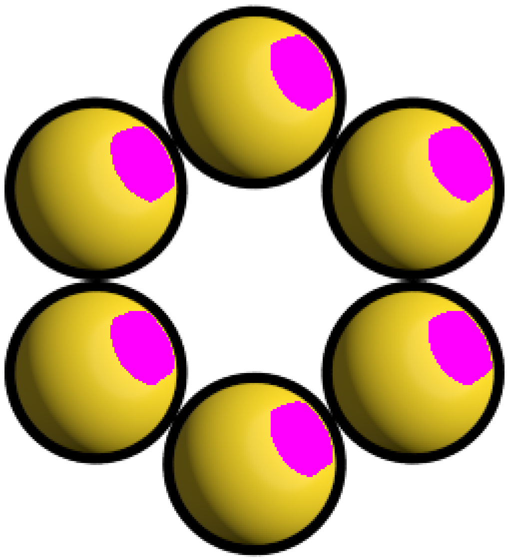
[10]:



Make the main light brighter to show the highlight warnings.

[11]:
```
scene.lights[0].color = (1.2, 1.2, 1.2)
tracer.render(scene)
```

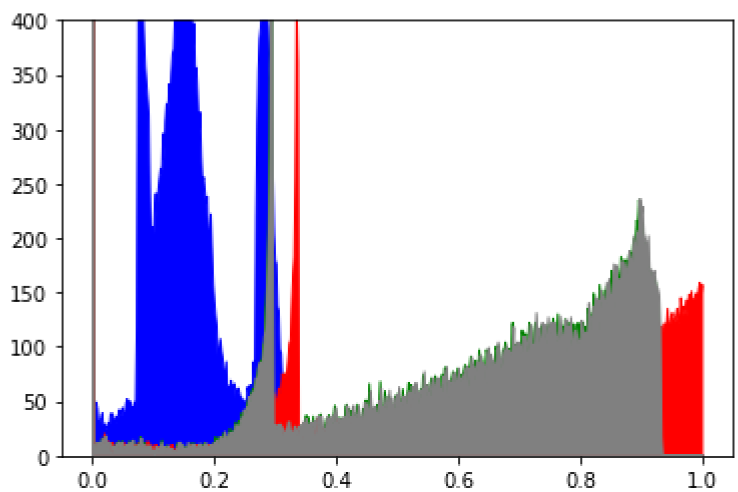
[11]:



Tracer can also compute the image histogram to evaluate image exposure.

[12]:
```
L, bins = tracer.histogram()
pyplot.fill_between(bins, L[:,3], color='blue');
pyplot.fill_between(bins, L[:,2], color='green');
pyplot.fill_between(bins, L[:,1], color='red');
pyplot.fill_between(bins, L[:,0], color='gray');
pyplot.axis(ymax=400, ymin=0)
```

[12]:
```
(-0.04794921875, 1.04990234375, 0, 400)
```



[13]:
```
tracer.disable_highlight_warning()
```

21.1.3 Resizing the output buffer

Call **resize** to set a new size for the output. When the image is resized, any existing rendered output is lost.

[14]:
```
tracer.resize(w=150, h=150)
```

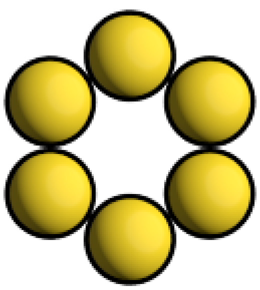
[15]:
```
tracer.output
```

[15]:

The next call to render will render into the new output size.

[16]:
```
tracer.render(scene)
```

[16]:



21.2 The Preview tracer

The **Preview** tracer renders output images quickly with approximate lighting effects.

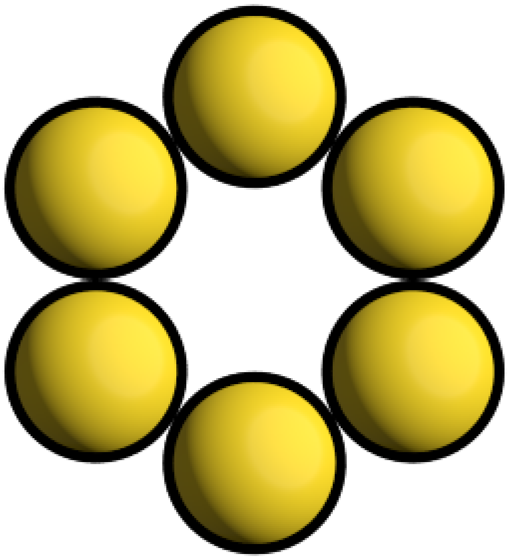
[17]:
```
tracer = fresnel.tracer.Preview(device=device, w=300, h=300)
```

A different random number seed will result in different jittered anti-aliasing samples.

[18]:
```
tracer.seed = 12
```

[19]:
```
tracer.render(scene)
```

[19]:



Here is a different scene rendered with the **Preview** tracer:

[20]:

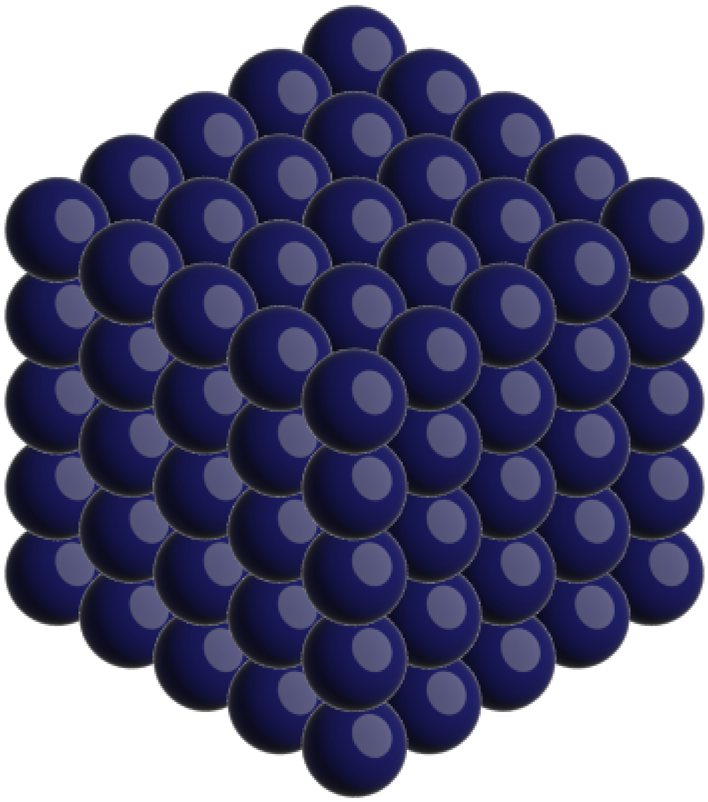
```
position = []
for k in range(5):
    for i in range(5):
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
scene = fresnel.Scene(device)
scene.lights[1].theta = math.pi

geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.1,0.1,0.
↪4]),
                                              roughness=0.1,
                                              specular=1.0)
```

[21]:

```
tracer.resize(w=450, h=450)
tracer.aa_level = 3
tracer.render(scene)
```

[21]:



21.3 The Path tracer

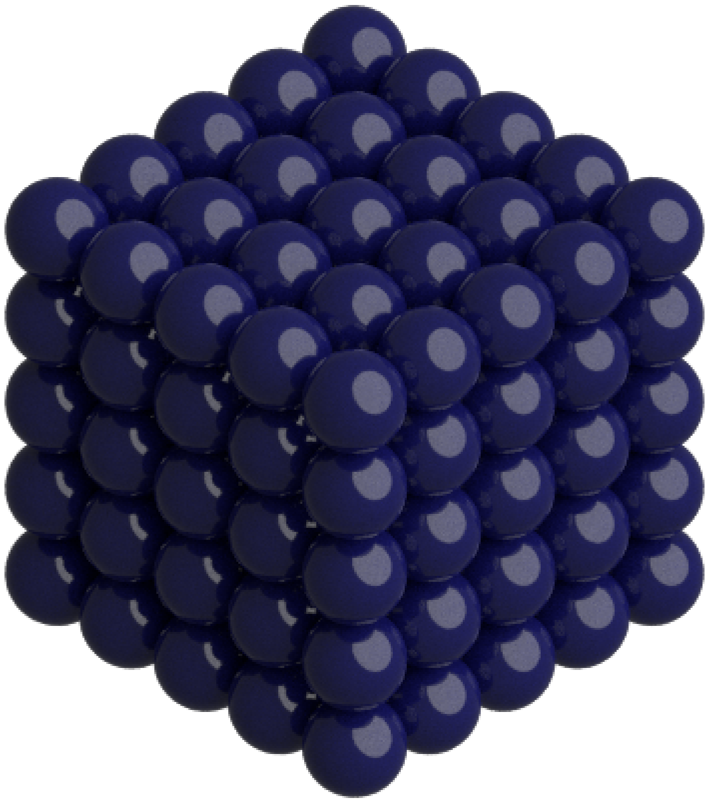
The **Path** tracer supports soft lighting, reflections, and other lighting effects.

