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# **raytraverse Documentation**

***Release 1.2.1***

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# COMMAND LINE INTERFACE

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raytraverse is a complete workflow for climate based daylight modelling, simulation, and evaluation of architectural spaces. Built around a wavelet guided adaptive sampling strategy, raytraverse can fully explore the daylight conditions throughout a space with efficient use of processing power and storage space.

- Free software: Mozilla Public License 2.0 (MPL 2.0)
- Documentation: <https://raytraverse.readthedocs.io/en/latest/>.



## INSTALLATION

The easiest way to install raytraverse is with pip:

```
pip install --upgrade pip setuptools wheel
pip install raytraverse
```

or if you have cloned this repository:

```
cd path/to/this/file
pip install .
```

note that on first run the skycalc module may download some auxiliary data which could take a minute, after that first run start-up is much faster.





## USAGE

raytraverse includes a complete command line interface with all commands nested under the *raytraverse* parent command enter:

```
raytraverse --help
```

raytraverse also exposes an object oriented API written primarily in python. calls to Radiance are made through Renderer objects that wrap the radiance c source code in c++ classes, which are made available in python with pybind11. see the `src/` directory for more.

For complete documentation of the API and the command line interface either use the Documentation link included above or:

```
pip install -r docs/requirements.txt  
make docs
```

to generate local documentation.



## GETTING STARTED

the following example script shows the basic workflow for a complete simulation it can be saved to a local file with:

```
raytraverse examplescript > example.py
```

or the file is located at raytraverse/example.py

```
# -*- coding: utf-8 -*-
# Copyright (c) 2020 Stephen Wasilewski, HSLU and EPFL
# =====
# This Source Code Form is subject to the terms of the Mozilla Public
# License, v. 2.0. If a copy of the MPL was not distributed with this
# file, You can obtain one at http://mozilla.org/MPL/2.0/.
# =====

"""example script for raytraverse."""

import numpy as np
from raytraverse.mapper import PlanMapper, SkyMapper, ViewMapper
from raytraverse.scene import Scene
from raytraverse.renderer import Rtrace, Rcontrib
from raytraverse.sampler import SkySamplerPt, SamplerArea, SamplerSuns
from raytraverse.sky import SkyData, skycalc
from raytraverse.lightfield import LightResult
from raytraverse.evaluate import MetricSet

# -----
# update these values
# -----

# output directory where are simulation results are written
out = "outdir"
# the radiance scene files (all materials and geometries, no sources)
scene_files = "room.rad"
# a horizontal analysis plane, for this demo should be 2x2 (or change ptres)
zone = "plane.rad"
# an 8760 epw or wea file with location data. although note that wea files
# do not include dew-point, a potentially important parameter of the perez
# sky model.
epw = "weather.epw"
# an output file path for writing compressed binary results
output = "metrics.npz"

# NOTE: many of the setting overrides are for demonstration only
# and may not yield accurate or meaningful results, they are accuracy
```

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```

# reductions made in order for this script to run quickly (less than 1 minute on
# a reasonably fast laptop).
# In this example, only directions are dynamically sampled, but position and
# solar sources are sampled for 1 level only at a low resolution. to sample
# points dynamically, set SamplerArea(nlev=3, jitter=True). To dynamically
# sample suns, change SamplerSuns(nlev=3) or other appropriate level.
# refer to the documentation for adjusting the sampling scheme used in
# directional sampling (SamplerPt, SkySamplerPt, SunSamplerPt).
def main():
    loc = skycalc.get_loc_epw(epw)
    # Make octree, manage output file directory
    scn = Scene(out, scene_files)
    # initialize sampling schemes and boundaries for position and solar source
    # sampling
    pm = PlanMapper(zone, ptres=2.0)
    sm = SkyMapper(loc=loc)
    # initialize rendering engines (note settings are appended to
    # Renderer.defaultargs, which are different from rtrace/rcontrib defaults)
    rcontrib = Rcontrib("-ab 2 -ad 4 -c 1000", scene=scn.scene)
    rtrace = Rtrace("-ab 2 -c 1", scene=scn.scene)

    # initialize sky point sampler and then call an area sampler to simulate
    # sky contribution
    sk_engine = SkySamplerPt(scn, rcontrib, accuracy=2.0)
    skysampler = SamplerArea(scn, sk_engine, accuracy=2.0, nlev=1, jitter=False)
    skyfield = skysampler.run(pm)
    print(rcontrib)
    rcontrib.reset()

    # to modify parameters for sun/pt sampler pass arguments to the ptkwargs
    # argument of SamperSuns
    ptkwargs = dict(accuracy=2.0)
    areakwargs = dict(accuracy=2.0, nlev=1, jitter=False)
    sunsampler = SamplerSuns(scn, rtrace, nlev=1,
                             ptkwargs=ptkwargs, areakwargs=areakwargs)

    daylightfield = sunsampler.run(sm, pm, specguide=skyfield)
    rtrace.reset()
    # calculate sky patch and sun contributions
    sd = SkyData(epw)

    # make a set of points to evaluate (here a regular grid at the final
    # sampling level (assuming nlev=2)
    pts = pm.point_grid(False, 1)

    # The raytraverse.lightfield.DayLightPlaneKD object holds the complete
    # sampling results. individual point data can be loaded by querying with
    # a 6 element solar position and plan coordinate
    # the first sun in skydata:
    sun = sd.sun[0, 0:3]
    # the first point in our grid:
    pt = pts[0]
    i, d = daylightfield.query((sun, pt))
    sun_lightpoint = daylightfield.data[i[0]]
    # we can also query for the closest skypoint:
    j, d = daylightfield.skyplane.query(pt)
    sky_lightpoint = daylightfield.skyplane.data[j]
    # for energy conserving operations (avg luminance, illuminance, an image)
    # we can evaluate the lightpoints seperately and then add, but for
    # general analysis we need to combine the points first:
    sun_sky_point = sky_lightpoint.add(sun_lightpoint)

```

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```

# because the sources are combined now we need to concatenate the solar
# value onto the rest of the skyvector:
skyvec = np.concatenate((sd.smtx[0], sd.sun[0, 3]), axis=None)

# and now we can make an hdr image:
vm = ViewMapper((0, -1, 0), viewangle=180)
# file named by hour of year
outf = f"hour_{sd.maskindices[0]:04d}.hdr"
sun_sky_point.make_image(outf, skyvec, vm)

# or calculate DGP and UGP:
vol = sun_sky_point.evaluate(skyvec, vm)
metrics = MetricSet(*vol, vm)
print(f"DGP: {metrics.dgp} UGP: {metrics.ugp}")

# for larger sets of metric evaluations, DaylightPlaneKD has its' own
# evaluate function to do bulk processing (also will use multiprocessing)
# Note that you can mask the SkyData object to limit the evaluation
# such as to only the first day of the year:
sd.mask = np.arange(24)

# view directions
vdirs = np.array([[1, 0, 0], [0, 1, 0], [-1, 0, 0], [0, -1, 0]], dtype=float)
# choose from ["illum", "avglum", "gcr", "ugp", "dgp", "tasklum", "backlum",
# "dgp_t1", "log_gc", "dgp_t2", "ugr", "threshold", "pws12", "view_area",
# "backlum_true", "srcillum", "srcarea", "maxlum"] or inherit
# raytraverse.evaluate.MetricSet and pass metricclass=YourMetricClass
metrics = ['illum', 'dgp', 'ugp']
result = daylightfield.evaluate(sd, pts, vdirs, metrics=metrics)
result.write(output)

# to reload these results:
result = LightResult(output)

# this result object stores a 4D array:
# (sky, point, view, metric)
# to reshape/slice results for viewing or analysis, use the pull method:
# here we get the south facing view for the first point in our grid:
data, axes, names = result.pull("sky", "metric", findices=[[0], [3]])
print("hour", *axes[2])
for d, h in zip(data[0], axes[1]):
    print(h, *d)

if __name__ == '__main__':
    main()

```



## COMMAND LINE INTERFACE

The raytraverse command provides command line access to executing common tasks. The best way to manage all of the options is with a .cfg file. First, generate a template:

```
raytraverse --template > options.cfg
```

and then edit the options for each file. To duplicate the run shown in the example script above save the following to options.cfg:

```
[raytraverse_scene]
out = outdir
scene = room.rad

[raytraverse_area]
ptres = 2.0
zone = plane.rad

[raytraverse_suns]
loc = weather.epw
epwloc = True

[raytraverse_skydata]
wea = weather.epw

[raytraverse_skyengine]
accuracy = 2.0
rayargs = -ab 2 -ad 4 -c 1000

[raytraverse_sunengine]
accuracy = 2.0
rayargs = -ab 2 -c 1

[raytraverse_skyrun]
accuracy = 2.0
jitter = True
nlev = 2
overwrite = False

[raytraverse_sunrun]
accuracy = 2.0
nlev = 2
srcaccuracy = 2.0
```

and then from the command line run:

```
raytraverse -c options.cfg skyrun sunrun
```

## 4.1 raytraverse

```
raytraverse [OPTIONS] COMMAND1 [ARGS]... [COMMAND2 [ARGS]...]...
```

the raytraverse executable is a command line interface to the raytraverse python package for running and evaluating climate based daylight models. sub commands of raytraverse can be chained but should be invoked in the order given.

the easiest way to manage options is to use a configuration file, to make a template:

```
raytraverse --template > run.cfg
```

after adjusting the settings, than each command can be invoked in turn and any dependencies will be loaded with the correct options, a complete run and evaluation can then be called by:

```
raytraverse -c run.cfg skyrun sunrun
```

as all required precursor commands will be invoked automatically as needed.

### Options

#### VALUE OPTIONS:

**-config, -c** <PATH>  
path of config file to load

**-n** <INTEGER>  
sets the environment variable RAYTRAVERSE\_PROC\_CAP set to 0 to clear (parallel processes will use cpu\_limit)

**-out** <DIRECTORY>

#### FLAGS (DEFAULT FALSE):

**--template, --no-template**  
write default options to std out as config

**Default** False

#### HELP:

**-opts, --opts**  
check parsed options

**Default** False

**--debug**  
show traceback on exceptions

**Default** False

**--version**  
Show the version and exit.

**Default** False



## Commands

- scene**  
define scene files for renderer and output...
- area**  
define sampling area
- suns**  
define solar sampling space
- skydata**  
define sky conditions for evaluation
- skyengine**  
initialize engine for skyrun
- sunengine**  
initialize engine for sunrun
- skyrun**  
run scene under sky for a set of points...
- sunrun**  
run scene for a set of suns (defined by...
- evaluate**  
evaluate metrics and/or make hdr for a...
- examplescript**  
print an example workflow for script...

### 4.1.1 scene

```
raytraverse scene [OPTIONS]
```

define scene files for renderer and output directory

## Effects

- creates outdir and outdir/scene.oct

## Options

### VALUE OPTIONS:

**-out** <DIRECTORY>

**-scene** <TEXT>

space separated list of radiance scene files (no sky) or precompiled octree

### FLAGS (DEFAULT TRUE):

**--log, --no-log**

log progress to stderr

**Default** True

**--reload, --no-reload**

if a scene already exists at OUT reload it, note that if this is False and overwrite is False, the program will abort

**Default** True

### FLAGS (DEFAULT FALSE):

**--overwrite, --no-overwrite**

Warning! if set to True all files inOUT will be deleted

**Default** False

### HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False

## 4.1.2 area

`raytraverse area [OPTIONS]`

define sampling area

### Effects

- None

### Options

#### VALUE OPTIONS:

**-name** <TEXT>

name for zone/point group (impacts file naming)

**Default** plan

**-ptres** <FLOAT>

initial sampling resolution for points

**Default** 1.0

**-rotation** <FLOAT>

positive Z rotation for point grid alignment

**Default** 0.0

**-static\_points** <TEXT>

points to simulate, this can be a .npz file, a whitespace separated text file or entered as a string with commas between components of a point and spaces between points. points should either all be 3 component (x,y,z) or 6 component (x,y,z,dx,dy,dz) but the dx,dy,dz is ignored

**-zheight** <FLOAT>

replaces z in points or zone

**-zone** <TEXT>

zone boundary to dynamically sample. can either be a radiance scene file defining a plane to sample or an array of points (same input options as -static\_points). Points are used to define a convex hull with an offset of 1/2\*ptres in which to sample. Note that if static\_points and zone are both give, static\_points is silently ignored

## HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False

## 4.1.3 suns

```
raytraverse suns [OPTIONS]
```

define solar sampling space

## Effects

- None

## Options

### VALUE OPTIONS:

**-loc** <TEXT>

can be a number of formats:

1. a string of 3 space separated values (lat lon mer) where lat is +west and mer is tz\*15 (matching gendaylit).
2. a string of comma separated sun positions with multiple items separated by spaces: "0,-.7,.7 .7,0,.7" following the shape requirements of 3.
3. a file loadable with np.loadtxt) of shape (N, 2), (N,3), (N,4), or (N,5):

- a. 2 elements: alt, azm (angles in degrees)
  - b. 3 elements: dx,dy,dz of sun positions
  - c. 4 elements: alt, azm, dirnorm, diffhoriz (angles in degrees)
  - d. 5 elements: dx, dy, dz, dirnorm, diffhoriz.
4. path to an epw or wea formatted file: solar positions are generated and used as candidates unless `-epwloc` is True.
  5. None (default) all possible sun positions are considered

in the case of a location, sun positions are considered valid when in the solar transit for that location. for candidate options (2., 3., 4.), sun positions are drawn from this set (with one randomly chosen from all candidates within adaptive grid.

**-name** <TEXT>

name for solar sourcee group (impacts file naming)

**Default** suns

**-skyro** <FLOAT>

counterclockwise sky-rotation in degrees (equivalent to clockwise project north rotation)

**Default** 0.0

**-sunres** <FLOAT>

initial sampling resolution for suns

**Default** 30.0

## FLAGS (DEFAULT FALSE):

**--epwloc, --no-epwloc**

if True, use location from epw/wea argument to `-loc` as a transit mask (like `-loc` option 1.) instead of as a list of candidate sun positions.

**Default** False

## HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False

### 4.1.4 skydata

```
raytraverse skydata [OPTIONS]
```

define sky conditions for evaluation

#### Effects

- Invokes scene
- write outdir/name.npz (SkyData initialization object)

#### Options

##### VALUE OPTIONS:

**-ground\_fac** <FLOAT>  
ground reflectance

**Default** 0.15

**-loc** <FLOATS>  
location data given as 'lat lon mer' with + west of prime meridian overrides location data in wea

**-minalt** <FLOAT>  
minimum solar altitude for daylight masking

**Default** 2.0

**-mindiff** <FLOAT>  
minumum diffuse horizontal irradiance for daylight masking

**Default** 5.0

**-name** <TEXT>  
output file name for skydata

**Default** skydata

**-skyres** <FLOAT>  
approximate square patch size in degrees (must match argument given to skyengine)

**Default** 10.0

**-skyro** <FLOAT>  
angle in degrees counter-clockwise to rotate sky (to correct model north, equivalent to clockwise rotation of scene)

**Default** 0.0

**-wea** <TEXT>  
path to epw, wea, .npy file or np.array, or .npz file,if loc not set attempts to extract location data (if needed).

