

Tauray 2.0 User Manual

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Chapter 1

Introduction



Figure 1.1: The logo of Tauray.

Tauray 2.0 is a GPU-accelerated rendering software developed at Tampere University. Its focus is on speed and scalability. Tauray can be used for generating datasets as well as developing real-time rendering algorithms. It is primarily used as a command-line program, which makes scripting and remote use over SSH easy.

This file is the end-user manual; it does not describe how to develop new features for tauray. See `DEVELOPERS.md`¹ for details on how to work with Tauray source code.

This document may not always be perfectly up-to-date. You can get the most up-to-date information on all available options through `tauray --help`. That information is gathered in such a way that the developers cannot accidentally miss updating it when they add new options or modify old ones.

In any case, you should install Tauray and prepare a scene first. Then, you should check that the scene works properly, using the interactive mode or a one-off offline rendering. After that, you should read how Tauray is configured and choose the options based on your needs, and render the final results.

¹`DEVELOPERS.md`

Chapter 2

Installing Tauray

It is recommended that you run Tauray on a PC running Ubuntu 22.04 LTS with one or more Nvidia RTX GPUs.

2.1 Building Tauray

Tauray has some dependencies, so install them first:

```
sudo apt install libvulkan-dev vulkan-validationlayers vulkan-tools imagemagick libnng-dev \
    libcbor-dev libczmq-dev libglm-dev libsdl2-dev
```

Then, you can build Tauray.

```
cmake -S . -B build
cmake --build build
```

You can use Tauray from `build/tauray` (make sure to run it like this, it won't find its internal `data` folder if you do `./tauray` in the build folder!), or you can install it system-wide with

```
sudo cmake --install build
```

The rest of the manual assumes a system-wide installation.

Chapter 3

Scene setup

If you want to skip this part, you can just use the included test model `test/test.glb` instead of the `example.glb` shown in example commands.

Tauray only supports glTF 2.0 files as inputs. They must be in the `.glb` binary format. These files can contain almost everything needed, such as the geometry, cameras, lights and even animations.

There are some features missing in glTF 2.0. To work around these limitations, Tauray comes with a Blender plugin. Usage of this plugin is not required, but recommended, as some scene features will not work properly without it. We will be going over how to install this plugin, author a scene in Blender, and export it for Tauray.

3.1 Blender setup

While not the only possible option, Blender¹ is a great open-source 3D authoring tool that we recommend for preparing scenes for Tauray. Start by installing the newest version, if you don't yet have it.

Next, we'll install the Tauray plugin. First, navigate to the Tauray folder and find the `blender` folder. Make a `.zip` file of the `tr_gltf_extension` file included within (unless it already exists).

Now, you can open Blender. Go to the preferences and open the “Add-ons” section.

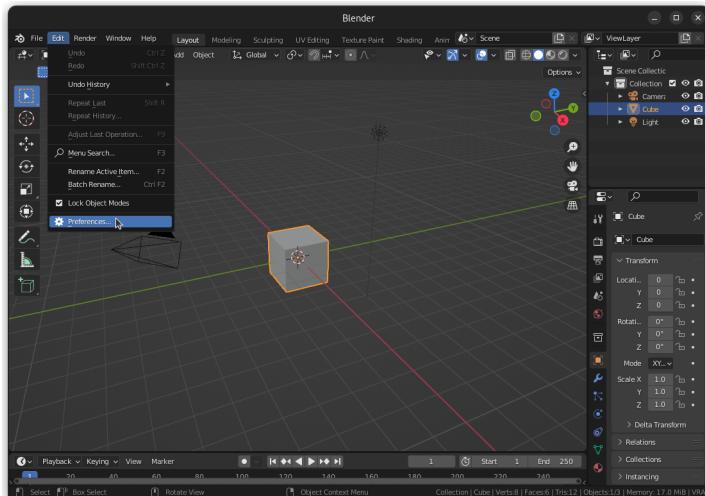


Figure 3.1: Select “Preferences” from the “Edit” drop-down.