Here is the same scene with the path tracer:

[22]:
```
path_tracer = fresnel.tracer.Path(device=device, w=450, h=450)
```

[23]:
```
path_tracer.sample(scene, samples=64, light_samples=40)
```

[23]:



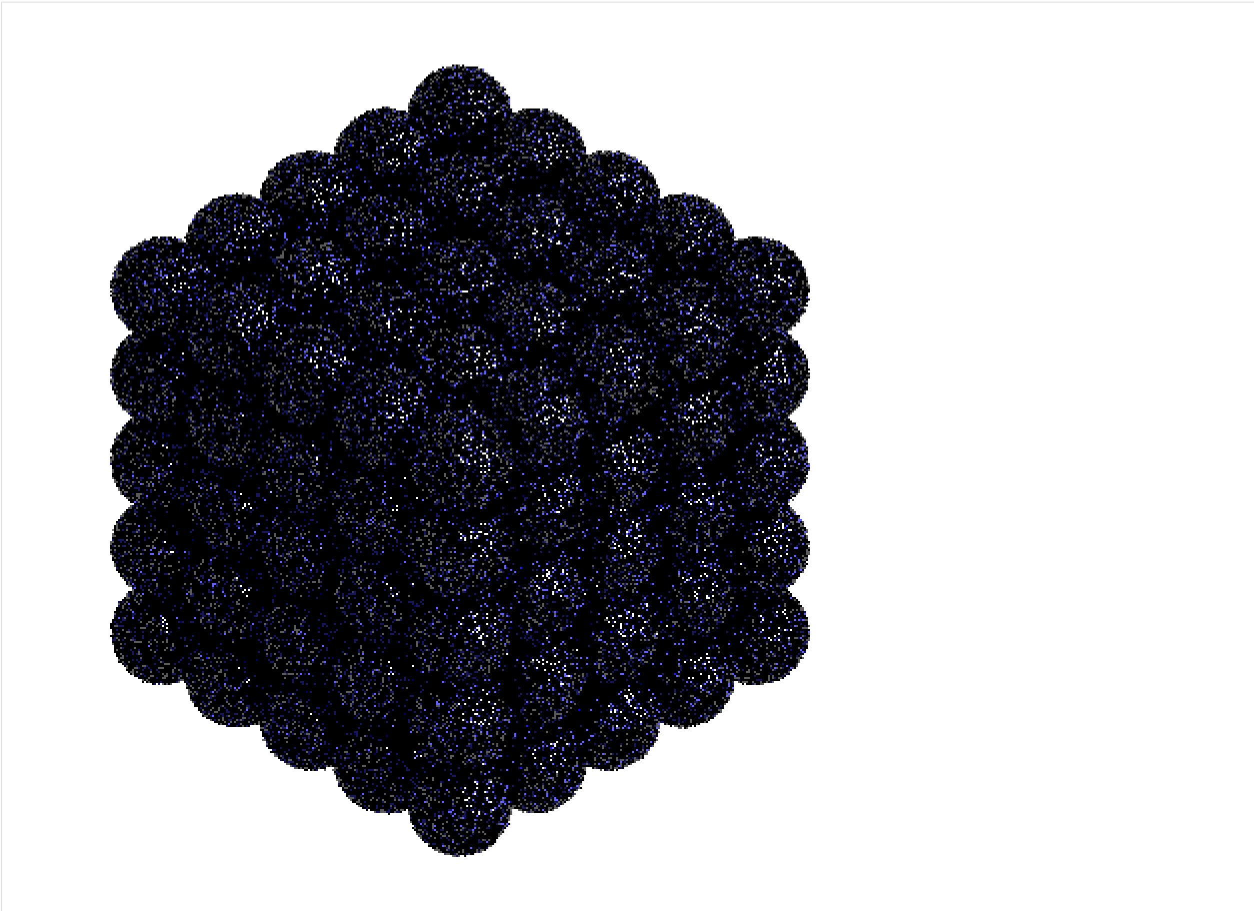
The **Path** tracer performs many independent samples and averages them together. **reset()** starts averaging a new image.

[24]:
```
path_tracer.reset()
```

render() accumulates a single sample into the resulting image.

[25]:
```
path_tracer.render(scene)
```

[25]:



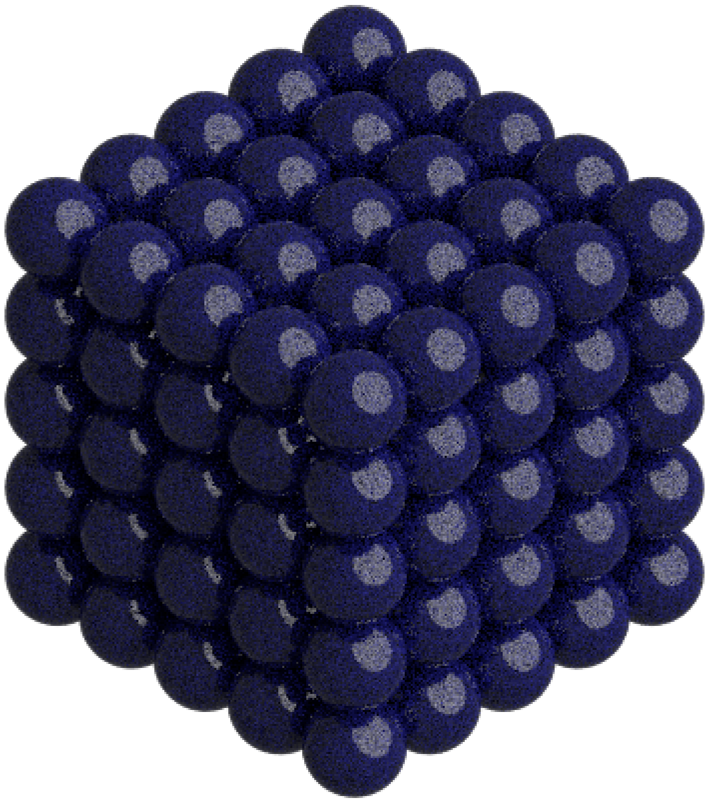
The resulting image is noisy, average many samples together to obtain a clean image.

[26]:

```
for i in range(64):
    path_tracer.render(scene)

path_tracer.output
```

[26]:



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[1]:
```
import fresnel
import math
```

CHAPTER

TWENTYTWO

INTERACTIVE SCENE VIEW

fresnel provides a Qt widget to interactively display scenes rendered with the **path tracer**. This is implemented with the PySide2 library. Using jupyter support for this library, you can open an interactive window outside if the browser and interact with it from the jupyter notebook.

First, initialize jupyter's pyside2 integration.

[2]:
```
from PySide2 import QtCore
%gui qt
```

Then, import `fresnel.interact`. This **must** be done after `%gui qt`.

[3]:
```
import fresnel.interact
```

Build a scene

[4]:
```
position = []
for k in range(5):
    for i in range(5):
        for j in range(5):
            position.append([2*i, 2*j, 2*k])
scene = fresnel.Scene()
scene.lights[1].theta = math.pi

geometry = fresnel.geometry.Sphere(scene, position = position, radius=1.0)
geometry.material = fresnel.material.Material(color=fresnel.color.linear([0.1,0.1,0.
↪8]),
                                              roughness=0.1,
                                              specular=1.0)
```

22.1 SceneView widget

Create a `interact.SceneView` widget to visualize the scene.

[5]:
```
view = fresnel.interact.SceneView(scene)
```

When the SceneView is the result of a cell, the windows shows and gets focus.