**FLAGS (DEFAULT TRUE):**

**--reload, --no-reload**  
reload saved skydata if it exists in scene directory  
**Default** True

**HELP:**

**-opts, --opts**  
check parsed options  
**Default** False

**--debug**  
show traceback on exceptions  
**Default** False

**--version**  
Show the version and exit.  
**Default** False

## 4.1.5 skyengine

`raytraverse skyengine [OPTIONS]`

initialize engine for skyrun

**Effects**

- Invokes scene
- creates outdir/scene\_sky.oct

**Options****VALUE OPTIONS:**

**-accuracy** <FLOAT>  
a generic accuracy parameter that sets the threshold variance to sample. A value of 1 will have a sample count at the final sampling level equal to the number of directions with a contribution variance greater than .25

**Default** 1.0

**-fdres** <INTEGER>  
the final directional sampling resolution, yielding a grid of potential samples at  $2^{\text{fdres}} \times 2^{\text{fdres}}$  per hemisphere

**Default** 9

**-idres** <INTEGER>  
the initial directional sampling resolution. each side of the sampling square (representing a hemisphere) will be subdivided  $2^{\text{idres}}$ , yielding  $2^{(2*\text{idres})}$  samples and a resolution of  $2^{(2*\text{idres})}/(2\pi)$  samples/steradian. this value should be smaller than 1/2 the size of the smallest view to an aperture that should be captured with 100% certainty

**Default** 5

**-rayargs** <TEXT>

additional arguments to pass to the rendering engine

**-skyres** <FLOAT>

approximate resolution for skypatch subdivision (in degrees). Patches will have (rounded) size skyres x skyres. So if skyres=10, each patch will be 100 sq. degrees (0.03046174197 steradians) and there will be  $18 * 18 = 324$  sky patches. Must match argument givein to skydata

**Default** 10.0

## FLAGS (DEFAULT TRUE):

**--default-args, --no-default-args**

use raytraverse defaults before -rayargs, if False, uses radiance defaults

**Default** True

## HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False

## 4.1.6 sunengine

`raytraverse sunengine [OPTIONS]`

initialize engine for sunrun

### Effects

- Invokes scene

### Options

#### VALUE OPTIONS:

**-accuracy** <FLOAT>

a generic accuracy parameter that sets the threshold variance to sample. A value of 1 will have a sample count at the final sampling level equal to the number of directions with a contribution variance greater than .25

**Default** 1.0

**-fdres** <INTEGER>

the final directional sampling resolution, yielding a grid of potential samples at  $2^{fdres} \times 2^{fdres}$  per hemisphere

**Default** 10

**-idres** <INTEGER>

the initial directional sampling resolution. each side of the sampling square (representing a hemisphere) will be subdivided  $2^{\text{idres}}$ , yielding  $2^{(2*\text{idres})}$  samples and a resolution of  $2^{(2*\text{idres})}/(2\pi)$  samples/steradian. this value should be smaller than 1/2 the size of the smallest view to an aperture that should be captured with 100% certainty

**Default** 5

**-maxspec** <FLOAT>

the maximum value in the specular guide considered as a specular reflection source. Above this value it is assumed that these are direct view rays to the source so are not sampled. in the case of low vlt glazing, this value should be reduced. In mixed (high-low) vlt scenes the specular guide will either over sample (including direct views) or under sample (miss specular reflections) depending on this setting.

**Default** 0.2

**-rayargs** <TEXT>

additional arguments to pass to the rendering engine

**-slimit** <FLOAT>

the minimum value in the specular guide considered as a potential specular reflection source, in the case of low vlt glazing, this value should be reduced.

**Default** 0.01

**-speclevel** <INTEGER>

at this sampling level, pdf is made from brightness of sky sampling rather than progressive variance to look for fine scale specular highlights, this should be atleast 1 level from the end and the resolution of this level should be smaller than the size of the source

**Default** 9

## FLAGS (DEFAULT TRUE):

**--default-args, --no-default-args**

use raytraverse defaults before -rayargs, if False, uses radiance defaults

**Default** True

## HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False



### 4.1.7 skyrun

```
raytraverse skyrun [OPTIONS]
```

run scene under sky for a set of points (defined by area)

#### Effects

- Invokes scene
- Invokes area (no effects)
- Invokes skyengine
- **creates** `outdir/area.name/sky_points.tsv`
  - contents: 5cols x N rows: [sample\_level idx x y z]
- **creates** `outdir/area.name/sky/#####.rytpt`
  - each file is a LightPointKD initialization object

#### Options

##### VALUE OPTIONS:

- accuracy** <FLOAT>  
parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling)  
**Default** 1.0
- nlev** <INTEGER>  
number of levels to sample (final resolution will be  $\text{ptres}/2^{(\text{nlev}-1)}$ )  
**Default** 3

##### FLAGS (DEFAULT TRUE):

- jitter, --no-jitter**  
jitter samples on plane within adaptive sampling grid  
**Default** True

##### FLAGS (DEFAULT FALSE):

- overwrite, --no-overwrite**  
If True, reruns sampler when invoked, otherwise will first attempt to load results  
**Default** False

**HELP:****-opts, --opts**

check parsed options

**Default** False**--debug**

show traceback on exceptions

**Default** False**--version**

Show the version and exit.

**Default** False

## 4.1.8 sunrun

```
raytraverse sunrun [OPTIONS]
```

run scene for a set of suns (defined by suns) for a set of points (defined by area)

**Effects**

- Invokes scene
- Invokes area (no effects)
- Invokes sunengine (no effects)
- invokes skyrun (if guided=True)
- **creates** `outdir/area.name/sun_####_points.tsv`
  - contents: 5cols x N rows: [sample\_level idx x y z]
- **creates** `outdir/area.name/sky/sun_####/#####.rytpt`
  - each file is a LightPointKD initialization object

**Options****VALUE OPTIONS:****-accuracy** <FLOAT>

parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling)

**Default** 1.0**-nlev** <INTEGER>number of levels to sample (final resolution will be  $ptres/2^{(nlev-1)}$ )**Default** 3**-srcaccuracy** <FLOAT>

parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling)

**Default** 1.0**-srcnlev** <INTEGER>number of levels to sample (final resolution will be  $sunres/2^{(nlev-1)}$ )

**Default** 3

#### FLAGS (DEFAULT TRUE):

**--guided, --no-guided**

If True, uses skysampling results to guide sun sampling this is necessary if the model has any specular reflections, will raise an error if skyrun has not been called yet.

**Default** True

**--jitter, --no-jitter**

jitter samples on plane within adaptive sampling grid

**Default** True

**--srcjitter, --no-srcjitter**

jitter solar source within adaptive sampling grid for candidate SkyMappers, only affects weighting of selecting candidates in the same grid true positions are still used

**Default** True

#### FLAGS (DEFAULT FALSE):

**--recover, --no-recover**

If True, recovers existing sampling

**Default** False

#### HELP:

**-opts, --opts**

check parsed options

**Default** False

**--debug**

show traceback on exceptions

**Default** False

**--version**

Show the version and exit.

**Default** False

### 4.1.9 evaluate

`raytraverse evaluate [OPTIONS]`

evaluate metrics and/or make hdr for a single sensor location

## Prerequisites

- skyrun and sunrun must be manually invoked prior to this

## Effects

- Invokes scene
- Invokes skydata
- invokes area (no effects)
- invokes suns (no effects)
- if hdr=True, writes: <basename>\_####.hdr
- if metric=True, writes: <basename>.tsv

## Options

### VALUE OPTIONS:

#### **-basename** <TEXT>

basename for hdr outputs will write: <basename>\_####.hdr for each value in skymask (or range(len(skydata)) if skymask is None).

**Default** results

#### **-metrics** <TEXTS>

metrics to compute, choices: ["illum", "avglum", "gcr", "ugp", "dgp", "tasklum", "backlum", "dgp\_t1", "log\_gc", "dgp\_t2", "ugr", "threshold", "pws12", "view\_area", "backlum\_true", "srcillum", "srcarea", "maxlum"]

**Default** illum dgp ugp

#### **-res** <INTEGER>

image resolution

**Default** 800

#### **-sensor** <FLOATS>

the sensor location (6 component vector 'x y z dx dy dz')

#### **-skymask** <INTS>

mask to reduce output from full SkyData, enter as index rows in wea/epw file using space seperated list or python range notation:

- 370 371 372 (10AM-12PM on jan. 16th)
- 12:8760:24 (everyday at Noon)

#### **-viewangle** <FLOAT>

applies to both image and metrics, should be <= 180 or 360

**Default** 180.0

**FLAGS (DEFAULT TRUE):**

**--metric, --no-metric**  
calculate metrics

**Default** True

**FLAGS (DEFAULT FALSE):**

**--hdr, --no-hdr**  
make an image for every unmasked item in skydata

**Default** False

**--interpolate, --no-interpolate**  
use linear interpolation in image output

**Default** False

**HELP:**

**-opts, --opts**  
check parsed options

**Default** False

**--debug**  
show traceback on exceptions

**Default** False

**--version**  
Show the version and exit.

**Default** False

**4.1.10 examplescript**

```
raytraverse examplescript [OPTIONS]
```

print an example workflow for script based/api level access to raytraverse

**Options****HELP:**

**-opts, --opts**  
check parsed options

**Default** False

**--debug**  
show traceback on exceptions

**Default** False

**--version**  
Show the version and exit.

**Default** False

## 4.2 raytraverse.scene

### 4.2.1 BaseScene

```
class raytraverse.scene.BaseScene(outdir, scene=None, frozen=True, formatter=<class  
    'raytraverse.formatter.formatter.Formatter'>,  
    reload=True, overwrite=False, log=True, loglevel=10,  
    utc=False)
```

Bases: object

container for scene description

#### Parameters

- **outdir** (*str*) – path to store scene info and output files
- **scene** (*str, optional (required if not reload)*) – space separated list of radiance scene files (no sky) or octree
- **frozen** (*bool, optional*) – create a frozen octree
- **formatter** (*raytraverse.formatter.Formatter, optional*) – intended renderer format
- **reload** (*bool, optional*) – if True attempts to load existing scene files in new instance overrides ‘overwrite’
- **overwrite** (*bool, optional*) – if True and outdir exists, will overwrite, else raises a `FileExistsError`
- **log** (*bool, optional*) – log progress events to outdir/log.txt
- **loglevel** (*int, optional*) – maximum sampler level to log

#### property scene

render scene files (octree)

**Getter** Returns this samplers’s scene file path

**Setter** Sets this samplers’s scene file path and creates run files

**Type** str

**log** (*instance, message, err=False, level=0*)  
print a message to the log file or stderr

#### Parameters

- **instance** (*Any*) – the parent class for the progress bar
- **message** (*str, optional*) – the message contents
- **err** (*bool, optional*) – print to stderr instead of self.\_logf
- **level** (*int, optional*) – the nested level of the message

**progress\_bar** (*instance, iterable=None, message=None, total=None, level=0, workers=False*)  
generate a tqdm progress bar and concurrent.futures Executor class

#### Parameters

- **instance** (*Any*) – the parent class for the progress bar
- **iterable** (*Sequence, optional*) – passed to tqdm, the sequence to loop over
- **message** (*str, optional*) – the prefix message for the progress bar
- **total** (*int, optional*) – the number of expected iterations (when iterable is none)
- **level** (*int, optional*) – the nested level of the progress bar

- **workers** (*Union[bool, str]*, *optional*) – if “thread/threads/t” returns a ThreadPoolExecutor, else if True returns a ProcessPoolExecutor.

**Returns** a subclass of tqdm that decorates messages and has a pool property for multiprocessing.

**Return type** `_TStqdm`

## Examples

with an iterable:

```
for i in self.scene.progress_bar(self, np.arange(10)):
    do stuff...
```

with workers=True:

```
with self.scene.progress_bar(self, total=len(jobs) workers=True) as pbar: exc =
    pbar.pool do stuff... pbar.update(1)
```

## 4.2.2 Scene

```
class raytraverse.scene.Scene(outdir, scene=None, frozen=True, formatter=<class 'ray-
traverse.formatter.radianceformatter.RadianceFormatter'>,
                             **kwargs)
```

Bases: `raytraverse.scene.basescene.BaseScene`

container for radiance scene description

### Parameters

- **outdir** (*str*) – path to store scene info and output files
- **formatter** (`raytraverse.formatter.RadianceFormatter`, *optional*) – intended renderer format

## 4.2.3 ImageScene

```
class raytraverse.scene.ImageScene(outdir, scene=None, reload=True, log=False)
```

Bases: `raytraverse.scene.basescene.BaseScene`

scene for image sampling

### Parameters

- **outdir** (*str*) – path to store scene info and output files
- **scene** (*str*, *optional*) – image file (hdr format -vta projection)

## 4.3 raytraverse.mapper

### 4.3.1 Mapper

```
class raytraverse.mapper.Mapper(dxyz=0.0, 0.0, 1.0, sf=1, 1, bbox=0, 0, 1, 1, aspect=None,
                                name='mapper', origin=0, 0, 0)
```

Bases: `object`

translate between world and normalized UV space. do not use directly, instead use an inheriting class.

### Parameters

- **sf** (*tuple np.array, optional*) – scale factor for each axis (array of length(2))
- **bbox** (*tuple np.array, optional*) – bounding box for mapper shape (2, 2)
- **name** (*str, optional*) – used for output file naming

**property aspect**

**property dxyz**

(float, float, float) central view direction

**property bbox**

bounding box of view

**Type** np.array of shape (2,2)

**view2world** (*xyz*)

rotate vectors from view direction to world Z

**world2view** (*xyz*)

rotate vectors from world Z to view direction

**xyz2uv** (*xyz*)

transform from world xyz space to mapper UV space

**uv2xyz** (*uv, stackorigin=False*)

transform from mapper UV space to world xyz

**static idx2uv** (*idx, shape, jitter=True*)

**Parameters**

- **idx** (*flattened index*) –
- **shape** – the shape to unravel into
- **jitter** (*bool, optional*) – randomly offset coordinates within grid

**Returns** **uv** – uv coordinates

**Return type** np.array

**static uv2idx** (*uv, shape*)

**xyz2vxy** (*xyz*)

transform from world xyz to view image space (2d)

**vxy2xyz** (*xy, stackorigin=False*)

transform from view image space (2d) to world xyz

**framesize** (*res*)

**pixels** (*res*)

generate pixel coordinates for image space

**pixelrays** (*res*)

world xyz coordinates for pixels in view image space

**ray2pixel** (*xyz, res, integer=True*)

world xyz to pixel coordinate

**pixel2ray** (*pxy, res*)

pixel coordinate to world xyz vector

**pixel2omega** (*pxy, res*)

pixel area

**in\_view** (*vec, indices=True*)

generate mask for vec that are in the field of view

**header** (*\*\*kwargs*)



**init\_img** (*res=512, \*\*kwargs*)

Initialize an image array with vectors and mask

#### Parameters

- **res** (*int, optional*) – image array resolution
- **kwargs** – passed to self.header

#### Returns

- **img** (*np.array*) – zero array of shape (res, res)
- **vecs** (*np.array*) – direction vectors corresponding to each pixel (img.size, 3)
- **mask** (*np.array*) – indices of flattened img that are in view
- **mask2** (*np.array None*) –

if ViewMapper has inverse, mask for opposite view, usage:

```
add_to_img(img, vecs[mask], mask)
add_to_img(img[res:], vecs[res:][mask2], mask2)
```

- **header** (*str*)

**add\_vecs\_to\_img** (*img, v, channels=1, 0, 0, grow=0, \*\*kwargs*)

**plot** (*xyz, outf, res=1000, grow=1, \*\*kwargs*)

## 4.3.2 AngularMixin

**class** raytraverse.mapper.angularmixin.**AngularMixin**

Bases: object

includes overrides of transformation functions for angular type mapper classes. Inherit before raytraverse.mapper.Mapper eg:

```
NewMapper(AngularMixin, Mapper)
```

initialization of NewMapper must include declarations of:

```
self._viewangle = viewangle
self._chordfactor = chordfactor
self._ivm = ivm
```

**xyz2uv** (*xyz*)

transform from world xyz space to mapper UV space

**uv2xyz** (*uv, stackorigin=False*)

transform from mapper UV space to world xyz

**xyz2vxy** (*xyz*)

transform from world xyz to view image space (2d)

**vxy2xyz** (*xy, stackorigin=False*)

transform from view image space (2d) to world xyz

**static framesize** (*res*)

**pixelrays** (*res*)

world xyz coordinates for pixels in view image space

**pixel2omega** (*pxy, res*)

pixel solid angle

**in\_view** (*vec*, *indices=True*)  
generate mask for *vec* that are in the field of view (up to 180 degrees) if view aspect is 2, only tests against primary view direction