Next, press the “Install” button.

From the file dialog that opens, navigate to the Tauray folder. Go to the `blender` directory and find the `.zip` you just created. Then, click the `Install Add-on` button.

¹<https://www.blender.org/>

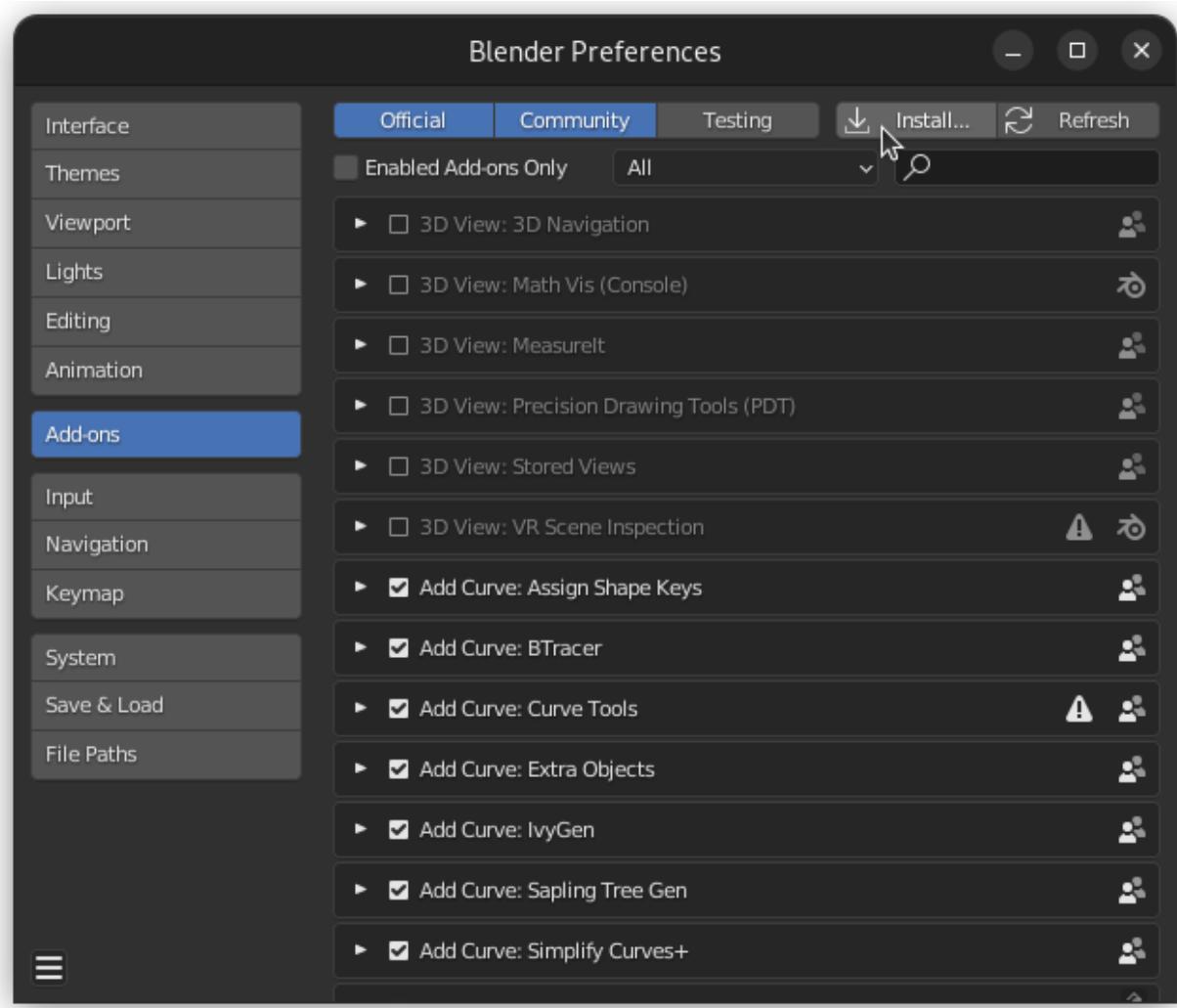


Figure 3.2: Click the “Install...” button in the Add-ons section.