[6]:
```
view
```

[6]:
```
<fresnel.interact.SceneView at 0x11872f288>
```

In the new window, you can click and drag to rotate the camera. Jupyter is still running so you can query changes to the window here. For example, after rotating the camera, inspect the new camera configuration:

[9]:
```
repr(scene.camera)
```

[9]:
```
'fresnel.camera.orthographic(position=(13.338582992553711, 5.879554748535156, 4.
↪090480327606201), look_at=(4.0, 4.0, 4.0), up=(-0.17314134538173676, 0.
↪8814100027084351, -0.4394752085208893), height=10.116935729980469)'
```

After you change scene properties, call `setScene` to re-render the scene with the changes. For example: change the material color.

[8]:
```
geometry.material.color = fresnel.color.linear([0.8,0.1,0.1])
view.setScene(scene)
```

This page was generated from a jupyter notebook. You can download and run the notebook locally from the fresnel-examples repository.

CHAPTER

TWENTYTHREE

RENDERING IMAGES IN MATPLOTLIB

Images rendered by **fresnel** can be converted to RGBA arrays for display with the **imshow** command in **matplotlib**. This example shows how to build subplots that display the geometries of the Platonic Solids.

[1]:
```
import numpy as np
import fresnel
import matplotlib
import matplotlib.pyplot as plt
```

[2]:
```
platonic_solid_vertices = {
    'Tetrahedron': [
        [0.0, 0.0, 0.612372],
        [-0.288675, -0.5, -0.204124],
        [-0.288675, 0.5, -0.204124],
        [0.57735, 0.0, -0.204124]],
    'Cube': [
        [-0.5, -0.5, -0.5],
        [-0.5, -0.5, 0.5],
        [-0.5, 0.5, -0.5],
        [-0.5, 0.5, 0.5],
        [0.5, -0.5, -0.5],
        [0.5, -0.5, 0.5],
        [0.5, 0.5, -0.5],
        [0.5, 0.5, 0.5]],
    'Octahedron': [
        [-0.707107, 0.0, 0.0],
        [0.0, 0.707107, 0.0],
        [0.0, 0.0, -0.707107],
        [0.0, 0.0, 0.707107],
        [0.0, -0.707107, 0.0],
        [0.707107, 0.0, 0.0]],
    'Dodecahedron': [
        [-1.37638, 0.0, 0.262866],
        [1.37638, 0.0, -0.262866],
        [-0.425325, -1.30902, 0.262866],
        [-0.425325, 1.30902, 0.262866],
        [1.11352, -0.809017, 0.262866],
        [1.11352, 0.809017, 0.262866],
        [-0.262866, -0.809017, 1.11352],
        [-0.262866, 0.809017, 1.11352],
        [-0.688191, -0.5, -1.11352],
        [-0.688191, 0.5, -1.11352],
        [0.688191, -0.5, 1.11352],
        [0.688191, 0.5, 1.11352],
```

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```
        [0.850651, 0.0, -1.11352],
        [-1.11352, -0.809017, -0.262866],
        [-1.11352, 0.809017, -0.262866],
        [-0.850651, 0.0, 1.11352],
        [0.262866, -0.809017, -1.11352],
        [0.262866, 0.809017, -1.11352],
        [0.425325, -1.30902, -0.262866],
        [0.425325, 1.30902, -0.262866]],
    'Icosahedron': [
        [0.0, 0.0, -0.951057],
        [0.0, 0.0, 0.951057],
        [-0.850651, 0.0, -0.425325],
        [0.850651, 0.0, 0.425325],
        [0.688191, -0.5, -0.425325],
        [0.688191, 0.5, -0.425325],
        [-0.688191, -0.5, 0.425325],
        [-0.688191, 0.5, 0.425325],
        [-0.262866, -0.809017, -0.425325],
        [-0.262866, 0.809017, -0.425325],
        [0.262866, -0.809017, 0.425325],
        [0.262866, 0.809017, 0.425325]],
    }
```

The `render` function returns a NumPy array of the output buffer, which can be passed directly to **imshow**.

```
[3]: def render(shape, color_id=0):
    verts = platonic_solid_vertices[shape]
    scene = fresnel.Scene(fresnel.Device(mode='cpu'))
    scene.lights = fresnel.light.lightbox()
    poly_info = fresnel.util.convex_polyhedron_from_vertices(verts)
    cmap = matplotlib.cm.get_cmap('tab10')
    geometry = fresnel.geometry.ConvexPolyhedron(
        scene, poly_info,
        position = [0, 0, 0],
        orientation = [0.975528, 0.154508, -0.154508, -0.024472],
        outline_width = 0.015)
    geometry.material = fresnel.material.Material(
        color = fresnel.color.linear(cmap(color_id)[:3]),
        roughness = 0.1,
        specular = 1)
    geometry.outline_material = fresnel.material.Material(
        color = (0., 0., 0.),
        roughness = 0.1,
        metal = 1.0)

    scene.camera = fresnel.camera.fit(scene, view='front')
    out = fresnel.pathtrace(scene, samples=64,
                            light_samples=32,
                            w=200, h=200)
    return out[:]
```

Below, **imshow** is used to render one scene in each subplot. Specifying an interpolation with **imshow** improves image quality.

```
[5]: def show_shape(shape, location, color_id):
    ax = axs[location]
```

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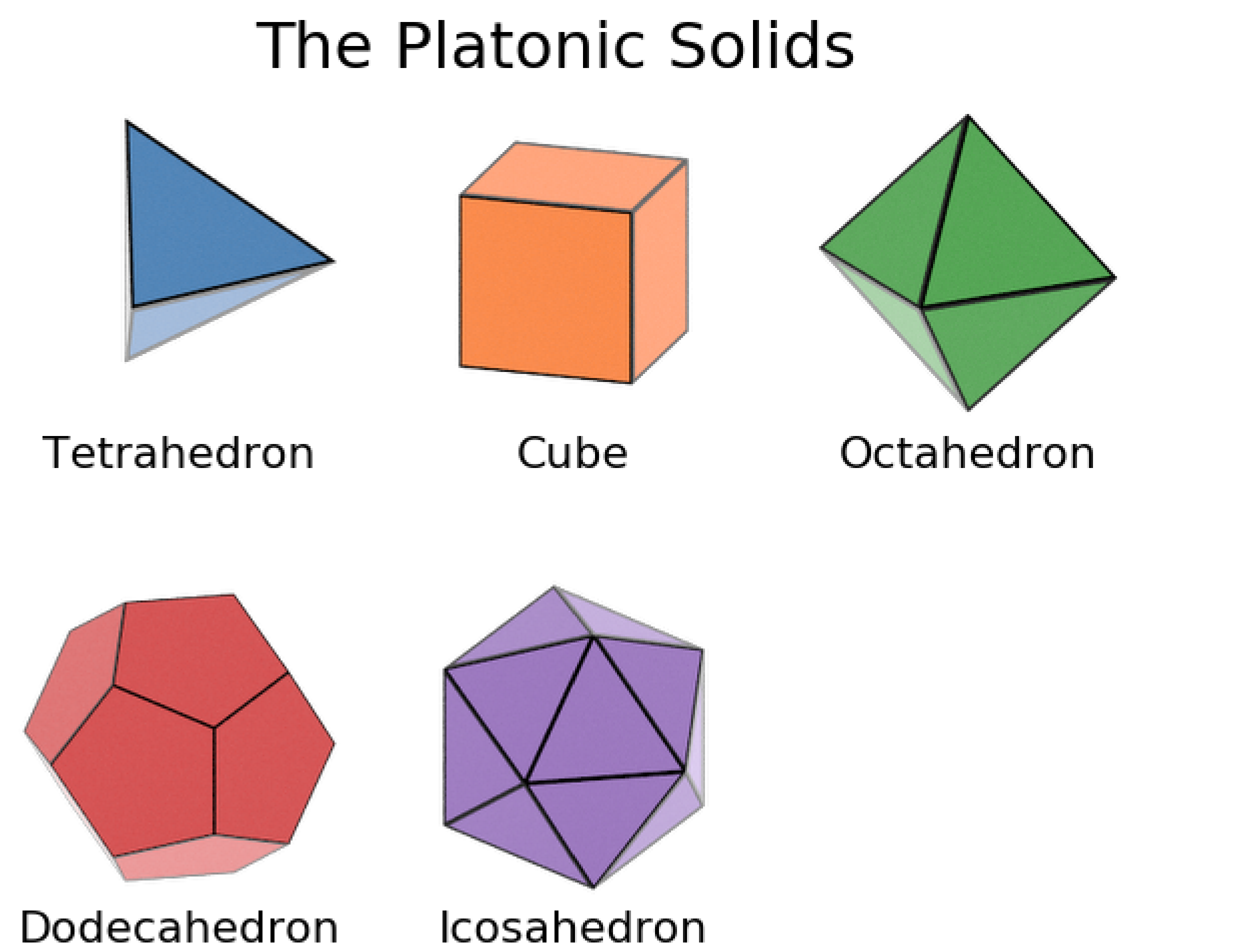
```
    ax.imshow(render(shape, color_id), interpolation='lanczos')
    ax.set_xlabel(shape, fontsize=22)