**header** (*pt=0, 0, 0*, *\*\*kwargs*)

**init\_img** (*res=512*, *pt=0, 0, 0*, *\*\*kwargs*)  
Initialize an image array with vectors and mask

#### Parameters

- **res** (*int*, *optional*) – image array resolution
- **pt** (*tuple*, *optional*) – view point for image header

#### Returns

- **img** (*np.array*) – zero array of shape (*res\*self.aspect*, *res*)
- **vecs** (*np.array*) – direction vectors corresponding to each pixel (*img.size*, 3)
- **mask** (*np.array*) – indices of flattened *img* that are in view
- **mask2** (*np.array None*) –

if ViewMapper is 360 degree, include mask for opposite view to use:

```
add_to_img(img, vecs[mask], mask)
add_to_img(img[res:], vecs[res:][mask2], mask2)
```

- **header** (*str*)

**add\_vecs\_to\_img** (*img*, *v*, *channels=1*, *0, 0*, *grow=0*, *fisheye=True*)

**property viewangle**

view angle

**property ivm**

viewmapper for opposite view direction (in case of 360 degree view)

**ctheta** (*vec*)

cos(theta) (dot product) between view direction and *vec*

**radians** (*vec*)

angle in radians between view direction and *vec*

**degrees** (*vec*)

angle in degrees between view direction and *vec*

### 4.3.3 ViewMapper

**class** raytraverse.mapper.**ViewMapper** (*dxyz=0.0, 1.0, 0.0*, *viewangle=360.0*, *name='view'*)

Bases: raytraverse.mapper.angularmixin.AngularMixin, raytraverse.mapper.mapper.Mapper

translate between world direction vectors and normalized UV space for a given view angle. pixel projection yields equiangular projection

#### Parameters

- **dxyz** (*tuple*, *optional*) – central view direction
- **viewangle** (*float*, *optional*) – if < 180, the horizontal and vertical view angle, if greater, view becomes 360, 180

**property aspect**

**property dxyz**

(float, float, float) central view direction

### 4.3.4 SkyMapper

**class** raytraverse.mapper.**SkyMapper** (*loc=None, skyro=0.0, sunres=20.0, name='sky'*)

Bases: raytraverse.mapper.angularmixin.AngularMixin, raytraverse.mapper.mapper.Mapper

translate between world direction vectors and normalized UV space for a given view angle. pixel projection yields equiangular projection

#### Parameters

- **loc** (*any, optional*) – can be a number of formats:
  1. either a numeric iterable of length 3 (lat, lon, mer) where lat is +west and mer is tz\*15 (matching gendaylit).
  2. an array (or tsv file loadable with np.loadtxt) of shape (N,3), (N,4), or (N,5):
    - a. 2 elements: alt, azm (angles in degrees)
    - b. 3 elements: dx,dy,dz of sun positions
    - c. 4 elements: alt, azm, dirnorm, diffhoriz (angles in degrees)
    - d. 5 elements: dx, dy, dz, dirnorm, diffhoriz.
  3. path to an epw or wea formatted file
  4. None (default) all possible sun positions are considered self.in\_solarbounds always returns True

in the case of a geo location, sun positions are considered valid when in the solar transit for that location. for candidate options, sun positions are drawn from this set (with one randomly chosen from all candidates within bin.

- **skyro** (*float, optional*) – counterclockwise sky-rotation in degrees (equivalent to clockwise project north rotation)
- **sunres** (*float, optional*) – initial sampling resolution for suns
- **name** (*str, optional*) –

**property skyro**

**property sunres**

**property loc**

**in\_solarbounds** (*xyz, level=0, include='center'*)  
for checking if src direction is in solar transit

#### Parameters

- **xyz** (*np.array*) – source directions
- **level** (*int*) – for determining patch size, 2\*\*level resolution from sunres
- **include** (*{'center', 'all', 'any'}, optional*) – boundary test condition. ‘center’ tests uv only, ‘all’ requires for corners of box centered at uv to be in, ‘any’ requires atleast one corner. ‘any’ is the least restrictive and ‘all’ is the most, but with increasing levels ‘any’ will exclude more positions while ‘all’ will exclude less (both approaching ‘center’ as level -> N)

**Returns result** – Truth of ray.src within solar transit

**Return type** np.array

**shape** (*level=0*)

**solar\_grid** (*jitter=True, level=0, masked=True*)  
generate a grid of solar positions

**Parameters**

- **jitter** (*bool, optional*) – if None, use the instance default, if True jitters point samples within stratified grid
- **level** (*int, optional*) – sets the resolution of the grid as a power of 2 from sunress
- **masked** (*bool, optional*) – apply in\_solarbounds to suns before returning

**Returns** shape (N, 3)**Return type** np.array

### 4.3.5 PlanMapper

```
class raytraverse.mapper.PlanMapper (area, ptres=1.0, rotation=0.0, zheight=None,  
                                     name='plan')
```

Bases: raytraverse.mapper.mapper.Mapper

translate between world positions on a horizontal plane and normalized UV space for a given view angle.  
pixel projection yields a parallel plan projection

**Parameters**

- **area** (*str np.array, optional*) – radiance scene geometry defining a plane to sample, tsv file of points to generate bounding box, or np.array of points.
- **ptres** (*float, optional*) – resolution for considering points duplicates, border generation (1/2) and add\_grid(). updateable
- **rotation** (*float, optional*) – positive Z rotation for point grid alignment
- **zheight** (*float, optional*) – override calculated zheight
- **str, optional** (*name*) – plan mapper name used for output file naming

**ptres = None**

point resolution for area look ups and grid

**Type** float

**property dxyz**

(float, float, float) central view direction

**property rotation**

ccw rotation (in degrees) for point grid on plane

**Type** float

**property bbox**

boundary frame for translating between coordinates [[xmin ymin zmin] [xmax ymax zmax]]

**Type** np.array

**update\_bbox** (*plane, level=0, updatez=True*)

handle bounding box generation from plane or points

**uv2xyz** (*uv, stackorigin=False*)

transform from mapper UV space to world xyz

**in\_view\_uv** (*uv, indices=True, \*\*kwargs*)

**in\_view** (*vec, indices=True*)

check if point is in boundary path

**Parameters**

- **vec** (*np.array*) – xyz coordinates, shape (N, 3)

- **indices** (*bool, optional*) – return indices of True items rather than boolean array

**Returns** **mask** – boolean array, shape (N,)

**Return type** np.array

**borders** ()

world coordinate vertices of planmapper boundaries

**bbox\_vertices** (*offset=0, close=False*)

**shape** (*level=0*)

**point\_grid** (*jitter=True, level=0, masked=True*)

generate a grid of points

**Parameters**

- **jitter** (*bool, optional*) – if None, use the instance default, if True jitters point samples within stratified grid
- **level** (*int, optional*) – sets the resolution of the grid as a power of 2 from ptres
- **masked** (*bool, optional*) – apply in\_view to points before returning

**Returns** shape (N, 3)

**Return type** np.array

**point\_grid\_uv** (*jitter=True, level=0, masked=True*)

add a grid of UV coordinates

**Parameters**

- **jitter** (*bool, optional*) – if None, use the instance default, if True jitters point samples within stratified grid
- **level** (*int, optional*) – sets the resolution of the grid as a power of 2 from ptres
- **masked** (*bool, optional*) – apply in\_view to points before returning

**Returns** shape (N, 2)

**Return type** np.array

## 4.4 raytraverse.formatter

### 4.4.1 Formatter

**class** raytraverse.formatter.Formatter

Bases: object

scene formatter readies scene files for simulation, must be compatible with desired renderer.

**comment** = '#'

line comment character

**scene\_ext** = ''

extension for renderer scene file

**static** **make\_scene** (*scene\_files, out, frozen=True*)

compile scene

**static** **add\_source** (*scene, src*)

add source files to compiled scene

```
static get_skydef (color, ground=True, name='skyglow')  
    assemble sky definition  
static get_sundef (vec, color, size=0.5333, mat_name='solar', mat_id='sun', glow=False)  
    assemble sun definition  
static extract_sources (srcdef, accuracy)  
    scan scene file for sun source definitions
```

## 4.4.2 RadianceFormatter

```
class raytraverse.formatter.RadianceFormatter  
    Bases: raytraverse.formatter.formatter.Formatter  
  
    scene formatter readies scene files for simulation, must be compatible with desired renderer.  
  
    comment = '#'  
        line comment character  
  
    scene_ext = '.oct'  
        extension for renderer scene file  
  
    static make_scene (scene_files, out, frozen=True)  
        compile scene  
  
    static add_source (scene, src)  
        add source files to compiled scene  
  
    static get_skydef (color, ground=True, name='skyglow')  
        assemble sky definition  
  
    static get_sundef (vec, color, size=0.5333, mat_name='solar', mat_id='sun')  
        assemble sun definition  
  
    static extract_sources (srcdef, accuracy)  
        scan scene file for sun source definitions
```

## 4.5 raytraverse.renderer

### 4.5.1 Renderer

```
class raytraverse.renderer.Renderer  
    Bases: object  
  
    virtual singleton renderer class. the Renderer is implemented as a singleton as specific subclasses (rtrace,  
    rcontrib) have many global variables set at import time. This ensures the python object is connected to the  
    current state of the engine c++-class.  
  
    All renderer classes are callable with with a numpy array of shape (N,6) representing the origin and direction  
    of ray samples to calculate.  
  
    args = None  
  
    instance = <raytraverse.renderer.renderer._VirtEngine object>  
  
    scene = None  
  
    classmethod set_args (args, nproc=None)  
  
    run (*args, **kwargs)  
        alias for call, for consistency with SamplerPt classes for nested dimensions of evaluation
```

### 4.5.2 RadianceRenderer

```
class raytraverse.renderer.RadianceRenderer (rayargs=None, scene=None,
                                             nproc=None, default_args=True)
```

Bases: raytraverse.renderer.renderer.Renderer

Virtual class for wrapping c++ Radiance renderer executable classes

Do not use directly, either subclass or use existing: Rtrace, Rcontrib

```
name = 'radiance_virtual'
```

```
engine = <cRtrace>
         raytraverse.crender.cRtrace
```

```
srcn = 1
```

```
defaultargs = ''
```

```
args = None
```

```
classmethod get_default_args ()
```

```
classmethod reset ()
         reset engine instance and unset associated attributees
```

```
classmethod set_args (args, nproc=None)
         prepare arguments to call engine instance initialization
```

#### Parameters

- **args** (*str*) – rendering options
- **nproc** (*int*, *optional*) – cpu limit

```
classmethod load_scene (scene)
         load octree file to engine instance
```

**Parameters** **scene** (*str*) – path to octree file

**Raises ValueError:** – can only be called after set\_args, otherwise engine instance will abort.

### 4.5.3 Rtrace

```
class raytraverse.renderer.Rtrace (rayargs=None, scene=None, nproc=None, de-
                                   fault_args=True, direct=False)
```

Bases: raytraverse.renderer.radiancerenderer.RadianceRenderer

singleton wrapper for c++ raytraverse.crender.cRtrace class

this class sets default arguments, helps with initialization and setting cpu limits of the cRtrace instance. see raytraverse.crender.cRtrace for more details.

#### Parameters

- **rayargs** (*str*, *optional*) – argument string (options and flags only) raises ValueError if arguments are not recognized by cRtrace.
- **scene** (*str*, *optional*) – path to octree
- **nproc** (*int*, *optional*) – if None, sets nproc to cpu count, or the RAYTRACE\_PROC\_CAP environment variable
- **default\_args** (*bool*, *optional*) – if True, prepend default args to rayargs parameter
- **direct** (*bool*, *optional*) – if True use Rtrace.directargs in place of default (also if True, sets default\_args to True.

## Examples

Basic Initialization and call:

```
r = renderer.Rtrace(args, scene)
ans = r(vecs)
# ans.shape -> (vecs.shape[0], 1)
```

If rayargs include cache files (ambient cache or photon map) be careful with updating sources. If you are going to swap sources, update the arguments as well with the new paths:

```
r = renderer.Rtrace(args, scene)
r.set_args(args.replace("temp.amb", "temp2.amb"))
r.load_source(srcdef)
```

Note that if you are using ambient caching, you must give an ambient file, because without a file ambient values are not shared across processes or successive calls to the instance.

```
name = 'rtrace'

engine = <cRtrace>
    raytraverse.crenderer.cRtrace

defaultargs = '-av 0 0 0 -aa 0 -ab 7 -ad 128 -as 0 -c 10 -as 0 -lw 1e-5'
directargs = '-av 0 0 0 -ab 0 -lr 0'

usedirect = False

classmethod get_default_args()
    return default arguments of the class

classmethod set_args(args, nproc=None)
    prepare arguments to call engine instance initialization
```

### Parameters

- **args** (*str*) – rendering options
- **nproc** (*int*, *optional*) – cpu limit

```
classmethod update_ospec(vs)
    set output of cRtrace instance
```

### Parameters **vs** (*str*) –

**output specifiers for rtrace::** o origin (input) d direction (normalized) v value (radiance) V contribution (radiance) w weight W color coefficient l effective length of ray L first intersection distance c local (u,v) coordinates p point of intersection n normal at intersection (perturbed) N normal at intersection (unperturbed) r mirrored value contribution x unmirrored value contribution R mirrored ray length X unmirrored ray length

**Returns** **outcnt** – the number of output columns to expect when calling rtrace instance

**Return type** **int**

**Raises** **ValueError**: – when an output specifier is not recognized

```
classmethod load_source(srcfile, freesrc=-1, ambfile=None)
    add a source description to the loaded scene
```

### Parameters

- **srcfile** (*str*) – path to radiance scene file containing sources, these should not change the bounding box of the octree and has only been tested with the “source” type.



- **fre-src**(*int*, *optional*) – the number of objects to unload from the end of the rtrace object list, if -1 unloads all objects loaded by previous calls to load\_source
- **ambfile**(*str*, *optional*) – path to ambient file. if given, and arguments

#### 4.5.4 Rcontrib

**class** raytraverse.renderer.Rcontrib(*rayargs=None*, *scene=None*, *nproc=None*, *skyres=10.0*, *modname='skyglow'*, *ground=True*, *default\_args=True*)

Bases: raytraverse.renderer.radiancerenderer.RadianceRenderer

singleton wrapper for c++ raytraverse.crenderer.cRcontrib class

this class sets default arguments, helps with initialization and setting cpu limits of the cRcontrib instance. see raytraverse.crenderer.cRcontrib for more details.

##### Parameters

- **rayargs**(*str*, *optional*) – argument string (options and flags only) raises ValueError if arguments are not recognized by cRtrace.
- **scene**(*str*, *optional*) – path to octree
- **nproc**(*int*, *optional*) – if None, sets nproc to cpu count, or the RAYTRACE\_PROC\_CAP environment variable
- **skyres**(*float*, *optional*) – approximate resolution for skypatch subdivision (in degrees). Patches will have (rounded) size skyres x skyres. So if skyres=10, each patch will be 100 sq. degrees (0.03046174197 steradians) and there will be 18 \* 18 = 324 sky patches.
- **modname**(*str*, *optional*) – passed the -m option of cRcontrib initialization
- **ground**(*bool*, *optional*) – if True include a ground source (included as a final bin)
- **default\_args**(*bool*, *optional*) – if True, prepend default args to rayargs parameter

##### Examples

Basic Initialization and call:

```
r = renderer.Rcontrib(args, scene)
ans = r(vecs)
# ans.shape -> (vecs.shape[0], 325)
```

```
name = 'rcontrib'
```

```
engine = <cRcontrib>
         raytraverse.crenderer.cRcontrib
```

```
ground = True
```

```
side = 18
```

```
srcn = 325
```

```
modname = 'skyglow'
```

```
classmethod setup(scene=None, ground=True, modname='skyglow', skyres=10.0)
                 set class attributes for proper argument initialization
```

##### Parameters

- **scene**(*str*, *optional*) – path to octree

- **ground** (*bool, optional*) – if True include a ground source (included as a final bin)
- **modname** (*str, optional*) – passed the -m option of cRcontrib initialization
- **skyres** (*float, optional*) – approximate resolution for skypatch subdivision (in degrees). Patches will have (rounded) size skyres x skyres. So if skyres=10, each patch will be 100 sq. degrees (0.03046174197 steradians) and there will be  $18 * 18 = 324$  sky patches.