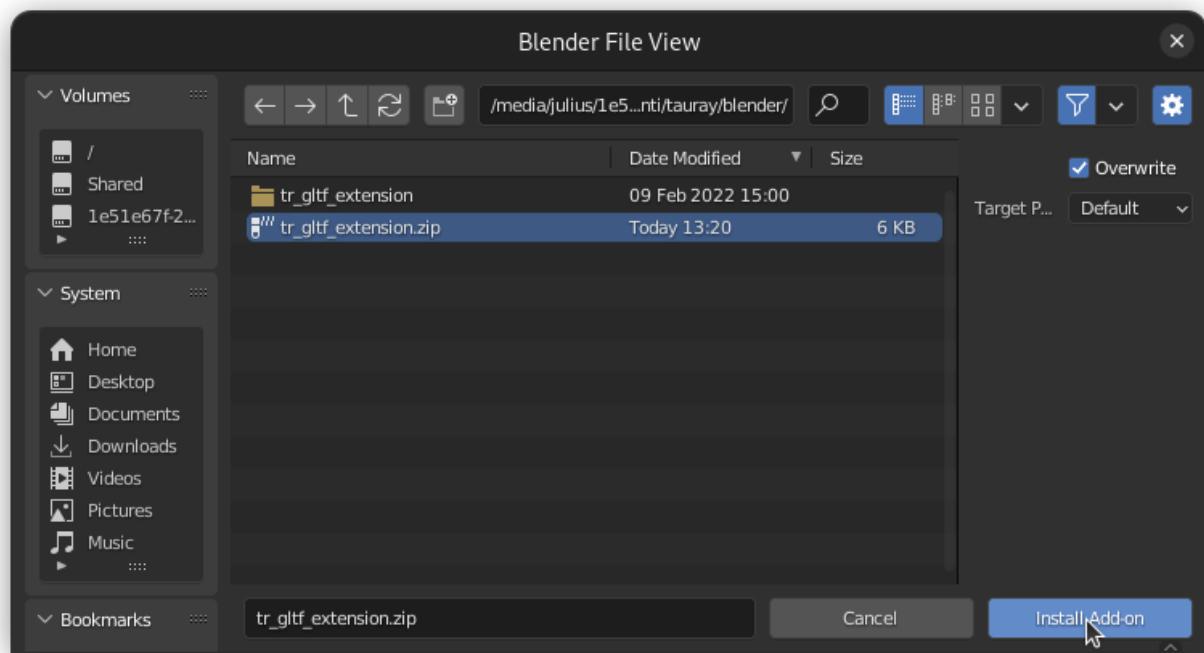


Figure 3.3: Clicking the Install button in the file dialog.

Depending on Blender version and whether you already had the plugin installed, it may be automatically shown in the Add-ons section. If not, search for “tauray”. In any case, enable the “Tauray glTF extension” by checking the checkbox next to the name.