fig, axs = plt.subplots(ncols=3, nrows=2, figsize=(10, 8))

show_shape('Tetrahedron', (0, 0), 0)
show_shape('Cube', (0, 1), 1)
show_shape('Octahedron', (0, 2), 2)
show_shape('Dodecahedron', (1, 0), 3)
show_shape('Icosahedron', (1, 1), 4)

for ax in axs.flatten():
    ax.set_xticks([])
    ax.set_yticks([])
    ax.spines['right'].set_visible(False)
    ax.spines['top'].set_visible(False)
    ax.spines['bottom'].set_visible(False)
    ax.spines['left'].set_visible(False)

fig.suptitle('The Platonic Solids', y=0.92, fontsize=32)
plt.show()
```



CHAPTER

TWENTYFOUR

VISUALIZING GSD FILE

In this example, we will use `fresnel` to visualize a gsd file. We will color the particles & bonds by types, as well as visualize the simulation box.

We will need the gsd package to run this example.

[1]:
```
import fresnel
import gsd.hoomd
import numpy as np
```

First we read in the `.gsd` file.

[2]:
```
with gsd.hoomd.open(name="molecules.gsd", mode="rb") as gsd_file:
    snap = gsd_file[0]

box = snap.configuration.box
```

We want to color by particle type. We will color A types red, B types blue, and C types green.

[3]:
```
N = snap.particles.N
particle_types = snap.particles.typeid
colors = np.empty((N, 3))

# Color by typeid
colors[particle_types == 0] = fresnel.color.linear([.95, 0, 0]) # A type
colors[particle_types == 1] = fresnel.color.linear([0, .95, 0]) # B type
colors[particle_types == 2] = fresnel.color.linear([0, 0, .95]) # C type
```

[4]:
```
scene = fresnel.Scene()

# Spheres for every particle in the system
geometry = fresnel.geometry.Sphere(scene, N=N, radius=0.2)
geometry.position[:] = snap.particles.position
geometry.material = fresnel.material.Material(roughness=0.9)
geometry.outline_width = 0.05



# use color instead of material.color
geometry.material.primitive_color_mix = 1.0
geometry.color[:] = fresnel.color.linear(colors)
```

[5]:
```
# create box in fresnel
fresnel.geometry.Box(scene, box, box_radius=.1)
```

[5]:
```
<fresnel.geometry.Box at 0x104cd7828>
```

We will visualize bonds using cylinders, and color the bonds to match the particle types. To aid visualization, we will first remove any bonds that span the periodic boundary.

[6]:
```
all_bonds = np.stack(
    [
        snap.particles.position[snap.bonds.group[:, 0]],
        snap.particles.position[snap.bonds.group[:, 1]],
    ],
    axis=1,
)

# Use a distance cutoff (L/2) to filter bonds that span the periodic boundary
bond_distances = np.linalg.norm(all_bonds[:,0,:]-all_bonds[:,1,:], axis=1)

# This simple method will work for cubic cells
L = box[0]
bond_indices = np.where(bond_distances < L/2)[0]
filtered_bonds = all_bonds[bond_indices, :, :]

N_bonds = filtered_bonds.shape[0]
bonds = fresnel.geometry.Cylinder(scene, N=N_bonds)
bonds.material = fresnel.material.Material(roughness=0.5)
bonds.outline_width = 0.05



# Color by bond typeid
bond_ids = snap.bonds.typeid[bond_indices]
bond_colors = np.empty((N_bonds, 3))
bond_colors[bond_ids == 0] = fresnel.color.linear([0, .95, 0])  # B-B Bonds
bond_colors[bond_ids == 1] = fresnel.color.linear([0, 0, .95])  # C-C Bonds

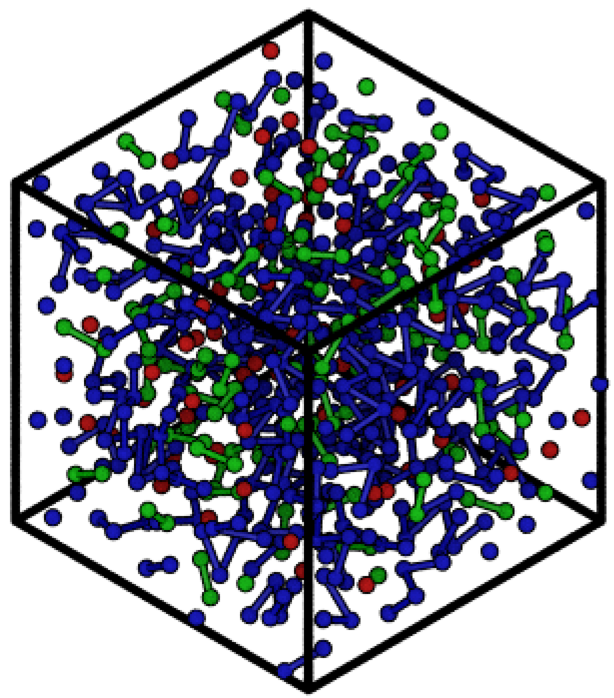
bonds.material.primitive_color_mix = 1.0
bonds.points[:] = filtered_bonds

bonds.color[:] = np.stack(
    [fresnel.color.linear(bond_colors), fresnel.color.linear(bond_colors)], axis=1
)
bonds.radius[:] = [0.1] * N_bonds
```

Now that we have everything setup, we will render everything and apply some ring lighting conditions.

[7]:
```
scene.lights = fresnel.light.ring()
fresnel.pathtrace(scene, light_samples=5)
```

[7]:



CHAPTER

TWENTYFIVE

FRESNEL

Overview

fresnel.Device	Hardware device to use for ray tracing.
fresnel.pathtrace	Path trace a scene.
fresnel.preview	Preview a scene.
fresnel.Scene	Content of the scene to ray trace.

Details

The fresnel ray tracing package.

fresnel.**__version__**
Fresnel version

Type str

class fresnel.**Device**(*mode='auto'*, *n=None*)
Hardware device to use for ray tracing.

Parameters

- **mode** (*str*) – Specify execution mode: Valid values are `auto`, `gpu`, and `cpu`.
- **n** (*int*) – Specify the number of cpu threads / GPUs this device will use. *None* sets no limit.

Device defines hardware device to use for ray tracing. *Scene* and *tracer* instances must be attached to a *Device*. You may attach any number of scenes and tracers to a single *Device*.

See also:

Tutorials:

- *Devices*
- *Tracer methods*

When mode is `auto`, the default, *Device* GPU rendering and fall back on CPU rendering if there is no GPU available or GPU support was not compiled in. Set mode to `gpu` or `cpu` to force a specific mode.

Important: By default (n==None), this device will use all available GPUs or CPU cores. Set *n* to the number of GPUs or CPU cores this device should use. When selecting *n* GPUs, the device selects the first *n* in the *available_gpus* list.

Tip: Use only a single *Device* to reduce memory consumption.

The static member *available_modes* lists which modes are available. For a mode to be available, the corresponding module must be enabled at compile time. Additionally, there must be at least one GPU present for the gpu mode to be available.