**Returns** *scene* – path to scene with added sky definition

**Return type** *str*

**classmethod** **get\_default\_args** ()  
construct default arguments

**classmethod** **set\_args** (*args, nproc=None*)  
prepare arguments to call engine instance initialization

**Parameters**

- **args** (*str*) – rendering options
- **nproc** (*int, optional*) – cpu limit

## 4.5.5 ImageRenderer

**class** raytraverse.renderer.**ImageRenderer** (*scene, viewmapper=None, method='linear'*)

Bases: raytraverse.renderer.renderer.Renderer

interface to treat image data as the source for ray tracing results

not implemented as a singleton, so multiple instances can exist in parallel.

**Parameters**

- **scene** (*str*) – path to hdr image file with projecting matching ViewMapper
- **viewmapper** (*raytraverse.mapper.ViewMapper, optional*) – if None, assumes 180 degree angular fisheye (vta)
- **method** (*str, optional*) – passed to scipy.interpolate.RegularGridInterpolator

## 4.6 raytraverse.sky

### 4.6.1 skycalc

functions for loading sky data and computing sun position

raytraverse.sky.skycalc.**read\_epw** (*epw*)  
read daylight sky data from epw or wea file

**Returns** *out* – (month, day, hour, dirnorn, difhoriz)

**Return type** *np.array*

raytraverse.sky.skycalc.**read\_epw\_full** (*epw, columns=None*)

**Parameters**

- **epw** –
- **columns** (*list, optional*) – integer indices or keys of columns to return

**Returns**

**Return type** requested columns from epw as np.array shape (8760, N)

`raytraverse.sky.skycalc.get_loc_epw(epw, name=False)`  
get location from epw or wea header

`raytraverse.sky.skycalc.sunpos_utc(timesteps, lat, lon, builtin=True)`  
Calculate sun position with local time

Calculate sun position (altitude, azimuth) for a particular location (longitude, latitude) for a specific date and time (time is in UTC)

#### Parameters

- **timesteps** (`np.array(datetime.datetime)`) –
- **lon** (`float`) – longitude in decimals. West is +ve
- **lat** (`float`) – latitude in decimals. North is +ve
- **builtin** (`bool`) – use skyfield builtin timescale

#### Returns

- (`skyfield.units.Angle, skyfield.units.Angle`)
- *altitude and azimuth in degrees*

`raytraverse.sky.skycalc.row_2_datetime64(ts, year=2020)`

`raytraverse.sky.skycalc.datetime64_2_datetime(timesteps, mer=0.0)`  
convert datetime representation and offset for timezone

#### Parameters

- **timesteps** (`np.array(np.datetime64)`) –
- **mer** (`float`) – Meridian of the time zone. West is +ve

#### Returns

**Return type** np.array(datetime.datetime)

`raytraverse.sky.skycalc.sunpos_degrees(timesteps, lat, lon, mer, builtin=True, ro=0.0)`  
Calculate sun position with local time

Calculate sun position (altitude, azimuth) for a particular location (longitude, latitude) for a specific date and time (time is in local time)

#### Parameters

- **timesteps** (`np.array(np.datetime64)`) –
- **lon** (`float`) – longitude in decimals. West is +ve
- **lat** (`float`) – latitude in decimals. North is +ve
- **mer** (`float`) – Meridian of the time zone. West is +ve
- **builtin** (`bool, optional`) – use skyfield builtin timescale
- **ro** (`float, optional`) – ccw rotation (project to true north) in degrees

**Returns** Sun position as (altitude, azimuth) in degrees

**Return type** np.array([float, float])

`raytraverse.sky.skycalc.sunpos_radians(timesteps, lat, lon, mer, builtin=True, ro=0.0)`  
Calculate sun position with local time

Calculate sun position (altitude, azimuth) for a particular location (longitude, latitude) for a specific date and time (time is in local time)

#### Parameters

- **timesteps** (`np.array(np.datetime64)`) –

- **lon** (*float*) – longitude in decimals. West is +ve
- **lat** (*float*) – latitude in decimals. North is +ve
- **mer** (*float*) – Meridian of the time zone. West is +ve
- **builtin** (*bool*) – use skyfield builtin timescale
- **ro** (*float, optional*) – ccw rotation (project to true north) in radians

**Returns** Sun position as (altitude, azimuth) in radians

**Return type** np.array([float, float])

`raytraverse.sky.skycalc.sunpos_xyz (timesteps, lat, lon, mer, builtin=True, ro=0.0)`  
Calculate sun position with local time

Calculate sun position (altitude, azimuth) for a particular location (longitude, latitude) for a specific date and time (time is in local time)

#### Parameters

- **timesteps** (*np.array (np.datetime64)*) –
- **lon** (*float*) – longitude in decimals. West is +ve
- **lat** (*float*) – latitude in decimals. North is +ve
- **mer** (*float*) – Meridian of the time zone. West is +ve
- **builtin** (*bool*) – use skyfield builtin timescale
- **ro** (*float, optional*) – ccw rotation (project to true north) in degrees

**Returns** Sun position as (x, y, z)

**Return type** np.array

`raytraverse.sky.skycalc.generate_wea (ts, wea, interp='linear')`

`raytraverse.sky.skycalc.coeff_lum_perez (sunz, epsilon, delta, catn)`  
matches `coeff_lum_perez` in `gendaylit.c`

`raytraverse.sky.skycalc.perez_apply_coef (coefs, cgamma, dz)`

`raytraverse.sky.skycalc.perez_lum_raw (tp, dz, sunz, coefs)`  
matches `calc_rel_lum_perez` in `gendaylit.c`

`raytraverse.sky.skycalc.perez_lum (xyz, coefs)`  
matches `perezlum.cal`

`raytraverse.sky.skycalc.scale_efficacy (dirdif, sunz, csunz, skybright, catn, td=10.9735311509)`

`raytraverse.sky.skycalc.perez (sxyz, dirdif, md=None, ground_fac=0.2, td=10.9735311509)`  
compute perez coefficients

#### Notes

to match the results of `gendaylit`, for a given sun angle without associated date, the assumed eccentricity is 1.035020

#### Parameters

- **sxyz** (*np.array*) – (N, 3) dx, dy, dz sun position
- **dirdif** (*np.array*) – (N, 2) direct normal, diffuse horizontal W/m<sup>2</sup>
- **md** (*np.array, optional*) – (N, 2) month day of sky calcs (for more precise eccentricity calc)
- **ground\_fac** (*float*) – scaling factor (reflectance) for ground brightness

- **td** (*np.array, float*) – (N,) dew point temperature in C

**Returns** **perez** – (N, 10) diffuse normalization, ground brightness, perez coefs, x, y, z

**Return type** np.array

`raytraverse.sky.skycalc.sky_mtx(sxyz, dirdif, side, jn=4, **kwargs)`  
generate sky, ground and sun values from sun position and sky values

#### Parameters

- **sxyz** (*np.array*) – sun directions (N, 3)
- **dirdif** (*np.array*) – direct normal and diffuse horizontal radiation (W/m<sup>2</sup>) (N, 2)
- **side** (*int*) – sky subdivision
- **jn** (*int*) – sky patch subdivision  $n = jn^2$
- **kwargs** (*dict, optional*) – passed to perez()

#### Returns

- **skymtx** (*np.array*) – (N, side\*side)
- **grndval** (*np.array*) – (N,)
- **sunval** (*np.array*) – (N, 4) - sun direction and radiance

## 4.6.2 SkyData

**class** `raytraverse.sky.SkyData` (*wea, loc=None, skyro=0.0, ground\_fac=0.15, skyres=10.0, minalt=2.0, mindiff=5.0*)

Bases: object

class to generate sky conditions

This class provides an interface to generate sky data using the perez sky model

#### Parameters

- **wea** (*str np.array*) – path to epw, wea, .npy file or np.array, or .npz file, if loc not set attempts to extract location data (if needed).
- **loc** (*tuple, optional*) – location data given as lat, lon, mer with + west of prime meridian overrides location data in wea (but not in sunfield)
- **skyro** (*float, optional*) – angle in degrees counter-clockwise to rotate sky (to correct model north, equivalent to clockwise rotation of scene)
- **ground\_fac** (*float, optional*) – ground reflectance
- **skyres** (*float, optional*) – approximate square patch size in degrees
- **minalt** (*float, optional*) – minimum solar altitude for daylight masking
- **mindiff** (*float, optional*) – minimum diffuse horizontal irradiance for daylight masking

**property** **skyres**

**property** **skyro**

sky rotation (in degrees, ccw)

**property** **loc**

lat, lon, mer (in degrees, west is positive)

**property** **skydata**

sun position and dirnorm diffhoriz

**write** (*name='skydata', scene=None, compressed=True*)

**property daysteps**

**property daymask**

shape (len(skydata),) boolean array masking timesteps when sun is below horizon

**property fullmask**

**property maskindices**

**property mask**

an additional mask for smtx data

**property smtx**

shape (np.sum(daymask), skyres\*\*2 + 1) coefficients for each sky patch each row is a timestep, coefficients exclude sun

**property sun**

shape (np.sum(daymask), 5) sun position (index 0,1,2) and coefficients for sun at each timestep assuming the true solid angle of the sun (index 3) and the weighted value for the sky patch (index 4).

**property sunproxy**

corresponding sky bin for each sun position in daymask

**smtx\_patch\_sun ()**

generate smtx with solar energy applied to proxy patch for directly applying to skysampler data (without direct sun components can also be used in a partial mode (with sun view / without sun reflection.

**header ()**

generate image header string

**fill\_data (x, fill\_value=0.0)**

**Parameters**

- **x** (*np.array*) – first axis size = len(self.daymask[self.mask])
- **fill\_value** (*Union[int, float], optional*) – value in padded array

**Returns** data in x padded with fill value to original shape of skydata

**Return type** np.array

**masked\_idx (i)**

**sky\_description (i, prefix='skydata', grid=False, sun=True)**

generate radiance scene files to directly render sky data at index i

**Parameters**

- **i** (*int*) – index of sky vector to generate (indexed from skydata, not daymask)
- **prefix** (*str, optional*) – name/path for output files
- **grid** (*bool, optional*) – render sky patches with grid lines
- **sun** (*bool, optional*) – include sun source in rad file

**Returns** basename of 3 files written: prefix\_i (.rad, .cal, and .dat) .cal and .dat must be located in RAYPATH (which can include .) or else edit the .rad file to explicitly point to their locations. note that if grid is True, the sky will not be accurate, so only use this for illustrative purposes.

**Return type** str

**Raises** **IndexError** – if i is not in masked indices

## 4.7 raytraverse.sampler

### 4.7.1 draw

wavelet and associated probability functions.

`raytraverse.sampler.draw.get_detail` (*data*, \**args*, *mode*='reflect', *cval*=0.0)  
convolve a set of kernels with data. computes the sum of the absolute values of each convolution.

#### Parameters

- **data** (*np.array*) – source data (atleast 2D), detail calculated over last 2D
- **args** (*np.array*) – filters
- **mode** (*str*) – signal extension mode (passed to `scipy.ndimage.convolve`)
- **cval** (*float*) – constant value (passed to `scipy.ndimage.convolve`, used when `mode='constant'`)

**Returns** **detail\_array** – 1d array of detail coefficients (row major order) matching size of data

**Return type** `np.array`

`raytraverse.sampler.draw.from_pdf` (*pdf*, *threshold*, *lb*=0.5, *ub*=4)  
generate choices from a numeric probability distribution

#### Parameters

- **pdf** (*np.array*) – 1-d array of weights
- **threshold** (*float*) – the threshold used to determine the number of choices to draw given by `pdf > threshold`
- **lb** (*float*, *optional*) – values below `threshold * lb` will be excluded from candidates (*lb* must be in (0,1))
- **ub** (*float*, *optional*) – the maximum weight is set to `ub*threshold`, meaning all values in `pdf >= ub*threshold` have an equal chance of being selected. in cases where extreme values are much higher than moderate values, but 100% sampling of extreme areas should be avoided, this value should be lower, such as when a region is sampled at a very high resolution ( as is the case with directional sampling). On the other hand, set this value higher for sampling schemes with a low final resolution (like area sampling). If `ub <= 1`, then a deterministic choice is made, returning the `idx` of all values in `pdf > threshold`.

**Returns** **idx** – an index array of choices, size varies.

**Return type** `np.array`

### 4.7.2 BaseSampler

`class raytraverse.sampler.BaseSampler` (*scene*, *engine*, *accuracy*=1.0, *stype*='generic', *samplerlevel*=0)

Bases: `object`

wavelet based sampling class this is a virtual class that holds the shared sampling methods across directional, area, and sunposition samplers. subclasses are named as: {Source}Sampler{SamplingRange}, for instance:

- **SamplerPt: virtual base class for sampling directions from a point**
  - SkySamplerPt: sampling directions from a point with a sky patch source.
  - SunSamplerPt: sampling directions from a point with a single sun source
  - SunSamplerPtView: sampling the view from a point of the sun

- ImageSampler: (re)sampling a fisheye image, useful for testing
- SamplerArea: sampling points on a horizontal planar area with any source type
- SamplerSuns: sampling sun positions (with nested area sampler)

#### Parameters

- **scene** (`raytraverse.scene.Scene`) – scene class containing geometry and formatter compatible with engine
- **engine** – has a `run()` method
- **accuracy** (`float, optional`) – parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling, default is 1.0)
- **stype** (`str, optional`) – sampler type (prefixes output files)

**t0 = 0.00390625**

initial sampling threshold coefficient this value times the accuracy parameter is passed to `raytraverse.sampler.draw.from_pdf()` at level 0

**t1 = 0.0625**

final sampling threshold coefficient this value times the accuracy parameter is passed to `raytraverse.sampler.draw.from_pdf()` at final level, intermediate sampling levels are thresholded by a linearly interpolated between t0 and t1

**lb = 0.25**

lower bound for drawing from pdf passed to `raytraverse.sampler.draw.from_pdf()`

**ub = 8**

upper bound for drawing from pdf passed to `raytraverse.sampler.draw.from_pdf()`

**scene = None**

scene information

**Type** `raytraverse.scene.Scene`

**accuracy = None**

accuracy parameter some subclassed samplers may apply a scale factor to normalize threshold values depending on source brightness (see for instance ImageSampler and SunSamplerPt)

**Type** `float`

**stype = None**

sampler type

**Type** `str`

**weights = None**

holds weights for `self.draw`

**Type** `np.array`

**property levels**

sampling scheme

**Getter** Returns the sampling scheme

**Setter** Set the sampling scheme

**Type** `np.array`

**sampling\_scheme (\*args)**

calculate sampling scheme

**run (mapper, name, levels, plotp=False, log='err', pfish=True, \*\*kwargs)**

trigger a sampling run. subclasses should return a LightPoint/LightField from the executed object state (first call this method with `super().run(...)`)



**Parameters**

- **mapper** (`raytraverse.mapper.Mapper`) – mapper to sample
- **name** (*str*) – output name
- **levels** (*np.array*) – the sampling scheme
- **plotp** (*bool, optional*) – plot weights, detail and vectors for each level
- **log** (*str, optional*) – whether to log level sampling rates can be ‘scene’, ‘err’ or None ‘scene’ - logs to Scene log file ‘err’ - logs to stderr anything else - does not log incremental progress
- **pfish** (*bool, optional*) – if True and plotp, use fisheye projection for detail/weight/vector images.
- **kwargs** – unused

**draw** (*level*)

draw samples based on detail calculated from weights

**Returns**

- **pdraws** (*np.array*) – index array of flattened samples chosen to sample at next level
- **p** (*np.array*) – computed probabilities

**sample\_to\_uv** (*pdraws, shape*)

generate samples vectors from flat draw indices

**Parameters**

- **pdraws** (*np.array*) – flat index positions of samples to generate
- **shape** (*tuple*) – shape of level samples

**Returns**

- **si** (*np.array*) – index array of draws matching samps.shape
- **vecs** (*np.array*) – sample vectors

**sample** (*vecs*)

call rendering engine to sample rays

**Parameters** **vecs** (*np.array*) – sample vectors (subclasses can choose which to use)**Returns** **lum** – array of shape (N,) to update weights**Return type** *np.array***detailfunc** = 'wav'

filter banks for calculating detail choices:

‘haar’:  $[[1 \ -1]]/2, [[1] \ [-1]]/2, [[1, \ 0] \ [0, \ -1]]/2$ ‘wav’:  $[[ -1 \ 2 \ -1]] / 2, [[ -1] \ [2] \ [-1]] / 2, [[ -1 \ 0 \ 0] \ [0 \ 2 \ 0] \ [0 \ 0 \ -1]] / 2$ 

### 4.7.3 SamplerSuns

```
class raytraverse.sampler.SamplerSuns (scene, engine, accuracy=1.0, nlev=3, jitter=True,
                                     ptkwargs=None, areakwargs=None, metric-
                                     set='avglum', 'loggcr')
```

Bases: `raytraverse.sampler.basesampler.BaseSampler`

wavelet based sun position sampling class

**Parameters**

- **scene** (`raytraverse.scene.Scene`) – scene class containing geometry and formatter compatible with engine
- **engine** (`raytraverse.renderer.Rtrace`) – initialized renderer instance (with scene loaded, no sources)
- **accuracy** (`float, optional`) – parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling, default is 1.0)
- **nlev** (`int, optional`) – number of levels to sample
- **jitter** (`bool, optional`) – jitter samples
- **ptkwargs** (`dict, optional`) – kwargs for `raytraverse.sampler.SunSamplerPt` initialization
- **areakwargs** (`dict, optional`) – kwargs for `raytraverse.sampler.SamplerArea` initialization
- **metricset** (`iterable, optional`) – subset of `samplerarea.metric` set to use for sun detail calculation.

**t0** = 0.05  
initial sampling threshold coefficient

**t1** = 0.5  
final sampling threshold coefficient

**ub** = 8  
upper bound for drawing from pdf

**sampling\_scheme** (`mapper`)  
calculate sampling scheme

**get\_existing\_run** (`skymapper, areamapper`)  
check for file conflicts before running/overwriting parameters match call to run

#### Parameters

- **skymapper** (`raytraverse.mapper.SkyMapper`) – the mapping for drawing suns
- **areamapper** (`raytraverse.mapper.PlanMapper`) – the mapping for drawing points

#### Returns

**conflicts** –

a tuple of found conflicts (None for each if no conflicts:

- **suns**: `np.array` of sun positions in vfile
- **ptfiles**: existing point files

**Return type** tuple

**run** (`skymapper, areamapper, specguide=None, recover=True, **kwargs`)  
adaptively sample sun positions for an area (also adaptively sampled)

#### Parameters

- **skymapper** (`raytraverse.mapper.SkyMapper`) – the mapping for drawing suns
- **areamapper** (`raytraverse.mapper.PlanMapper`) – the mapping for drawing points
- **specguide** (`raytraverse.lightfield.LightPlaneKD`) – sky source lightfield to use as specular guide for sampling

- **recover** (*continue run on top of existing files, if false, overwrites*) – previous run.
- **kwargs** – passed to self.run()

**Returns**

**Return type** raytraverse.lightplane.LightPlaneKD

**draw** (*level*)

draw on condition of in\_solarbounds from skymapper. In this way all solar positions are presented to the area sampler, but the area sampler is initialized with a weighting to sample only where there is variance between sun position. this keeps the subsampling of area and solar position independent, escaping dimensional curses.

**Returns**

- **pdraws** (*np.array*) – index array of flattened samples chosen to sample at next level
- **p** (*np.array*) – computed probabilities

**sample\_to\_uv** (*pdraws, shape*)

generate samples vectors from flat draw indices

**Parameters**

- **pdraws** (*np.array*) – flat index positions of samples to generate
- **shape** (*tuple*) – shape of level samples

**Returns**

- **si** (*np.array*) – index array of draws matching samp.shape
- **vecs** (*np.array*) – sample vectors

**sample** (*vecs*)

call rendering engine to sample rays

**Parameters** **vecs** (*np.array*) – sample vectors (subclasses can choose which to use)

**Returns** **lum** – array of shape (N,) to update weights

**Return type** np.array

## 4.7.4 SamplerArea

```
class raytraverse.sampler.SamplerArea(scene, engine, accuracy=1.0, nlev=3,
                                       jitter=True, edgemode='constant',
                                       metricclass=<class raytraverse.evaluate.samplingmetrics.SamplingMetrics>,
                                       metricset=('avglum', 'loggr', 'xpeak', 'ypeak'),
                                       metricfunc=<function amax>, **kwargs)
```

Bases: raytraverse.sampler.basesampler.BaseSampler

wavelet based area sampling class

**Parameters**

- **scene** (*raytraverse.scene.Scene*) – scene class containing geometry and formatter compatible with engine
- **engine** (*raytraverse.sampler.SamplerPt*) – point sampler
- **accuracy** (*float, optional*) – parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling, default is 1.0)
- **nlev** (*int, optional*) – number of levels to sample
- **jitter** (*bool, optional*) – jitter samples

- **edgemode** (`{'reflect', 'constant', 'nearest', 'mirror', 'wrap'}`, *optional*) – default: 'constant', if 'constant' value is set to -self.t1, so edge is always seen as detail. Internal edges (resulting from PlanMapper borders) will behave like 'nearest' for all options except 'constant'
- **metricclass** (`raytraverse.evaluate.BaseMetricSet`, *optional*) – the metric calculator used to compute weights
- **metricset** (*iterable*, *optional*) – list of metrics (must be recognized by metricclass. metrics containing “lum” will be normalized to 0-1)
- **metricfunc** (*func*, *optional*) – takes detail array as an argument, shape: (len(metricset),N, M) and an axis=0 keyword argument, returns shape (N, M). could be np.max, np.sum np.average or us custom function following the same pattern.

**t0** = 0.1  
initial sampling threshold coefficient

**t1** = 0.9  
final sampling threshold coefficient

**ub** = 100  
upper bound for drawing from pdf

**metricclass** = None  
raytraverse.evaluate.BaseMetricSet

**metricset** = None  
iterable

**features** = None  
int:

**sampling\_scheme** (*mapper*)  
calculate sampling scheme

**run** (*mapper*, *name=None*, *specguide=None*, *\*\*kwargs*)  
adapively sample an area defined by mapper

#### Parameters

- **mapper** (`raytraverse.mapper.PlanMapper`) – the pointset to build/run if initialized with points runs a static sampler
- **name** (*str*, *optional*) –
- **specguide** (`raytraverse.lightfield.LightPlaneKD`) – sky source lightfield to use as specular guide for sampling (used by engine of type raytraverse.sampler.SunSamplerPt)
- **kwargs** – passed to self.run()

#### Returns

**Return type** raytraverse.lightplane.LightPlaneKD

**draw** (*level*)  
draw samples based on detail calculated from weights

#### Returns

- **pdraws** (*np.array*) – index array of flattened samples chosen to sample at next level
- **p** (*np.array*) – computed probabilities

**sample\_to\_uv** (*pdraws*, *shape*)  
generate samples vectors from flat draw indices

#### Parameters

- **pdraws** (*np.array*) – flat index positions of samples to generate

- **shape** (*tuple*) – shape of level samples

#### Returns

- **si** (*np.array*) – index array of draws matching samps.shape
- **vecs** (*np.array*) – sample vectors

**sample** (*vecs*)

call rendering engine to sample rays

**Parameters** **vecs** (*np.array*) – sample vectors (subclasses can choose which to use)

**Returns** **lum** – array of shape (N,) to update weights

**Return type** np.array

### 4.7.5 SamplerPt

```
class raytraverse.sampler.SamplerPt(scene, engine, idres=5, fdres=9, accuracy=1.0,
                                     srcn=1, stype='generic', bands=1, samplerlevel=0,
                                     **kwargs)
```

Bases: raytraverse.sampler.basesampler.BaseSampler

wavelet based sampling class for direction rays from a point

#### Parameters

- **scene** ([raytraverse.scene.Scene](#)) – scene class containing geometry and formatter compatible with engine
- **engine** ([raytraverse.renderer.Renderer](#)) – should inherit from raytraverse.renderer.Renderer
- **idres** (*int, optional*) – initial direction resolution (as log2(res))
- **fdres** (*int, optional*) – final directional resolution given as log2(res)
- **accuracy** (*float, optional*) – parameter to set threshold at sampling level relative to final level threshold (smaller number will increase sampling, default is 1.0)
- **srcn** (*int, optional*) – number of sources return per vector by run
- **stype** (*str, optional*) – sampler type (prefixes output files)
- **srcdef** (*str, optional*) – path or string with source definition to add to scene
- **plotp** (*bool, optional*) – show probability distribution plots at each level (first point only)
- **bands** (*int, optional*) – number of spectral bands returned by the engine
- **engine\_args** (*str, optional*) – command line arguments used to initialize engine
- **nproc** (*int, optional*) – number of processors to give to the engine, if None, uses os.cpu\_count()

**bands = None**

number of spectral bands / channels returned by renderer based on given renderopts (user ensures these agree).

**Type** int

**srcn = None**

number of sources return per vector by run

**Type** int

**idres** = None  
initial direction resolution (as log2(res))  
**Type** int  
**sampling\_scheme** (*a*)  
calculate sampling scheme  
**run** (*point*, *posidx*, *mapper=None*, *lpargs=None*, *\*\*kwargs*)  
sample a single point, poosition index handles file naming

**Parameters**

- **point** (*np.array*) – point to sample
- **posidx** (*int*) – position index
- **mapper** (*raytraverse.mapper.ViewMapper*) – view direction to sample
- **lpargs** (*dict*, *optional*) – keyword arguments forwarded to LightPointKD construction
- **kwargs** – passed to BaseSampler.run()

**Returns**

**Return type** *LightPointKD*

## 4.7.6 SkySamplerPt

**class** raytraverse.sampler.SkySamplerPt (*scene*, *engine*, *\*\*kwargs*)

Bases: raytraverse.sampler.samplerpt.SamplerPt

sample contributions from the sky hemisphere according to a square grid transformed by shirley-chiu mapping using rcontrib.

**Parameters**

- **scene** (*raytraverse.scene.Scene*) – scene class containing geometry, location and analysis plane scene: str, optional (required if not reload) space separated list of radiance scene files (no sky) or octree
- **engine** (*raytraverse.renderer.Rcontrib*) – initialized rendering instance

**sample** (*vecs*)

call rendering engine to sample rays

**Parameters** **vecs** (*np.array*) – sample vectors (subclasses can choose which to use)

**Returns** **lum** – array of shape (N,) to update weights

**Return type** np.array

## 4.7.7 SunSamplerPt

**class** raytraverse.sampler.SunSamplerPt (*scene*, *engine*, *sun*, *sunbin*, *speclevel=9*,  
*fdres=10*, *slimit=0.01*, *maxspec=0.2*,  
*stype='sun'*, *\*\*kwargs*)

Bases: raytraverse.sampler.samplerpt.SamplerPt

sample contributions from direct suns.

**Parameters**

- **scene** (*raytraverse.scene.Scene*) – scene class containing geometry, location and analysis plane

- **engine** (`raytraverse.renderer.Rtrace`) – initialized renderer instance (with scene loaded, no sources)
- **sun** (`np.array`) – shape 3, sun position
- **sunbin** (`int`) – sun bin
- **speclevel** (`int, optional`) – at this sampling level, pdf is made from brightness of sky sampling rather than progressive variance to look for fine scale specular highlights, this should be atleast 1 level from the end and the resolution of this level should be smaller than the size of the source
- **slimit** (`float, optional`) – the minimum value in the specular guide considered as a potential specular reflection source, in the case of low vlt glazing, this value should be reduced.
- **maxspec** (`float, optional`) – the maximum value in the specular guide considered as a specular reflection source. above this value it is assumed that these are direct view rays to the source so are not sampled. in the case of low vlt glazing, this value should be reduced. In mixed (high-low) vlt scenes the specular guide will either over sample (including direct views) or under sample (miss specular reflections) depending on this setting.

**specidx = None**

index of level at which brightness sampling occurs

**Type** `int`

**sunpos = None**

sun position x,y,z

**Type** `np.array`

**run** (`point, posidx, vm=None, plotp=False, specguide=None, **kwargs`)

sample a single point, position index handles file naming

#### Parameters

- **point** (`np.array`) – point to sample
- **posidx** (`int`) – position index
- **mapper** (`raytraverse.mapper.ViewMapper`) – view direction to sample
- **lpargs** (`dict, optional`) – keyword arguments forwarded to `LightPointKD` construction
- **kwargs** – passed to `BaseSampler.run()`

#### Returns

**Return type** `LightPointKD`

**draw** (`level`)

draw samples based on detail calculated from weights

**Returns** `pdraws` – index array of flattened samples chosen to sample at next level

**Return type** `np.array`

### 4.7.8 SunSamplerPtView

**class** raytraverse.sampler.SunSamplerPtView (*scene, engine, sun, sunbin, \*\*kwargs*)

Bases: raytraverse.sampler.samplerpt.SamplerPt

sample view rays to a source.

#### Parameters

- **scene** (raytraverse.scene.Scene) – scene class containing geometry, location and analysis plane
- **sun** (np.array) – the direction to the source
- **sunbin** (int) – index for naming

**ub** = 1

deterministic sample draws

**run** (*point, posidx, vm=None, plotp=False, log=None, \*\*kwargs*)

sample a single point, position index handles file naming

#### Parameters

- **point** (np.array) – point to sample
- **posidx** (int) – position index
- **mapper** (raytraverse.mapper.ViewMapper) – view direction to sample
- **lpargs** (dict, optional) – keyword arguments forwarded to LightPointKD construction
- **kwargs** – passed to BaseSampler.run()

#### Returns

Return type *LightPointKD*

### 4.7.9 ImageSampler

**class** raytraverse.sampler.ImageSampler (*scene, vm=None, scalefac=None, method='linear', \*\*kwargs*)

Bases: raytraverse.sampler.samplerpt.SamplerPt

sample image (for testing algorithms).