```
>>> fresnel.Device.available_modes
['gpu', 'cpu', 'auto']
```

available_modes
List of the available execution modes (static member).

Type list

available_gpus
List of the available gpus (static member).

Type list

mode
The active mode

Type str

class fresnel.**Scene**(*device=None, camera='auto', lights=[<fresnel.light.Light object>, <fresnel.light.Light object>]*)
Content of the scene to ray trace.

Parameters **device** (*Device*) – Device to create this Scene on.

Scene defines the contents of the scene to be ray traced, including any number of *geometry* objects, the *camera*, *background color*, *background alpha*, and the *lights*.

Every *Scene* attaches to a *Device*. For convenience, *Scene* creates a default *Device* when **device** is *None*. If you want a non-default device, you must create it explicitly.

See also:

Tutorials:

- *Introduction*
- *Scene properties*
- *Lighting setups*
- *Devices*

Lights

lights is a sequence of up to 4 directional lights that apply to the scene globally. Each light has a direction and color. You can assign lights using one of the predefined setups:

```
scene.lights = fresnel.light.butterfly()
```

You can assign a sequence of *Light* objects:

```
scene.lights = [fresnel.light.Light(direction=(1,2,3))]
```

You can modify the lights in place:

```
>>> print(len(scene.lights))
2
>>> l.append(fresnel.light.Light(direction=(1,0,0), color=(1,1,1)))
>>> print(len(3))
1
>>> print(l[2]).direction
(1,0,0)
>>> l[0].direction = (-1,0,0)
>>> print(l[0]).direction
(-1,0,0)
```

device
Device this Scene is attached to.

Type *Device*

camera
Camera view parameters, or 'auto' to automatically choose a camera.

Type *camera.Camera*

background_color
Background color (r,g,b) as a tuple or other 3-length python object, in the linearized color space. Use *fresnel.color.linear()* to convert standard sRGB colors

Type tuple[float]

background_alpha
Background alpha (opacity).

Type float

lights
Globals lights in the scene.

Type list[*light.Light*]

get_extents()
Get the extents of the scene

Returns

[[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

fresnel.**pathtrace**(*scene*, *w=600*, *h=370*, *samples=64*, *light_samples=1*)
Path trace a scene.

Parameters

- **scene** (*Scene*) – Scene to render.
- **w** (*int*) – Output image width.
- **h** (*int*) – Output image height.
- **samples** (*int*) – Number of times to sample the pixels of the scene.
- **light_samples** (*int*) – Number of light samples to take for each pixel sample.

pathtrace() is a shortcut to rendering output with the *Path* tracer. See the *Path* tracer for a complete description.

fresnel.**preview**(*scene*, *w=600*, *h=370*, *anti_alias=True*)
Preview a scene.

Parameters

- **scene** (*Scene*) – Scene to render.
- **w** (*int*) – Output image width.
- **h** (*int*) – Output image height.
- **anti_alias** (*bool*) – Whether to perform anti-aliasing.

preview() is a shortcut to rendering output with the *Preview* tracer. See the *Preview* tracer for a complete description.

Modules

25.1 fresnel.camera

Overview

fresnel.camera.Camera	Defines the view into the *Scene*.
fresnel.camera.fit	Fit a camera to a *Scene*
fresnel.camera.orthographic	Orthographic camera

Details

Cameras.

class fresnel.camera.**Camera**(*_camera=None*)

Defines the view into the *Scene*.

Use one of the creation functions to create a *Camera*:

- *orthographic()*

See also:

Tutorials:

- *Scene properties*

The camera is a property of the *Scene*. You may read and modify any of these camera attributes.

position

the position of the camera (the center of projection).

Type tuple[float, float, float]

look_at

the point the camera looks at (the center of the focal plane).

Type tuple[float, float, float]

up

a vector pointing up.

Type tuple[float, float, float]

height

the height of the image plane.

Type float

basis
three orthonormal vectors defining the camera coordinate basis in right-handed order: right, look direction, up (read only)

Camera space is a coordinate system centered on the camera's position. Positive *x* points to the right in the image, positive *y* points up, and positive *z* points out of the screen. *Camera* space shares units with *Scene* space.

`fresnel.camera.`**`fit`**(*scene*, *view='auto'*, *margin=0.05*)
Fit a camera to a *Scene*

Create a camera that fits the entire height of the scene in the image plane.

Parameters

- **scene** (*Scene*) – Fit the camera to this scene.
- **view** (*str*) – Select view
- **margin** (*float*) – Fraction of extra space to leave on the top and bottom of the scene.

view may be 'auto', 'isometric', or 'front'.

The isometric view is an orthographic projection from a particular angle so that the x,y, and z directions are equal lengths. The front view is an orthographic projection where +x points to the right, +y points up and +z points out of the screen in the image plane. 'auto' automatically selects 'isometric' for 3D scenes and 'front' for 2D scenes.

`fresnel.camera.`**`orthographic`**(*position*, *look_at*, *up*, *height*)
Orthographic camera

Parameters

- **position** (`numpy.ndarray` or `array_like`) – (`3 : float32`) - the position of the camera.
- **look_at** (`numpy.ndarray` or `array_like`) – (`3 : float32`) - the point the camera looks at (the center of the focal plane).
- **up** (`numpy.ndarray` or `array_like`) – (`3 : float32`) - a vector pointing up.
- **height** (*float*) – the height of the image plane.

An orthographic camera traces parallel rays from the image plane into the scene. Lines that are parallel in the *Scene* will remain parallel in the rendered image.

position is the center of the image plane in *Scene* space. *look_at* is the point in *Scene* space that will be in the center of the image. Together, these vectors define the image plane which is perpendicular to the line from *position* to *look_at*. Objects in front of the plane will appear in the rendered image, objects behind the plane will not.

up is a vector in *Scene* space that defines which direction points up (+y direction in the image). *up* does not need to be perpendicular to the line from *position* to *look_at*, but it must not be parallel to that line. *height* sets the height of the image in *Scene* units. The image width is determined by the aspect ratio of the image. The area *width* by *height* about the *look_at* point will be included in the rendered image.

25.2 fresnel.color

Overview

fresnel.color.linear	Convert a sRGB color (or array of such colors) from the gamma corrected color space into the linear space.

Details

Color utilities.

fresnel.color.**linear**(*color*)

Convert a sRGB color (or array of such colors) from the gamma corrected color space into the linear space.

Standard tools for working with sRGB colors provide gamma corrected values. fresnel needs to perform calculations in a linear color space. This method converts from sRGB to the linear space. Use *linear()* when specifying material or particle colors with sRGB inputs (such as you find in a color picker).

linear() accepts RGBA input (such as from matplotlib's colors.to_rgba colormap method), but ignores the alpha channel and outputs an Nx3 array.

Parameters **color** (numpy.ndarray or array_like) – (3, 4, Nx3, or Nx4 : float32) - RGB or RGBA color in the range [0,1].

Returns numpy.ndarray with the linearized color(s), same shape as color.

25.3 fresnel.geometry

Overview

fresnel.geometry.Geometry	Base class for all geometry.
fresnel.geometry.ConvexPolyhedron	Convex polyhedron geometry.
fresnel.geometry.Cylinder	Cylinder geometry.
fresnel.geometry.Box	Box geometry.
fresnel.geometry.Polygon	Polygon geometry.
fresnel.geometry.Sphere	Sphere geometry.

Details

Geometric primitives.

Geometry provides operations common to all geometry classes. Use a specific geometry class to add objects to the *fresnel.Scene*.

See also:

Tutorials:

- *Primitive properties*
- *Material properties*
- *Outline materials*

- *Multiple geometries*

class `fresnel.geometry.`**`Box`**(*scene, box, box_radius=0.5, box_color=[0, 0, 0]*)

Box geometry.

Generate a triclinic box shape.

Parameters

- **scene** (`fresnel.Scene`) – Add the geometry to this scene
- **box_radius** (`numpy.ndarray` or `array_like`) – (`` `1` ``, `` `3` ``, or `` `6` `` : `float32`) Assumes 1x1 is cubic, 1x3 is orthorhombic, and 1x6 is triclinic.
- **radius** (`float`) – Radius of box edges.
- **box_color** (`numpy.ndarray` or `array_like`) – (`1x3 : float32`) - Color of box edges.

See also:

Tutorials:

- *Box*
- *Visualizing GSD File*

Note: The constructor arguments `radius` and `color` are optional. If you do not provide them, they are initialized to 0.5 and black, respectively.

Note: The Box class is constructed from Cylinders, which can be modified individually. The convenience attributes `box_radius` and `box_color` can be used to easily modify the thickness and color of the box. If the individual cylinders are modified, the getter for the `box_radius` will return the radius of the 0th element cylinder.

`points`

Read or modify the start and end points of the cylinders.

Type *`fresnel.util.Array`*

`radius`

Read or modify the radii of the cylinders.

Type *`fresnel.util.Array`*

`color`

Read or modify the colors of the start and end points of the cylinders.

Type *`fresnel.util.Array`*

`box`

Read or modify the box parameters. Boxes will be converted from any acceptable box type to a tuple (Lx, Ly, Lz, xy, xz, yz). Changing the box will update the points used to generate the cylinders.

Type `tuple`

`box_radius`

Read or modify the radii of all the cylinders.

Type `float`

box_color
Read or modify the color of the box material.

Type `tuple`

class `fresnel.geometry.ConvexPolyhedron`(*scene, polyhedron_info, position=None, orientation=None, color=None, N=None, material=<fresnel.material.Material object>, outline_material=<fresnel.material.Material object>, outline_width=0.0*)

Convex polyhedron geometry.

Define a set of convex polyhedron primitives. A convex polyhedron is defined by *P* outward facing planes (origin and normal vector) and a radius that encompass the shape. `fresnel.util.convex_polyhedron_from_vertices()` can construct this by computing the convex hull of a set of vertices.