#### Parameters

- **scene** (raytraverse.scene.ImageScene) – scene class containing image file information
- **scalefac** (float, optional) – by default set to the average of non-zero pixels in the image used to establish sampling thresholds similar to contribution based samplers

### 4.7.10 DeterministicImageSampler

**class** raytraverse.sampler.DeterministicImageSampler (*scene, vm=None, scalefac=None, method='linear', \*\*kwargs*)

Bases: raytraverse.sampler.imagesampler.ImageSampler

**ub** = 1



## 4.8 raytraverse.lightpoint

### 4.8.1 LightPointKD

```
class raytraverse.lightpoint.LightPointKD(scene, vec=None, lum=None, vm=None,
                                           pt=0, 0, 0, posidx=0, src='sky', srcn=1, sr-
                                           cdir=0, 0, 1, calcomega=True, write=True,
                                           omega=None, filterviews=True, sr-
                                           cviews=None, parent=None)
```

Bases: object

light distribution from a point with KDtree structure for directional query

#### Parameters

- **scene** (raytraverse.scene.BaseScene) –
- **vec** (np.array, optional) – shape (N, >=3) where last three columns are normalized direction vectors of samples. If not given, tries to load from scene.outdir
- **lum** (np.array, optional) – reshapeable to (N, srcn). sample values for each source corresponding to vec. If not given, tries to load from scene.outdir
- **vm** (raytraverse.mapper.ViewMapper, optional) – a default viewmapper for image and metric calculations, should match viewmapper of sampler.run() if possible.
- **pt** (tuple list np.array) – 3 item point location of light distribution
- **posidx** (int, optional) – index position of point, will govern file naming so must be set to avoid clobbering writes. also used by spacemapper for planar sampling
- **src** (str, optional) – name of source group. will govern file naming so must be set to avoid clobbering writes.
- **srcn** (int, optional) – must match lum, does not need to be set if reloading from scene.outdir
- **calcomega** (bool, optional) – if True (default) calculate solid angle of rays. This is unnecessary if point will be combined before calculating any metrics. setting to False will save some computation time.
- **write** (bool, optional) – whether to save ray data to disk.
- **omega** (np.array, optional) – provide precomputed omega values, if given, overrides calcomega

**vm** = None  
raytraverse.mapper.ViewMapper

**scene** = None  
raytraverse.scene.Scene

**posidx** = None  
index for point

**Type** int

**pt** = None  
point location

**Type** np.array

**src** = None  
source key

**Type** str

**file** = None  
relative path to disk storage  
**Type** str

**srcdir** = None  
direction to source(s)

**load()**

**dump()**

**property vec**  
direction vector (N,3)

**property lum**  
luminance (N,srcn)

**property d\_kd**  
kd tree for spatial query  
**Getter** Returns kd tree structure  
**Type** scipy.spatial.cKDTree

**property omega**  
solid angle (N)  
**Getter** Returns array of solid angles  
**Setter** sets soolid angles with viewmapper  
**Type** np.array

**calc\_omega** (*write=True*)  
calculate solid angle  
**Parameters** **write** (*bool, optional*) – update/write kdtree data to file

**apply\_coef** (*coefs*)  
apply coefficient vector to self.lum  
**Parameters** **coefs** (*np.array int float list*) – shape (N, self.srcn) or broadcastable  
**Returns** **alum** – shape (N, self.vec.shape[0])  
**Return type** np.array

**add\_to\_img** (*img, vecs, mask=None, skyvec=1, interp=False, omega=False, vm=None, rnd=False*)  
add luminance contributions to image array (updates in place)  
**Parameters**

- **img** (*np.array*) – 2D image array to add to (either zeros or with other source)
- **vecs** (*np.array*) – vectors corresponding to img pixels shape (N, 3)
- **mask** (*np.array, optional*) – indices to img that correspond to vec (in case where whole image is not being updated, such as corners of fisheye)
- **skyvec** (*int float np.array, optional*) – source coefficients, shape is (1,) or (srcn,)
- **interp** (*bool, optional*) – for linear interpolation (falls back to nearest outside of convexhull)
- **omega** (*bool*) – if true, add value of ray solid angle instead of luminance
- **vm** (*raytraverse.mapper.ViewMapper, optional*) –

- **rnd** (*bool, optional*) – use random values as contribution (for visualizing data shape)

**evaluate** (*skyvec, vm=None, idx=None, srcvecoverride=None, srconly=False*)

return rays within view with skyvec applied. this is the analog to add\_to\_img for metric calculations

#### Parameters

- **skyvec** (*int float np.array, optional*) – source coefficients, shape is (1,) or (srcn,)
- **vm** (*raytraverse.mapper.ViewMapper, optional*) –
- **idx** (*np.array, optional*) – precomputed query\_ball result
- **srcvecoverride** (*np.array, optional*) – replace source vector of any source views with this value. For example, by giving the actual sun position, this will improve irradiance calculations (and yield more consistent results when the sampled sun position over an area varies) compared with using the sampled ray direction directly.
- **srconly** (*bool, optional*) – only evaluate direct sources (stored in self.srcviews)

#### Returns

- **rays** (*np.array*) – shape (N, 3) rays falling within view
- **omega** (*np.array*) – shape (N,) associated solid angles
- **lum** (*np.array*) – shape (N,) associated luminances

**query\_ray** (*vecs*)

return the index and distance of the nearest ray to each of vecs

**Parameters** **vecs** (*np.array*) – shape (N, 3) normalized vectors to query, could represent image pixels for example.

#### Returns

- **i** (*np.array*) – integer indices of closest ray to each query
- **d** (*np.array*) – distance (corresponds to chord length on unit sphere) from query to ray in lightpoint. use `translate.chord2theta` to convert to angle.

**query\_ball** (*vecs, viewangle=180*)

return set of rays within a view cone

#### Parameters

- **vecs** (*np.array*) – shape (N, 3) vectors to query.
- **viewangle** (*int float*) – opening angle of view cone

**Returns** **i** – if vecs is a single point, a list of vector indices of rays within view cone. if vecs is a set of point an array of lists, one for each vec is returned.

**Return type** list np.array

**make\_image** (*outf, skyvec, vm=None, res=1024, interp=False, showsample=False*)

**direct\_view** (*res=512, showsample=False, showweight=True, rnd=False, srcidx=None, interp=False, omega=False, scalefactor=1, vm=None, fisheye=True*)  
create an unweighted summary image of lightpoint

**add** (*lf2, src=None, calcomega=True, write=False*)

add light points of distinct sources together results in a new lightpoint with `srcn=self.srcn+srcn2` and `vector size=self.vecsize+vecsize2`

#### Parameters

- **lf2** (*raytraverse.lightpoint.LightPointKD*) –

- **src** (*str*, *optional*) – if None (default), src is “{lf1.src}\_{lf2.src}”
- **calcomega** (*bool*, *optional*) – passed to LightPointKD constructor
- **write** (*bool*, *optional*) – passed to LightPointKD constructor

**Returns** will be subtyped according to self, unless lf2 is needed to preserve data

**Return type** *raytraverse.lightpoint.LightPointKD*

**update** (*vec*, *lum*, *omega=None*, *calcomega=True*, *write=True*, *filterviews=False*)  
add additional rays to lightpoint in place

**Parameters**

- **vec** (*np.array*, *optional*) – shape (N, >=3) where last three columns are normalized direction vectors of samples.
- **lum** (*np.array*, *optional*) – reshapeable to (N, srcn). sample values for each source corresponding to vec.
- **omega** (*np.array*, *optional*) – provide precomputed omega values, if given, overrides calcomega
- **calcomega** (*bool*, *optional*) – if True (default) calculate solid angle of rays. This is unnecessary if point will be combined before calculating any metrics. setting to False will save some computation time. If False, resets omega to None!
- **write** (*bool*, *optional*) – whether to save updated ray data to disk.
- **filterviews** (*bool*, *optional*) – delete rays near sourceviews

## 4.8.2 SrcViewPoint

```
class raytraverse.lightpoint.SrcViewPoint (scene, vecs, lum, pt=0, 0, 0, posidx=0,  
                                           src='sunview', res=64, blursun=1.0,  
                                           srcomega=6.796702357283834e-05)
```

Bases: object

interface for sun view data

**static offset** (*points*, *target*)

**scene** = None  
raytraverse.scene.Scene

**posidx** = None  
index for point

**Type** int

**pt** = None  
point location

**Type** np.array

**src** = None  
source key

**Type** str

**raster** = None  
individual vectors that hit the source (pixels)

**Type** np.array

**lum** = None  
source luminance (average)

**Type** float

**radius** = None  
 source radius

Type float

property **vm**

**add\_to\_img** (*img, vecs, mask=None, coefs=1, vm=None*)

**evaluate** (*sunval, vm=None*)

**direct\_view** (*res=80*)

### 4.8.3 CompressedPointKD

**class** raytraverse.lightpoint.CompressedPointKD (*scene, vec=None, lum=None, write=True, src=None, dist=0.0981, lerr=0.01, plotc=False, \*\*kwargs*)

Bases: raytraverse.lightpoint.lightpointkd.LightPointKD

compressed data needs special methods for making images.

can be initialized either like LightPointKD (but with required omega argument), or if 'scene' is a LightPointKD then a compressed output is calculated from the input

#### Parameters

- **scene** (*BaseScene LightpointKD*) –
- **src** (*str, optional*) – new name for src passed to LightPointKD constructor
- **dist** (*float, optional*) – `translate.theta2chord(np.pi/32)`, primary clustering distance using the birch algorithm, for lossy compression of lf. this is the maximum radius of a cluster, preserving important directional information. clustering acts on ray direction and luminance, with weight of luminance dimension controlled by the lweight parameter.
- **lerr** (*float, optional*) – min-max normalized error in luminance grouping.
- **plotc** (*bool, optional*) – make directview plot of compressed output showing source vectors

**add\_to\_img** (*img, vecs, mask=None, skyvec=1, vm=None, \*\*kwargs*)  
 add luminance contributions to image array (updates in place)

#### Parameters

- **img** (*np.array*) – 2D image array to add to (either zeros or with other source)
- **vecs** (*np.array*) – vectors corresponding to img pixels shape (N, 3)
- **mask** (*np.array, optional*) – indices to img that correspond to vec (in case where whole image is not being updated, such as corners of fisheye)
- **skyvec** (*int float np.array, optional*) – source coefficients, shape is (1,) or (srcn,)
- **vm** (*raytraverse.mapper.ViewMapper, optional*) –

**compress** (*lp, src=None, dist=0.0981, lerr=0.01*)

A lossy compression based on clustering. Rays are clustered using the birch algorithm on a 4D vector (x,y,z,lum) where lum is the sum of contributions from all sources in the LightPoint. In the optional second stage (activated with `secondary=True`) sources are further grouped through agglomerative clustering using an average linkage. this is to help with source identification/matching between LightPoints, but can introduce significant errors to computing non energy conserving metrics in cases where the applied sky vectors have large relative differences between adjacent patches (> 1.5:1) or if the variance in peak luminance above the lthreshold parameter is significant. These include cases where nearby transmitting materials is varied (example: a trans upper above a clear lower), or lthreshold is set too

low. For this reason, it is better to use single stage compression for metric computation and only do glare source grouping for interpolation between LightPoints.

#### Parameters

- **lp** (`LightPointKD`) –
- **src** (`str`, *optional*) – new name for src passed to LightPointKD constructor
- **dist** (`float`, *optional*) – `translate.theta2chord(np.pi/32)`, primary clustering distance using the birch algorithm, for lossy compression of lf. this is the maximum radius of a cluster, preserving important directional information. clustering acts on ray direction and luminance, with weight of luminance dimension controlled by the `lweight` parameter.
- **lerr** (`float`, *optional*) – min-max normalized error in luminance grouping.
- **plotc** (`bool`, *optional*) – make directview plot of compressed output showing source vectors

#### Returns

**Return type** arguments for initializing a CompressedPointKD

## 4.9 raytraverse.lightfield

### 4.9.1 LightField

**class** raytraverse.lightfield.**LightField** (`scene`, `vecs`, `pm`, `src`)

Bases: object

collection of light data with KDtree structure for spatial query

#### Parameters

- **scene** (`raytraverse.scene.BaseScene`) –
- **vecs** (`np.array str`) – the vectors used to organizing the child data as array or file shape (N,3) or (N,4) if 3, indexed from 0
- **pm** (`raytraverse.mapper.PlanMapper`) –
- **src** (`str`) – name of source group.

**property** `samplelevel`

the level at which the vec was sampled (all zero if not provided upon initialization)

**property** `vecs`

indexing vectors (such as position, sun positions, etc.)

**property** `data`

light data

**property** `kd`

kdtree for spatial queries built on demand

**property** `omega`

solid angle or area

**query** (`vecs`)

return the index and distance of the nearest point to each of points

**Parameters** `vecs` (`np.array`) – shape (N, 3) vectors to query.

#### Returns

- **i** (`np.array`) – integer indices of closest ray to each query

- **d** (*np.array*) – distance from query to point in spacemapper.

**query\_ball** (*pts, dist=1.0*)

return set of vectors within a distance

#### Parameters

- **pts** (*np.array*) – shape (N, 3) vectors to query.
- **dist** (*int float*) – radius

**Returns** **i** – if vecs is a single vector, a list of indices within radius. if vecs is a set of points an array of lists, one for each is returned.

**Return type** list *np.array*

**evaluate** (*\*args, \*\*kwargs*)

## 4.9.2 LightPlaneKD

**class** raytraverse.lightfield.**LightPlaneKD** (*scene, vecs, pm, src*)

Bases: raytraverse.lightfield.lightfield.LightField

collection of lightpoints with KDtree structure for positional query

#### property data

LightPointSet

#### property omega

representative area of each point

**Getter** Returns array of areas

**Setter** sets areas

**Type** *np.array*

**evaluate** (*skyvec, points=None, vm=None, metricclass=<class 'raytraverse.evaluate.metricset.MetricSet'>, metrics=None, mask=True, \*\*kwargs*)

**make\_image** (*outf, vals, res=1024, interp=False, showsample=False*)

make an image from precomputed values for every point in LightPlane

#### Parameters

- **outf** (*str*) – the file to write
- **vals** (*np.array*) – shape (len(self.points),) the values computed for each point
- **res** (*int, optional*) – image resolution (the largest dimension)
- **interp** (*bool, optional*) – apply linear interpolation, points outside convex hull of results fall back to nearest
- **showsample** (*bool, optionaal*) – color pixel at sample location red

**direct\_view** (*res=512, showsample=True, vm=None, area=False, metricclass=<class 'raytraverse.evaluate.metricset.MetricSet'>, metrics=('avglum', ), interp=False*)

create a summary image of lightplane showing samples and areas

**add** (*lf2, src=None, calcomega=True, write=False, compress=False*)

add light planes of distinct sources together

### 4.9.3 DayLightPlaneKD

**class** raytraverse.lightfield.DayLightPlaneKD (*scene, vecs, pm, src, includesky=True*)

Bases: raytraverse.lightfield.lightfield.LightField

collection of lightplanes with KDtree structure for sun position query

#### Parameters

- **scene** (raytraverse.scene.BaseScene) –
- **vecs** (*np.array str*) – suns as array or file shape (N,3), (N,4) or (N,5) if 3, indexed from 0
- **pm** (raytraverse.mapper.PlanMapper) –
- **src** (*str*) – name of sun sources group.

**property samplelevel**

the level at which the vec was sampled (all zero if not provided upon initialization)

**property vecs**

indexing vectors (sx, sy, sz, px, py, pz)

**property data**

LightPlaneSet

**property kd**

kdtree for spatial queries built on demand

**property skyplane**

LightPlaneKD of sky results

**query** (*vecs*)

return the index and distance of the nearest vec to each of vecs

**Parameters** **vecs** (*np.array*) – shape (N, 6) vectors to query.

#### Returns

- **i** (*np.array*) – integer indices of closest ray to each query
- **d** (*np.array*) – distance from query to point, positional distance is normalized by the average chord-length between level 0 sun samples divided by the PlanMapper ptres \* sqrt(2).

**evaluate** (*skydata, points, vm, metricclass=<class 'raytraverse.evaluate.metricset.MetricSet'>, metrics=None, logerr=True, datainfo=False, hdr=False, res=1024, interp=False, prefix='img', \*\*kwargs*)

#### Parameters

- **skydata** (raytraverse.sky.Skydata) –
- **points** (*np.array*) – shape (N, 3)
- **vm** (*Union[raytraverse.mapper.ViewMapper, np.array]*) –
- **metricclass** (raytraverse.evaluate.BaseMetricSet, *optional*) –
- **metrics** (*Sized, optional*) –
- **logerr** (*bool, optional*) –
- **datainfo** (*Union[Sized[str], bool], optional*) – include information about source data as additional metrics. Valid values include: [“sun\_pt\_err”, “sun\_pt\_bin”, “sky\_pt\_err”, “sky\_pt\_bin”, “sun\_err”, “sun\_bin”]. If True, includes all. “err” is distance from queried vector to actual. “bin” is the unraveled idx of source vector at a 500^2 resolution of the mapper. order is ignored, info is always in order listed above after the last metric.



- **hdr** (*bool, optional*) – whether to write a 180 degree fisheye hdr image for each point/sky combo (be careful with large sets), named by `img_row(skydata)_pt_vdir.hdr`
- **res** (*int, optional*) – image resolution
- **interp** (*bool, optional*) – interpolate image
- **prefix** (*str, optional*) – prefix for output file naming

**Returns**

**Return type** `raytraverse.lightfield.LightResult`

#### 4.9.4 LightResult

**class** `raytraverse.lightfield.LightResult` (*data, \*axes*)

Bases: `object`

a dense representation of lightfield data analyzed for a set of metrics

this class handles writing and loading results to disk as binary data and intuitive result extraction and re-shaping for downstream visualisation and analysis using one of the “pull” methods. axes are indexed both numerically and names for increased transparency and ease of use.