Parameters

- **scene** (`fresnel.Scene`) – Add the geometry to this scene
- **polyhedron_info** (`dict`) – A dictionary containing the face normals (`face_normal`), origins (`face_origin`), colors (`face_color`), and the radius (`radius`)).
- **position** (`numpy.ndarray` or `array_like`) – (`Nx3 : float32`) - Position of each polyhedra.
- **orientation** (`numpy.ndarray` or `array_like`) – (`Nx4 : float32`) - Orientation of each polyhedra (as a quaternion).
- **color** (`numpy.ndarray` or `array_like`) – (`Nx3 : float32`) - Color of each polyhedron.
- **N** (*int*) – Number of spheres in the geometry. If `None`, determine `N` from `position`.

See also:

Tutorials:

- *Convex polyhedron*

Note: The constructor arguments `position`, `orientation`, and `color` are optional. If you do not provide them, they are initialized to 0's.

Hint: Avoid costly memory allocations and type conversions by specifying primitive properties in the appropriate numpy array type.

---

position
Read or modify the positions of the polyhedra.

Type `fresnel.util.Array`

orientation
Read or modify the orientations of the polyhedra.

Type `fresnel.util.Array`

color
Read or modify the color of the polyhedra.

Type `fresnel.util.Array`

color_by_face

Set to 0 to color particles by the per-particle color. Set to 1 to color faces by the per-face color. Set to a value between 0 and 1 to blend per-particle and per-face colors.

Type float

get_extents()

Get the extents of the geometry

Returns [[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

class fresnel.geometry.**Cylinder**(*scene*, *points=None*, *radius=None*, *color=None*, *N=None*, *material=<fresnel.material.Material object>*, *outline_material=<fresnel.material.Material object>*, *outline_width=0.0*)

Cylinder geometry.

Define a set of spherocylinder primitives with start and end positions, radii, and individual colors.

Parameters

- **scene** (*fresnel.Scene*) – Add the geometry to this scene
- **points** (numpy.ndarray or array_like) – (Nx2x3 : float32) - cylinder start and end points.
- **radius** (numpy.ndarray or array_like) – (N : float32) - Radius of each cylinder.
- **color** (numpy.ndarray or array_like) – (Nx2x3 : float32) - Color of each start and end point.
- **N** (*int*) – Number of cylinders in the geometry. If None, determine N from *points*.

See also:

Tutorials:

- *Cylinder*

Note: The constructor arguments points, radius, and color are optional. If you do not provide them, they are initialized to 0's.

Hint: Avoid costly memory allocations and type conversions by specifying primitive properties in the appropriate numpy array type.

Tip: When all cylinders are the same size, pass a single value for *radius* and numpy will broadcast it to all elements of the array.

points

Read or modify the start and end points of the cylinders.

Type *fresnel.util.Array*

radius

Read or modify the radii of the cylinders.

Type *fresnel.util.Array*

color
Read or modify the colors of the start and end points of the cylinders.

Type *fresnel.util.Array*

get_extents()
Get the extents of the geometry

Returns [[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

class fresnel.geometry.**Geometry**
Base class for all geometry.

Geometry provides operations common to all geometry classes.

material
The geometry's material.

Type *fresnel.material.Material*

outline_material
The geometry's outline material.

Type *fresnel.material.Material*

outline_width
The geometry's outline width, in distance units in the scene's coordinate system.

Type float

Note: You cannot instantiate a Geometry directly. Use one of the sub classes.

disable()
Disable the geometry.

When disabled, the geometry will not be present in the scene.

enable()
Enable the geometry.

When enabled, the geometry will be present when rendering the scene.

remove()
Remove the geometry from the scene.

After calling remove, the geometry is no longer part of the scene. It cannot be added back into the scene. Use *disable()* if you want a reversible operation.

class fresnel.geometry.**Mesh**(*scene*, *vertices*, *position=None*, *orientation=None*, *color=None*, *N=None*, *material=<fresnel.material.Material object>*, *outline_material=<fresnel.material.Material object>*, *outline_width=0.0*)
Mesh geometry.

Define a set of triangle mesh primitives.

Parameters

- **scene** (*fresnel.Scene*) – Add the geometry to this scene
- **vertices** (numpy.ndarray or array_like) – (3Tx3 : float32) - Vertices of the triangles, listed contiguously. Vertices 0,1,2 define the first triangle, 3,4,5 define the second, and so on.

- **color** (`numpy.ndarray` or `array_like`) – (`3Tx3 : float32`) - Color of each vertex.
- **position** (`numpy.ndarray` or `array_like`) – (`Nx3 : float32`) - Positions of each mesh instance.
- **orientation** (`numpy.ndarray` or `array_like`) – (`Nx4 : float32`) - Orientation of each mesh instance (as a quaternion).
- **N** (*int*) – Number of mesh instances in the geometry. If `None`, determine `N` from `position`.

See also:

Tutorials:

- *Mesh*

Note: The constructor arguments `position`, `orientation`, and `color` are optional, and just short-hand for assigning the attribute after construction.

Colors are in the linearized sRGB color space. Use *`fresnel.color.linear()`* to convert standard sRGB colors into this space. *`Mesh`* determines the color of a triangle using interpolation with the barycentric coordinates in every triangular face.

Hint: Avoid costly memory allocations and type conversions by specifying primitive properties in the appropriate numpy array type.

---

position
Read or modify the positions of the mesh instances.

Type *`fresnel.util.Array`*

orientation
Read or modify the orientations of the mesh instances.

Type *`fresnel.util.Array`*

color
Read or modify the color of the vertices.

Type *`fresnel.util.Array`*

get_extents()
Get the extents of the geometry

Returns [[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

class fresnel.geometry.**Polygon**(*scene, vertices, position=None, angle=None, color=None, rounding_radius=0, N=None, material=<fresnel.material.Material object>, outline_material=<fresnel.material.Material object>, outline_width=0.0*)

Polygon geometry.

Define a set of simple polygon primitives. Each polygon face is always in the xy plane. Each polygon may have a different color and rotation angle.

Parameters

- **scene** (*`fresnel.Scene`*) – Add the geometry to this scene

- **vertices** (numpy.ndarray or array_like) – (Nx2 : float32) - Polygon vertices.
- **position** (numpy.ndarray or array_like) – (Nx2 : float32) - Position of each polygon.
- **angle** (numpy.ndarray or array_like) – (N : float32) - Orientation angle of each polygon.
- **color** (numpy.ndarray or array_like) – (Nx3 : float32) - Color of each polygon.
- **rounding_radius** (*float*) – Rounding radius for spheropolygons.
- **N** (*int*) – Number of polygons in the geometry. If None, determine N from position.

See also:

Tutorials:

- *Polygon*

Note: The constructor arguments position, angle, and color are optional. If you do not provide them, they are initialized to 0's.

Hint: Avoid costly memory allocations and type conversions by specifying primitive properties in the appropriate numpy array type.

position
Read or modify the positions of the polygons.

Type *fresnel.util.Array*

angle
Read or modify the orientation angles of the polygons.

Type *fresnel.util.Array*

color
Read or modify the colors of the polygons.

Type *fresnel.util.Array*

get_extents()
Get the extents of the geometry

Returns [[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

class fresnel.geometry.**Sphere**(*scene, position=None, radius=None, color=None, N=None, material=<fresnel.material.Material object>, outline_material=<fresnel.material.Material object>, outline_width=0.0*)

Sphere geometry.

Define a set of sphere primitives with positions, radii, and individual colors.

Parameters

- **scene** (*fresnel.Scene*) – Add the geometry to this scene
- **position** (numpy.ndarray or array_like) – (Nx3 : float32) - Position of each sphere.
- **radius** (numpy.ndarray or array_like) – (N : float32) - Radius of each sphere.

- **color** (`numpy.ndarray` or `array_like`) – (`Nx3` : `float32`) - Color of each sphere.
- **N** (*int*) – Number of spheres in the geometry. If `None`, determine `N` from `position`.

See also:

Tutorials:

- *Sphere*

Note: The constructor arguments `position`, `radius`, and `color` are optional. If you do not provide them, they are initialized to 0's.

Hint: Avoid costly memory allocations and type conversions by specifying primitive properties in the appropriate numpy array type.

Tip: When all spheres are the same size, pass a single value for *radius* and numpy will broadcast it to all elements of the array.

position
Read or modify the positions of the spheres.

Type *fresnel.util.Array*

radius
Read or modify the radii of the spheres.

Type *fresnel.util.Array*

color
Read or modify the color of the spheres.

Type *fresnel.util.Array*

get_extents()
Get the extents of the geometry

Returns [[minimum x, minimum y, minimum z], [maximum x, maximum y, maximum z]]

25.4 fresnel.interact

Overview

fresnel.interact.SceneView	View a fresnel Scene in real time

Details

Interactive Qt widgets.

class fresnel.interact.**SceneView**(*scene*, *max_samples=2000*)

View a fresnel Scene in real time

SceneView is a PySide2 widget that displays a *fresnel.Scene*, rendering it with *fresnel.tracer.Path* interactively. Use the mouse to rotate the camera view.

Parameters

- **scene** (*Scene*) – The scene to display.
- **max_samples** (*int*) – Sample until `max_samples` have been averaged.

- Left click to pitch and yaw
- Right click to roll
- Middle click to pan
- Hold ctrl to make small adjustments

Using in a standalone script

To use SceneView in a standalone script, import the *fresnel.interact* module, create your *fresnel.Scene*, instantiate the *SceneView*, show it, and start the app event loop.