**Parameters**

- **data** (*np.array str*) – multidimensional array of result data or file path to saved LightResult
- **axes** (*Sequence[raytraverse.lightfield.ResultAxis]*) – axis information

**property data**

**property axes**

**property names**

**static load** (*file*)

**write** (*file, compressed=True*)

**pull** (*\*axes, aindices=None, findices=None, order=None*)

arrange and extract data slices from result

**Parameters**

- **axes** (*Union[int, str]*) – the axes (by name or integer index) to maintain and order the returned result (where axes will be the last N axes of result)
- **aindices** (*Sequence[array\_like], optional*) – sequence of returned axis indices, up to one per each of axes to return a subset of data along these axes.
- **findices** (*Sequence[array\_like], optional*) – sequence of indices for pre-flattened axes to be flattened. give in order matching “order”
- **order** (*Sequence*) – the remainder of the axes in the order in which they should be arranged prior to flattening. by default uses their original order in `self.data`

**Returns**

- **result** (*np.array*) – the result array, will have `1+len(axes)` dims, with the shaped determined by axis size and any indices argument.
- **labels** (*Sequence*) – list of labels for each axis, for flattened axes will be a tuple of broadcast axis labels.
- **names** (*Sequence*) – list of strings of returned axis names

**pull2pandas** (*ax1*, *ax2*, *\*\*kwargs*)

returns a list of dicts suitable for initializing pandas.DataFrames

#### Parameters

- **ax1** (*Union[int, str]*) – the output row axis
- **ax2** (*Union[int, str]*) – the output column axis
- **kwargs** (*dict*) – additional parameters for self.pull()

#### Returns

- **panda\_args** (*Sequence[dict]*) –  
list of keyword arguments for initializing a pandas DataFrame:

```
frames = [pandas.DataFrame(**kw) for kw in panda_args]
```

keys are ['data', 'index', 'columns']

- **frame\_info** (*Sequence[dict]*) –  
information for each data frame keys:
  - name: the summary name of the frame, a concatenation of the flattened axes (for example: “point\_view” implies the frame is extracted for a particular point and view direction)
  - item: the values of the frame from each of the flatten axes (for example: for a name “point\_view” this item = [(x, y, z), (vx, vy, vz)])
  - axis0: the name of the row axis (for example: “sky”)
  - axis1: the name of the column axis (for example: “metric”)

## 4.10 raytraverse.evaluate

### 4.10.1 BaseMetricSet

```
class raytraverse.evaluate.BaseMetricSet(vec, omega, lum, vm, metricset=None,  
                                         scale=179.0, omega_as_view_area=True,  
                                         **kwargs)
```

Bases: object

object for calculating metrics based on a view direction, and rays consisting on direction, solid angle and luminance information

by encapsulating these calculations within a class, metrics with redundant calculations can take advantage of cached results, for example `dgp` does not need to recalculate illuminance when it has been directly requested. all metrics can be accessed as properties (and are calculated just in time) or the object can be called (no arguments) to return a `np.array` of all metrics defined in “metricset”

#### Parameters

- **vm** (`raytraverse.mapper.ViewMapper`) – the view direction
- **vec** (`np.array`) – (N, 3) directions of all rays in view
- **omega** (`np.array`) – (N,) solid angle of all rays in view
- **lum** (`np.array`) – (N,) luminance of all rays in view (multiplied by “scale”)
- **metricset** (*list, optional*) – keys of metrics to return, same as property names
- **scale** (*float, optional*) – scalefactor for luminance

- **kwargs** – additional arguments that may be required by additional properties

```
allmetrics = ['illum', 'avglum', 'gcr', 'density', 'avgraylum']
safe2sum = {'avglum', 'illum'}
defaultmetrics = ['illum', 'avglum', 'gcr']
    available metrics (and the default return set)

classmethod check_metrics (metrics, raise_error=False)
    returns list of valid metric names from argument if raise_error is True, raises an Attribute Error

classmethod check_safe2sum (metrics)
    checks if list of metrics is safe to compute for separate sources before adding

property vec
property lum
property omega
property ctheta
    cos angle between ray and view
property radians
    cos angle between ray and view
property illum
    illuminance
property avglum
    average luminance
property avgraylum
    average luminance (not weighted by omega)
property gcr
    a unitless measure of relative contrast defined as the average of the squared luminances divided by the
    average luminance squared
property density
```

#### 4.10.2 MultiLumMetricSet

```
class raytraverse.evaluate.MultiLumMetricSet (vec, omega, lum, vm, met-
                                             ricset=None, scale=179.0,
                                             omega_as_view_area=True,
                                             **kwargs)
```

Bases: raytraverse.evaluate.basemetricset.BaseMetricSet

object for calculating metrics based on a view direction, and rays consisting on direction, solid angle and luminance information

by encapsulating these calculations within a class, metrics with redundant calculations can take advantage of cached results, for example `dgp` does not need to recalculate illuminance when it has been directly requested. all metrics can be accessed as properties (and are calculated just in time) or the object can be called (no arguments) to return a `np.array` of all metrics defined in “metricset”

##### Parameters

- **vm** (`raytraverse.mapper.ViewMapper`) – the view direction
- **vec** (`np.array`) – (N, 3) directions of all rays in view
- **omega** (`np.array`) – (N,) solid angle of all rays in view
- **lum** (`np.array`) – (N, M) luminance of all rays in view (multiplied by “scale”)

- **metricset** (*list, optional*) – keys of metrics to return, same as property names
- **scale** (*float, optional*) – scalefactor for luminance
- **kwargs** – additional arguments that may be required by additional properties

**property illum**  
illuminance

**property avglum**  
average luminance

**property avgraylum**  
average luminance (not weighted by omega)

**property gcr**  
a unitless measure of relative contrast defined as the average of the squared luminances divided by the average luminance squared

### 4.10.3 MetricSet

```
class raytraverse.evaluate.MetricSet (vec, omega, lum, vm, metricset=None, scale=179.0,  
                                     threshold=2000.0, guth=True, tradius=30.0,  
                                     omega_as_view_area=False, **kwargs)
```

Bases: raytraverse.evaluate.basemetricset.BaseMetricSet

object for calculating metrics based on a view direction, and rays consisting on direction, solid angle and luminance information

by encapsulating these calculations within a class, metrics with redundant calculations can take advantage of cached results, for example dgp does not need to recalculate illuminance when it has been directly requested. all metrics can be accessed as properties (and are calculated just in time) or the object can be called (no arguments) to return a np.array of all metrics defined in “metricset”

#### Parameters

- **vm** ([raytraverse.mapper.ViewMapper](#)) – the view direction
- **vec** (*np.array*) – (N, 3) directions of all rays in view
- **omega** (*np.array*) – (N,) solid angle of all rays in view
- **lum** (*np.array*) – (N,) luminance of all rays in view (multiplied by “scale”)
- **metricset** (*list, optional*) – keys of metrics to return, same as property names
- **scale** (*float, optional*) – scalefactor for luminance
- **threshold** (*float, optional*) – threshold for glaresource/background similar behavior to evalglare ‘-b’ parameter. if greater than 100 used as a fixed luminance threshold. otherwise used as a factor times the task luminance (defined by ‘tradius’)
- **guth** (*bool, optional*) – if True, use Guth for the upper field of view and iwata for the lower if False, use Kim
- **tradius** (*float, optional*) – radius in degrees for task luminance calculation
- **kwargs** – additional arguments that may be required by additional properties

**defaultmetrics** = ['illum', 'avglum', 'gcr', 'ugp', 'dgp']  
available metrics (and the default return set)

**allmetrics** = ['illum', 'avglum', 'gcr', 'density', 'avgraylum', 'ugp', 'dgp', 'taskl

**property src\_mask**  
boolean mask for filtering source/background rays

**property task\_mask**

**property sources**  
vec, omega, lum of rays above threshold

**property background**  
vec, omega, lum of rays below threshold

**property source\_pos\_idx**

**property threshold**  
threshold for glaresource/background similar behavior to evalglare ‘-b’ parameter

**property pws12**  
position weighted source luminance squared, used by dgp, ugr, etc  $\sum(L_s^2 * \omega / P_s^2)$

**property srcillum**  
source illuminance

**property srcarea**  
total source area

**property maxlum**  
peak luminance

**property backlum**  
average background luminance CIE estimate (official for some metrics)

**property backlum\_true**  
average background luminance mathematical

**property tasklum**  
average task luminance

**property dgp**

**property dgp\_t1**

**property log\_gc**

**property dgp\_t2**

**property ugr**

**property ugp**

#### 4.10.4 FieldMetric

```
class raytraverse.evaluate.FieldMetric(vec, omega, lum, vm=None, scale=1.0,
                                         npts=360, close=True, sigma=0.05,
                                         omega_as_view_area=True, **kwargs)
```

Bases: raytraverse.evaluate.basemetricset.BaseMetricSet

calculate metrics on full spherical point clouds rather than view based metrics.

##### Parameters

- **vec** (*np.array*) – (N, 3) directions of all rays
- **omega** (*np.array*) – (N,) solid angle of all rays
- **lum** (*np.array*) – (N,) luminance of all rays (multiplied by “scale”)
- **metricset** (*list, optional*) – keys of metrics to return, same as property names
- **scale** (*float, optional*) – scalefactor for luminance
- **npts** (*int, optional*) – for equatorial metrics, the number of points to interpolate

- **close** (*bool*, *optional*) – include npts+1 duplicate to draw closed curve
- **sigma** (*float*, *optional*) – scale parameter of gaussian for kernel estimated metrics
- **omega\_as\_view\_area** (*bool*, *optional*) – set to true when vectors either represent a whole sphere or a subset that does not match the viewmapper. if False, corrects boundary omega to properly trim to correct size.
- **kwargs** – additional arguments that may be required by additional properties

**property tp**  
vectors in spherical coordinates

**property phi**  
interpolated output phi values

**property eq\_xyz**  
interpolated output xyz vectors

**property avg**  
overall vector (with magnitude)

**property peak**  
overall vector (with magnitude)

**property eq\_lum**  
luminance along an interpolated equator with a bandwidth=sigma

**property eq\_density**  
ray density along an interpolated equator

**property eq\_illum**  
illuminance along an interpolated equator

**property eq\_gcr**  
cosine weighted gcr along an interpolated equator

**property eq\_loggc**

**property eq\_dgp**

#### 4.10.5 SamplingMetrics

```
class raytraverse.evaluate.SamplingMetrics(vec, omega, lum, vm, scale=1.0, peak-  
                                           threshold=0.0, lmin=0, **kwargs)  
    Bases: raytraverse.evaluate.basemetricset.BaseMetricSet  
    default metricset for areasampler  
  
    defaultmetrics = ['avglum', 'loggcr', 'xpeak', 'ypeak']  
        available metrics (and the default return set)  
  
    allmetrics = ['avglum', 'loggcr', 'xpeak', 'ypeak']  
  
    property peakvec  
        average vector (with magnitude) for peak rays  
  
    property xpeak  
        x-component of avgvec as positive number (in range 0-2)  
  
    property ypeak  
        y-component of avgvec as positive number (in range 0-2)  
  
    property loggcr  
        log of global contrast ratio
```

### 4.10.6 PositionIndex

**class** raytraverse.evaluate.PositionIndex (*guth=True*)

Bases: object

calculate position index according to guth/iwata or kim

**Parameters** *guth* (*bool*) – if True, use Guth for the upper field of view and iwata for the lower if False, use Kim

**positions** (*vm, vec*)

calculate position indices for a set of vectors

**Parameters**

- *vm* (*raytraverse.mapper.ViewMapper*) – the view/analysis point, should have 180 degree field of view
- *vec* (*np.array*) – shape (N,3) the view vectors to calculate

**Returns** *posidx* – shape (N,) the position indices

**Return type** np.array

**positions\_vec** (*viewvec, srcvec, up=0, 0, 1*)

### 4.10.7 retina

raytraverse.evaluate.retina.rgcf\_density\_on\_meridian (*deg, mi*)

retinal ganglion cell field density along a meridian as a functional best fit.

the field density accounts for the input region of the ganglion cell to account for displaced ganglion cells. This value is estimate from cone density and the inferred density of midget ganglion cells. see Watson (2014) for important caveats.

**Parameters**

- *deg* (*np.array*) – eccentricity in degrees along meridian
- *mi* (*int*) – meridian index. [0, 1, 2, 3] for Temporal, Superior, Nasal, Inferior.

**Returns** 1d array of retinal ganglion cell density along a meridian

**Return type** np.array

raytraverse.evaluate.retina.rgc\_density\_on\_meridian (*deg, mi*)

retinal ganglion cell density along a meridian as a linear interpolation between non-zero measurements

As opposed to the field density this estimate the actual location of ganglion cells, which could be important to consider for intrinsically photosensitive cells. These are (partially?) responsible for pupillary response. However, even iprgc (may?) receive signals from rods/cones

**Parameters**

- *deg* (*np.array*) – eccentricity in degrees along meridian
- *mi* (*int*) – meridian index. [0, 1, 2, 3] for Temporal, Superior, Nasal, Inferior.

**Returns** 1d array of retinal ganglion cell density along a meridian

**Return type** np.array

raytraverse.evaluate.retina.rgcf\_density\_xy (*xy, func=<function rgcf\_density\_on\_meridian>*)

interpolate density between meridia, selected by quadrant

**Parameters**

- *xy* (*np.array*) – xy visual field coordinates on a disk in degrees (eccentricity 0-90 from fovea)

- **func** (*callable*) – density function along a meridian, takes r in degrees and an axes index: [0, 1, 2, 3] for Temporal, Superior, Nasal, Inferior.

**Returns** 1d array of single eye densities

**Return type** np.array

`raytraverse.evaluate.retina.binocular_density(xy, func=<function  
rgcf_density_on_meridian>)`  
average density between both eyes.

**Parameters**

- **xy** (*np.array*) – xy visual field coordinates on a disk (eccentricity 0-1 from fovea)
- **func** (*callable*) – density function along a meridian, takes r in degrees and an axes index: [0, 1, 2, 3] for Temporal, Superior, Nasal, Inferior. coordinates are for the visual field.

**Returns** 1d array of average binocular densities

**Return type** np.array

`raytraverse.evaluate.retina.rgcf_density(xy)`  
retinal ganglion cell field density

**Parameters** **xy** (*np.array*) – xy visual field coordinates on a disk (eccentricity 0-1 from fovea)

**Returns** 1d array retinal ganglion cell field density according to model by Watson

**Return type** np.array

`raytraverse.evaluate.retina.rgc_density(xy)`  
retinal ganglion cell density (includes displaced ganglion cells)

**Parameters** **xy** (*np.array*) – xy visual field coordinates on a disk (eccentricity 0-1 from fovea)

**Returns** 1d array retinal ganglion cell density according to measurements by Curcio

**Return type** np.array

## 4.11 raytraverse.craytraverse

## 4.12 raytraverse.io

functions for reading and writing

`raytraverse.io.get_nproc(nproc=None)`

`raytraverse.io.set_nproc(nproc)`

`raytraverse.io.unset_nproc()`

`raytraverse.io.np2bytes(ar, dtype='<f')`  
format ar as bytestring

**Parameters**

- **ar** (*np.array*) –
- **dtype** (*str*) – argument to pass to np.dtype()

**Returns**

**Return type** bytes



`raytraverse.io.np2bytefile (ar, outf, dtype='<f', mode='wb')`  
save vectors to file

**Parameters**

- **ar** (*np.array*) – array to write
- **outf** (*str*) – file to write to
- **dtype** (*str*) – argument to pass to `np.dtype()`

`raytraverse.io.bytes2np (buf, shape, dtype='<f')`  
read ar from bytestring

**Parameters**

- **buf** (*bytes, str*) –
- **shape** (*tuple*) – array shape
- **dtype** (*str*) – argument to pass to `np.dtype()`

**Returns**

**Return type** `np.array`

`raytraverse.io.bytefile2np (f, shape, dtype='<f')`  
read binary data from f

**Parameters**

- **f** (*IOBase*) – file object to read array from
- **shape** (*tuple*) – array shape
- **dtype** (*str*) – argument to pass to `np.dtype()`

**Returns** necessary for reconstruction

**Return type** `ar.shape`

`raytraverse.io.version_header ()`  
generate image header string

`raytraverse.io.array2hdr (ar, imgf, header=None)`  
write 2d `np.array (x,y)` to hdr image format

**Parameters**

- **ar** (*np.array*) – image array
- **imgf** (*str*) – file path to right
- **header** (*list*) – list of header lines to append to image header

**Returns**

**Return type** `imgf`

`raytraverse.io.carray2hdr (ar, imgf, header=None)`  
write color channel `np.array (3, x, y)` to hdr image format

**Parameters**

- **ar** (*np.array*) – image array
- **imgf** (*str*) – file path to right
- **header** (*list*) – list of header lines to append to image header

**Returns**

**Return type** `imgf`

`raytraverse.io.hdr2array (imgf, stdin=None)`  
read np.array from hdr image

**Parameters**

- **imgf** (*file path of image*) –
- **stdin** – passed to Popen (imgf should be “”)

**Returns** ar

**Return type** np.array

`raytraverse.io.rgb2rad (rgb)`

`raytraverse.io.rgb2lum (rgb)`

`raytraverse.io.rgbe2lum (rgbe)`  
convert from Radiance hdr rgbe 4-byte data format to floating point luminance.