```
import fresnel, fresnel.interact
# build Scene
view = fresnel.interact.SceneView(scene)
view.show()
fresnel.interact.app.exec_();
```

Using with jupyter notebooks

To use SceneView in a jupyter notebook, import PySide2.QtCore and activate Jupyter's qt5 integration.

```
from PySide2 import QtCore
% gui qt
```

Import the *fresnel.interact* module, create your *fresnel.Scene*, and instantiate the *SceneView*. Do not call the app event loop, jupyter is already running the event loop in the background. When the SceneView object is the result of a cell, it will automatically show and activate focus.

```
import fresnel, fresnel.interact
# build Scene
fresnel.interact.SceneView(scene)
```

Note: The interactive window will open on the system that *hosts* jupyter.

scene

The *fresnel.Scene* rendered in this view.

See also:

Tutorials:

- *Interactive scene view*

25.5 fresnel.light

Overview

`fresnel.light.Light`	Define a single light
`fresnel.light.butterfly`	Create a butterfly lighting setup.
`fresnel.light.cloudy`	Create a cloudy day lighting setup.
`fresnel.light.lightbox`	Create a light box lighting setup.
`fresnel.light.loop`	Create a loop lighting setup.
`fresnel.light.rembrandt`	Create a Rembrandt lighting setup.
`fresnel.light.ring`	Create a ring lighting setup.

Details

Lights provide light to a `fresnel.Scene`.

Without lights, nothing will be visible in the scene. Fresnel provides a number of quality lighting setups for your use, and you can always define custom lights.

See also:

Tutorials:

- *Scene properties*
- *Lighting setups*

class `fresnel.light.`**`Light`**(*direction*, *color=(1, 1, 1)*, *theta=0.375*)

Define a single light

Parameters

- **direction** (`numpy.ndarray` or `array_like`) – (`3`, `float32`) - Vector direction the light points (*in camera space*).
- **color** (`numpy.ndarray` or `array_like`) – (`3`, `float32`) - Linear RGB color and intensity of the light.
- **theta** (*float*) – Half angle of the cone that defines the area of the light (*radians*).

The direction vector may have any non-zero length, but only the direction the vector points matters.

The color also sets the light intensity. A `(0.5, 0.5, 0.5)` light is twice as bright as `(0.25, 0.25, 0.25)`.

`fresnel.light.`**`butterfly`**()

Create a butterfly lighting setup.

The butterfly portrait lighting setup is front lighting with the key light (index 0) placed high above the camera and the fill light (index 1) below the camera.

Returns A list of lights.

`fresnel.light.cloudy()`

Create a cloudy day lighting setup.

The cloudy lighting setup mimics a cloudy day. A strong light comes from all directions above. A weaker light comes from all directions below (accounting for light reflected off the ground). Use path tracing for best results with this setup.

Returns A list of lights.

`fresnel.light.lightbox()`

Create a light box lighting setup.

The light box lighting setup places a single massive area light that covers the top, bottom, left, and right. Use path tracing for best results with this setup.

Returns A list of lights.

`fresnel.light.loop(side='right')`

Create a loop lighting setup.

The loop portrait lighting setup places the key light slightly to one side of the camera and slightly up (index 0). The fill light is on the other side of the camera at the level of the camera (index 1).

Parameters **side** (*str*) – 'right' or 'left' to choose which side of the camera to place the key light.

Returns A list of lights.

`fresnel.light.rembrandt(side='right')`

Create a Rembrandt lighting setup.

The Rembrandt portrait lighting setup places the key light 45 degrees to one side of the camera and slightly up (index 0). The fill light is on the other side of the camera at the level of the camera (index 1).

Parameters **side** (*str*) – 'right' or 'left' to choose which side of the camera to place the key light.

Returns A list of lights.

`fresnel.light.ring()`

Create a ring lighting setup.

The ring lighting setup provides a strong front area light. This type of lighting is common in fashion photography. Use path tracing for best results with this setup.

Returns A list of lights.

25.6 fresnel.material

Overview

fresnel.material.Material	Define material properties.

Details

Materials describe the way light interacts with surfaces.

class fresnel.material.**Material**(*solid=0*, *color=(0, 0, 0)*, *primitive_color_mix=0*, *roughness=0.3*, *specular=0.5*, *spec_trans=0*, *metal=0*)

Define material properties.

Materials control how light interacts with the geometry.

Parameters

- **solid** (*float*) – Set to 1 to pass through a solid color, regardless of the light and view angle.
- **color** (`numpy.ndarray` or `array_like`) – (3, `float32`) - Linear RGB color of the material.
- **primitive_color_mix** (*float*) – Set to 1 to use the color provided in the Geometry, 0 to use the color specified in the material, or a value in the range [0,1] to mix the two colors.
- **roughness** (*float*) – Roughness of the material. Nominally in the range [0.1,1].
- **specular** (*float*) – Control the strength of the specular highlights. Nominally in the range [0,1].
- **spec_trans** (*float*) – Control the amount of specular light transmission. In the range [0,1].
- **metal** (*float*) – Set to 0 for dielectric material, or 1 for metal. Intermediate values interpolate between the two.

See also:

Tutorials:

- *Material properties*

Note: Colors are in the linearized color space. Use `fresnel.color.linear()` to convert standard sRGB colors into this space.

25.7 fresnel.tracer

Overview

`fresnel.tracer.Path`	Path tracer.
`fresnel.tracer.Preview`	Preview ray tracer.
`fresnel.tracer.Tracer`	Base class for all ray tracers.

Details

Ray tracers process a `fresnel.Scene` and render output images.

Fresnel provides a `Preview` tracer to generate a quick approximate render and `Path` which provides soft shadows, reflections, and other effects.

See also:

Tutorials:

- *Introduction*
- *Tracer methods*

class fresnel.tracer.**Path**(*device*, *w*, *h*)

Path tracer.

Parameters

- **device** (`Device`) – Device to use.
- **w** (*int*) – Output image width.
- **h** (*int*) – Output image height.

The path tracer applies advanced lighting effects, including soft shadows, reflections, etc.... It operates by Monte Carlo sampling. Each call to `render()` performs one sample per pixel. The output image is the mean of all the samples. Many samples are required to produce a smooth image. `sample()` provides a convenience API to make many samples with a single call.

reset()

Clear the output buffer and start sampling a new image. Increment the random number seed so that the new image is statistically independent from the previous.

sample(*scene*, *samples*, *reset=True*, *light_samples=1*)

Parameters

- **scene** (`Scene`) – The scene to render.
- **samples** (*int*) – The number of samples to take per pixel.
- **reset** (*bool*) – When True, call `reset()` before sampling

Returns A reference to the current output buffer as a `fresnel.util.ImageArray`.

Note: When *reset* is False, subsequent calls to `sample()` will continue to add samples to the current output image. Use the same number of light samples when sampling an image in this way.

class fresnel.tracer.**Preview**(*device*, *w*, *h*, *anti_alias=True*)

Preview ray tracer.

Parameters

- **device** (`Device`) – Device to use.
- **w** (*int*) – Output image width.
- **h** (*int*) – Output image height.
- **anti_alias** (*bool*) – Whether to perform anti-aliasing. If True, uses an 8x8 subpixel grid.

Overview

The `Preview` tracer produces a preview of the scene quickly. It approximates the effect of light on materials. The output of the `Preview` tracer will look very similar to that from the `Path` tracer, but will miss soft shadows, reflection, transmittance, and other lighting effects.

Anti-aliasing

The default value of `anti_alias` is True to smooth sharp edges in the image. The anti-aliasing level corresponds to aa_level=3 in fresnel versions up to 0.11.0. Different `seed` values will result in different output images.

property anti_alias
Whether to perform anti-aliasing

class fresnel.tracer.**Tracer**
Base class for all ray tracers.

`Tracer` provides operations common to all ray tracer classes.

Each `Tracer` instance stores a pixel output buffer. When you `render()` a `Scene`, the current data stored in the buffer is overwritten with the new image.

Note: You cannot instantiate a Tracer directly. Use one of the sub classes.

---

output
Reference to the current output buffer (modified by `render()`)

Type `fresnel.util.ImageArray`

linear_output
Reference to the current output buffer in linear color space (modified by `render()`)

Type `fresnel.util.Array`

seed
Random number seed.

Type int

disable_highlight_warning()
Disable the highlight clipping warnings.

enable_highlight_warning(*color=(1, 0, 1)*)
Enable highlight clipping warnings.

When a pixel in the rendered image is too bright to represent, make that pixel the given *color* to flag the problem to the user.

Parameters **color** (*tuple*) – Color to make the highlight warnings.

histogram()
Compute a histogram of the image.

The histogram is computed as a lightness in the sRGB color space. The histogram is computed only over the visible pixels in the image, fully transparent pixels are ignored. The returned histogram is nbins x 4, the first column contains the lightness histogram and the next 3 contain R,B, and G channel histograms respectively.

Returns (histogram, bin_positions).

render (*scene*)
Render a scene.

Parameters **scene** (*Scene*) – The scene to render.

Returns A reference to the current output buffer as a *fresnel.util.ImageArray*.

Render the given scene and write the resulting pixels into the output buffer.

resize (*w*, *h*)
Resize the output buffer.

Parameters

- **w** (*int*) – New output buffer width.
- **h** (*int*) – New output buffer height.

> **Warning:** *resize()* clears any existing image in the output buffer.

25.8 fresnel.util

Overview

fresnel.util.Array	Map internal fresnel buffers as numpy.ndarray objects.
fresnel.util.convex_polyhedron_from_vertices	Convert convex polyhedron vertices to fresnel data structures
fresnel.util.ImageArray	Map internal image buffers as numpy.ndarray objects.

Details

Utilities.

class fresnel.util.**Array** (*buf*, *geom*)
Map internal fresnel buffers as numpy.ndarray objects.

fresnel.util.Array provides a python interface to access internal data of memory buffers stored and managed by fresnel. You can access a *fresnel.util.Array* as if it were a numpy.ndarray (with limited operations). Below, *slice* is a slice or array indexing mechanic that **numpy** understands.

Writing

Write to an array with `array[slice] = v` where *v* is numpy.ndarray, list, or scalar value to broadcast. When *v* is a *contiguous* numpy.ndarray of the same data type, the data is copied directly from *v* into the internal buffer. Otherwise, it is converted to a numpy.ndarray before copying.

Reading

Read from an array with `v = array[slice]`. This returns a **copy** of the data as a `numpy.ndarray` each time it is called.

`shape`
Dimensions of the array.

Type tuple

`dtype`
Numpy data type

class `fresnel.util.`**`ImageArray`**(*buf*, *geom*)
Map internal image buffers as `numpy.ndarray` objects.

Inherits from *`Array`* and provides all of its functionality, plus some additional convenience methods specific to working with images. Images are represented as `WxHx4` `numpy.ndarray` of `uint8` values in **RGBA** format.

When a *`ImageArray`* is the result of an image in a Jupyter notebook cell, Jupyter will display the image.

`fresnel.util.`**`convex_polyhedron_from_vertices`**(*vertices*)
Convert convex polyhedron vertices to fresnel data structures

Parameters **vertices** (`numpy.ndarray` or `array_like`) – (`Nx3` : `float64`) - The vertices of the polyhedron.

Returns A dict containing the information used to draw the polyhedron. The dict contains the keys `face_origin`, `face_normal`, `face_color`, and `radius`.

The dictionary can be used directly to draw a polyhedron from its vertices:

```
scene = fresnel.Scene()
polyhedron = fresnel.util.convex_polyhedron_from_vertices(vertices)
geometry = fresnel.geometry.ConvexPolyhedron(scene,
                                             polyhedron,
                                             position=[0, 0, 0],
                                             orientation=[1, 0, 0, 0])
```

CHAPTER

TWENTYSIX

CODE STYLE

All code in fresnel must follow a consistent style to ensure readability. We provide configuration files for linters (specified below) so that developers can automatically validate and format files.

26.1 Python

Python code in fresnel should follow PEP8 with the following choices:

- 80 character line widths.
- Hang closing brackets.
- Break before binary operators.

26.1.1 Tools

- Linter: flake8 with pep8-naming
- Autoformatter: autopep8
- Run: `flake8` to see a list of violations.
- See `setup.cfg` for the **flake8** configuration (also used by **autopep8**).

26.1.2 Documentation

Python code should be documented with docstrings and added to the Sphinx documentation index in `doc/`. Docstrings should follow Google style formatting for use in Napoleon.

26.2 C++/CUDA

- 100 character line width.
- Indent only with spaces.
- 4 spaces per indent level.
- Naming conventions:
  - Namespaces: All lowercase `somenamespace`
  - Class names: `UpperCamelCase`

  - Methods: `lowerCamelCase`
  - Member variables: `m_` prefix followed by lowercase with words separated by underscores `m_member_variable`
  - Constants: all upper-case with words separated by underscores `SOME_CONSTANT`
  - Functions: `lowerCamelCase`

26.2.1 Tools

- Autoformatter: clang-format.
- Run: `./run-clang-format.py -r fresnel` to see needed changes.
- Run: `clang-format -i file.cc` to apply the changes to a specific file.
- Style configuration: See `.clang-format`.

Note: We plan to provide change the style once **clang-format** 10 is available.

26.2.2 Documentation

Documentation comments should be in Javadoc format and precede the item they document for compatibility with Doxygen and most source code editors. Multi-line documentation comment blocks start with `/**` and single line ones start with `///`.

26.3 Other file types

Use your best judgment and follow existing patterns when styling CMake, restructured text, markdown, and other files. The following general guidelines apply:

- 100 character line width.
- 4 spaces per indent level.
- 4 space indent.

CHAPTER TWENTYSEVEN

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```

CHAPTER

TWENTYEIGHT

CREDITS

The following people contributed to **fresnel**.

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- Tim Moore, University of Michigan
- Vyas Ramasubramani, University of Michigan
- Bryan VanSaders, University of Michigan
- Mike Henry, Boise State University
- Jenny Fothergill, Boise State University
- Corwin Kerr, University of Michigan

28.1 Libraries

Fresnel links to the following libraries:

28.1.1 Python

Python is used under the Python license (http://www.python.org/psf/license/).

28.1.2 Embree

Embree is used under the Apache License, 2.0:

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28.1.3 pybind11

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