**Parameters** **rgbe** (*np.array*) – r,g,b,e unsigned integers according to: <http://radsite.lbl.gov/radiance/refer/filefmts.pdf>

**Returns** lum

**Return type** luminance in cd/m<sup>2</sup>

## 4.13 raytraverse.translate

functions for translating between coordinate spaces and resolutions

`raytraverse.translate.norm (v)`  
normalize 2D array of vectors along last dimension

`raytraverse.translate.norm1 (v)`  
normalize flat vector

`raytraverse.translate.uv2xy (uv)`  
translate from unit square (0,1),(0,1) to disk (x,y) <http://psgraphics.blogspot.com/2011/01/improved-code-for-concentric-map.html>.

`raytraverse.translate.uv2xyz (uv, axes=0, 1, 2, xsign=-1)`  
translate from 2 x unit square (0,2),(0,1) to unit sphere (x,y,z) <http://psgraphics.blogspot.com/2011/01/improved-code-for-concentric-map.html>.

`raytraverse.translate.xyz2uv (xyz, normalize=False, axes=0, 1, 2, flipu=True)`  
translate from vector x,y,z (normalized) to u,v (0,2),(0,1) Shirley, Peter, and Kenneth Chiu. A Low Distortion Map Between Disk and Square. Journal of Graphics Tools, vol. 2, no. 3, Jan. 1997, pp. 45-52. Taylor and Francis+NEJM, doi:10.1080/10867651.1997.10487479.

`raytraverse.translate.xyz2skybin (xyz, side, tol=0, normalize=False)`

`raytraverse.translate.skybin2xyz (bn, side)`  
generate source vectors from sky bins

**Parameters**

- **bn** (*np.array*) – bin numbers
- **side** (*int*) – square side of discretization

**Returns** xyz – direction to center of sky patches

**Return type** np.array

`raytraverse.translate.xyz2xy (xyz, axes=0, 1, 2, flip=True)`  
xyz coordinates to xy mapping of angular fisheye projection

`raytraverse.translate.tpnorm(theta, phi)`  
normalize angular vector to 0-pi, 0-2pi

`raytraverse.translate.tp2xyz(theta, phi, normalize=True)`  
calculate x,y,z vector from theta (0-pi) and phi (0-2pi) RHS Z-up

`raytraverse.translate.xyz2tp(xyz)`  
calculate theta (0-pi), phi from x,y,z RHS Z-up

`raytraverse.translate.tp2uv(theta, phi)`  
calculate UV from theta (0-pi), phi

`raytraverse.translate.uv2tp(uv)`  
calculate theta (0-pi), phi from UV

`raytraverse.translate.aa2xyz(aa)`  
calculate altitude (0-90), azimuth (-180,180) from xyz

`raytraverse.translate.xyz2aa(xyz)`  
calculate xyz from altitude (0-90), azimuth (-180,180)

`raytraverse.translate.chord2theta(c)`  
compute angle from chord on unit circle

**Parameters** `c` (*float*) – chord or euclidean distance between normalized direction vectors

**Returns** `theta` – angle captured by chord

**Return type** `float`

`raytraverse.translate.theta2chord(theta)`  
compute chord length on unit sphere from angle

**Parameters** `theta` (*float*) – angle

**Returns** `c` – chord or euclidean distance between normalized direction vectors

**Return type** `float`

`raytraverse.translate.uv2ij(uv, side, aspect=2)`

`raytraverse.translate.uv2bin(uv, side)`

`raytraverse.translate.bin2uv(bn, side, offset=0.5)`

`raytraverse.translate.resample(samps, ts=None, gauss=True, radius=None)`  
simple array resampling. requires whole number multiple scaling.

**Parameters**

- **samps** (*np.array*) – array to resample along each axis
- **ts** (*tuple, optional*) – shape of output array, should be multiple of samps.shape
- **gauss** (*bool, optional*) – apply gaussian filter to upsampling
- **radius** (*float, optional*) – when gauss is True, filter radius, default is the scale ratio - 1

**Returns** to resampled array

**Return type** `np.array`

`raytraverse.translate.rmtx_elem(theta, axis=2, degrees=True)`

`raytraverse.translate.rotate_elem(v, theta, axis=2, degrees=True)`

`raytraverse.translate.rmtx_yp(v)`

generate a pair of rotation matrices to transform from vector `v` to `z`, enforcing a `z`-up in the source space and a `y`-up in the destination. If `v` is `z`, returns pair of identity matrices, if `v` is `-z` returns pair of 180 degree rotation matrices.

**Parameters**  $\mathbf{v}$  (*array-like of size (3,)*) – the vector direction representing the starting coordinate space

**Returns**  $\mathbf{ymtx}$ ,  $\mathbf{pmtx}$  – two rotation matrices to be premultiplied in order to reverse transform, swap order and transpose. Forward:  $(\mathbf{pmtx} @ (\mathbf{ymtx} @ \mathbf{xyz.T})).T$  Backward:  $(\mathbf{ymtx.T} @ (\mathbf{pmtx.T} @ \mathbf{xyz.T})).T$

**Return type** (np.array, np.array)

## TUTORIALS

### 5.1 Directional Sampling Overview

(starting at 4:56:25)

#### 5.1.1 Transcript

##### 1. Title Slide

Hello, my name is Stephen Wasilewski and I am presenting some work I have prepared along with my co-authors. Raytraverse is a new method that guides the sampling process of a daylight simulation.

##### 2. The Daylight Simulation Process

To understand how this method can enhance the daylight simulation process, it is useful to view the process by parts.

##### 2.b

The model describes how geometry, materials, and light sources are represented.

##### 2.c

Sampling determines how the analysis dimensions are subdivided into discrete points to simulate.

##### 2.d

These views rays are solved for by a renderer, yielding a radiance or an irradiance value for each view ray.

##### 2.e

This output is evaluated according to some metric or otherwise preparing the data for interpretation.

##### 3. Assumptions

To make a viable workflow, each of these parts require (whether explicitly or implicitly) a number of assumptions that define the limitations and opportunities of the method. To explain this in practical terms, here are three examples of well known climate based modeling methods for visual comfort.

##### 4. CBDM Methods for Visual Comfort: Ev based

Illuminance based methods, including DGPs (simplified Daylight Glare Probability), limit the directional sampling resolution to a single sample per view direction in order to efficiently sample a larger number of positions and sky conditions throughout a space.

Unfortunately: Even if the employed rendering method perfectly captures the true Illuminance, as a model for discomfort glare it fails to account for scenes where the dominant driver of discomfort is contrast based or due to small bright sources in an otherwise dim scene.

##### 5. CBDM Methods for Visual Comfort: 3/5 Phase

The 3-phase and 5-phase methods focus on the model and render steps. These methods fix the implementations of the material and sky models by discretizing the transmitting materials and sky dome in order to replace some steps of the rendering process with a matrix multiplication.

## **6. CBDM Methods for Visual Comfort: eDGPs**

Like the 5-phase method, The enhanced-simplified daylight glare probability method, developed to overcome the limitations of illuminance only metrics, uses separate sampling and rendering assumptions for the indirect contribution and direct view rays. The adaptation level is captured by an illuminance value, but glare sources are identified with an image calculated for direct view ray contributions only.

## **7. Existing Options For Sampling a Point**

In all of these methods, the sampling is treated as a fixed assumption.

### **7.b**

Either directional sampling is directly integrated into an illuminance by the renderer,

### **7.c**

or a high resolution image is generated.

### **7.d**

This is because at intermediate image resolutions the accuracy of the results can be worse than an illuminance sample, and are unreliable for capturing contrast effects due to small sources.

### **7.e**

So unlike sampling positions or timesteps which can be set at arbitrary spacing and easily tuned to the needs of the analysis, directional sampling is much more of an all or nothing choice; where the additional insights offered by an image can require 1 million times more data than a point sample. But is this really necessary?

### **7.f**

Whether through direct image interpretation or any of the commonly used glare metrics, the critical information embedded in an HDR image is usually simplified to a small set of sources and background, each with a size, direction and intensity. We cannot directly sample this small set of rays because we do not know these important directions ahead of time, but how close can we get?

### **7.g**

The raytraverse method provides a means to bridge the gap between point samples and high resolution images, allowing for a tunable tradeoff between simulation time and accuracy.

Our approach is structured by a wavelet space representation of the directional sampling. It works by applying a set of filters to an image to locate these important details.

## **8. Wavelet Decomposition**

To match our sampling space, we apply these filters to a square image space based on the Shirley-Chiu disk to square transform, which preserves adjacency and area, both necessary for locating true details.

### **8.b**

For each level of the decomposition, The high pass filters, applied across each axis (vertical, horizontal, and in combination) isolate the detail in the image, and the low pass filter performs an averaging yielding an image of half the size. This process is repeated, applying the high pass filters to the approximation, down to some base resolution. Each level of the decomposition stores the relative change in intensity at a particular resolution (or frequency).

### **8.c**

The total size of the output arrays is the same as the original, and can be used to perfectly recover the original signal through the inverse transform.

The benefit to compression comes from the fact that the magnitude of the detail coefficients effectively rank the data in terms of their contribution to the reconstruction. By thresholding the coefficients, less important data can be discarded.

#### 8.d

Even after discarding over 99% of the wavelet coefficients, the main image details are recoverable and only some minor artifacts have been introduced.

This property, that the wavelet coefficients rank the importance of samples at given resolutions, makes detail coefficients useful for guiding the sampling of view rays from a point.

### 9. Reconstruction Through Sampling

This process works as follows:

Beginning with a low resolution initial sampling the large scale features of the scene are captured.

Mimicking the wavelet transform, We apply a set of filters to this estimate and then use the resulting detail coefficients both to find an appropriate number of samples, and as probability distribution for the direction of these samples.

The new sample results returned by the renderer are used to update the estimate, which is lifted to a higher resolution.

This process is repeated up to a maximum resolution, equivalent to (or higher than) what a full resolution image might be rendered at.

### 10. Component Sampling

There are some cases where the wavelet based sampling will not find important details, such as specular views and reflections of the direct sun. Fortunately, because our method uses sky-patch coefficients to efficiently capture arbitrary sky conditions (similar to 3 phase and others), we can structure the simulation process in such a way to compensate for these misses. I refer you to our paper for details on how this works.

### 11. Results

Instead, I'll spend my remaining time sharing a few examples of scenes captured with: our approach, a high resolution reference and a matching uniform resolution image to demonstrate the benefits of variable sampling.

In addition to image reconstructions, the relative deviation from the reference is shown for vertical illuminance (characterizing energy conservation) and UGR (Unified Glare Rating, characterizing contrast), relative errors greater than 10% are highlighted in red.

This very glary scene highlights the different paths that light takes from the sun to the eye, including direct views, rough specular and diffuse reflections of the sun and sky. While the deviation in the low resolution image is unlikely to change a prediction in this case, the large errors show a failure case for uniform low-res sampling.

#### 11.b

A more complex, but also more likely scenario is that roller shades will be closed. While there are open questions on how to evaluate the specular transmission of such materials, raytraverse does not introduce any substantial new errors to this process.

#### 11.c

Raytraverse performs similarly well for partially open venetian blinds.

11.d Including deeper in a space where the floor reflection dominates.

#### 11.e

Raytraverse, without virtual sources or other rendering tricks, handles the case of specular reflections of the direct sun, a difficult problem for low resolution sampling.

#### 11.f

One case that we would expect raytraverse to struggle with would be a high frequency pattern like the dot frit shown here. And while the sampling does miss parts of the pattern, especially the lower contrast areas, enough of the detail is caught to meaningfully understand the image and, because of the direct sun view sampling, maintains high accuracy.

#### 11.g

In cases where more image fidelity is desired, raytraverse can be tuned to increase the sampling rate with a proportional increase in simulation time, but in our paper we show that the low sampling rates previously shown achieve a high level of accuracy for field of view metrics.

## 12. Thank you

Thank you for watching my presentation.

## 5.2 History

### 5.2.1 1.0.4 (2020-11-18)

- create and manage log file (attribute of Scene) for run directories
- possible fix for bug in interpolate\_kd resulting in index range errors
- protect imports in cli.py so documentation can be built without installing

### 5.2.2 1.0.3 (2020-11-10)

- new module for calculating position based on retinal features
- view specifications for directview plotting
- options for samples/weight visibility on directview plotting

### 5.2.3 0.2.0 (2020-09-25)

- Build now includes all radiance dependencies to setup multi-platform testing
- In the absence of craytraverse, sampler falls back to SPRenderer
- install process streamlined for developer mode
- travis ci deploys linux and mac wheels directly to pypi
- **release.sh should be run after updating this file, tests past locally and docs build.**

### 5.2.4 0.1.0 (2020-05-19)

- First release on PyPI.

## 5.3 Index

## 5.4 Search

## 5.5 Todo

## 5.6 Git Info

this project is hosted in two places, a private repo (master branch) at:

<https://gitlab.enterpriselab.ch/lightfields/raytraverse>

and a public repo (release branch) at:



<https://github.com/stephanwaz/raytraverse>

the repo also depends on two submodules, to initialize run the following:

```
git clone https://github.com/stephanwaz/raytraverse
cd raytraverse
git submodule init
git submodule update --remote
git -C src/Radiance config core.sparseCheckout true
cp src/sparse-checkout .git/modules/src/Radiance/info/
git submodule update --remote --force src/Radiance
```

after a “git pull” make sure you also run:

```
git submodule update
```

to track with the latest commit used by raytraverse.



**CITATION**

Either the latest or specific releases of this software are archived with a DOI at zenodo. See: <https://doi.org/10.5281/zenodo.4091318>

Additionally, please cite this [conference paper](#) for a description of the directional sampling and integration method:

Stephen Wasilewski, Lars O. Grobe, Roland Schregle, Jan Wienold, and Marilyne Andersen. 2021. *Raytraverse: Navigating the Lightfield to Enhance Climate-Based Daylight Modeling*. In 2021 Proceedings of the Symposium on Simulation in Architecture and Urban Design.



## **LICENCE**

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## SOFTWARE CREDITS

- Raytraverse uses [Radiance](#)
- As well as all packages listed in the requirements.txt file, raytraverse relies heavily on the Python packages [numpy](#), [scipy](#), and for key parts of the implementation.
- C++ bindings, including exposing core radiance functions as methods to the renderer classes are made with [pybind11](#)
- Installation and building from source uses [cmake](#) and [scikit-build](#)
- This package was created with [Cookiecutter](#) and the [audreyr/cookiecutter-pypackage](#) project template.



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