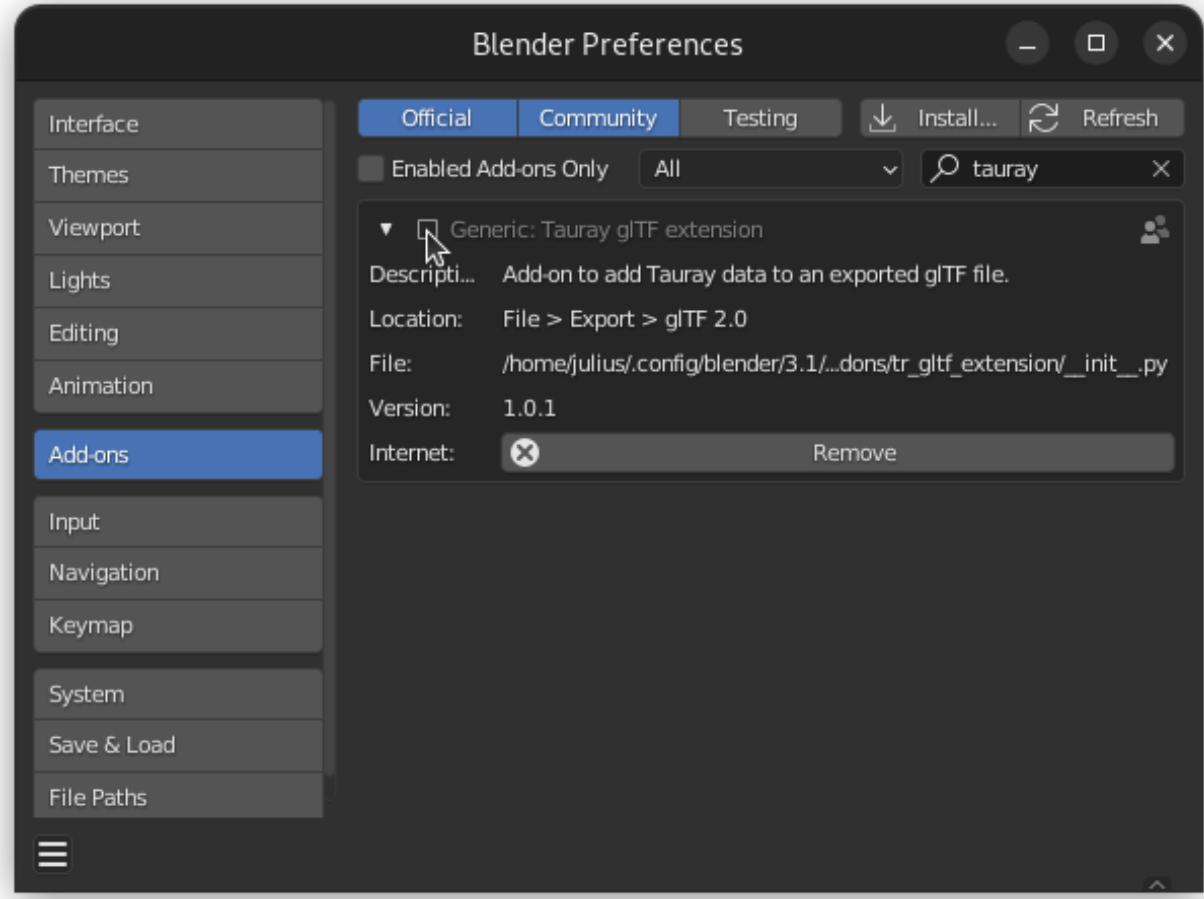


Figure 3.4: Enable the Tauray addon.

You only need to install and enable the addon once, Blender will remember it across projects. You can now close the preferences window and start working with the scene.

3.2 Scene preparation

This is not really the proper place for a full Blender modeling tutorial. If you need to make models yourself, you can use any tutorial you find, but please only use the “Principled BSDF” material. Also, make sure that the scene has a light source! Otherwise, you won’t see anything. Setting up a camera is also important, otherwise you may only get a poorly placed default camera.

You can find high-quality ready-made models with good free licenses from Poly Haven², some Sketchfab collections³, and danish museum scans⁴. You can import some of these in Blender, move them around, add a camera and a light, then export.

Reusing random models found online in the .blend format is often problematic as they tend to use complicated Blender-specific material nodes and features; it’s best to import general-purpose models instead.

Tauray supports rigid and skeletal animations. Morph targets are not supported, so scenes relying on those will not work properly. You should also ensure that all meshes are triangulated, especially if they use normal maps.

²<https://polyhaven.com/models>

³<https://sketchfab.com/nebulousflynn/collections/cc0>

⁴<https://www.myminifactory.com/users/SMK%20-%20Statens%20Museum%20for%20Kunst>

3.3 Exporting from Blender

Once you've designed a suitable scene, it's time to export it from Blender. From the File dropdown, select the Export > glTF 2.0 option.

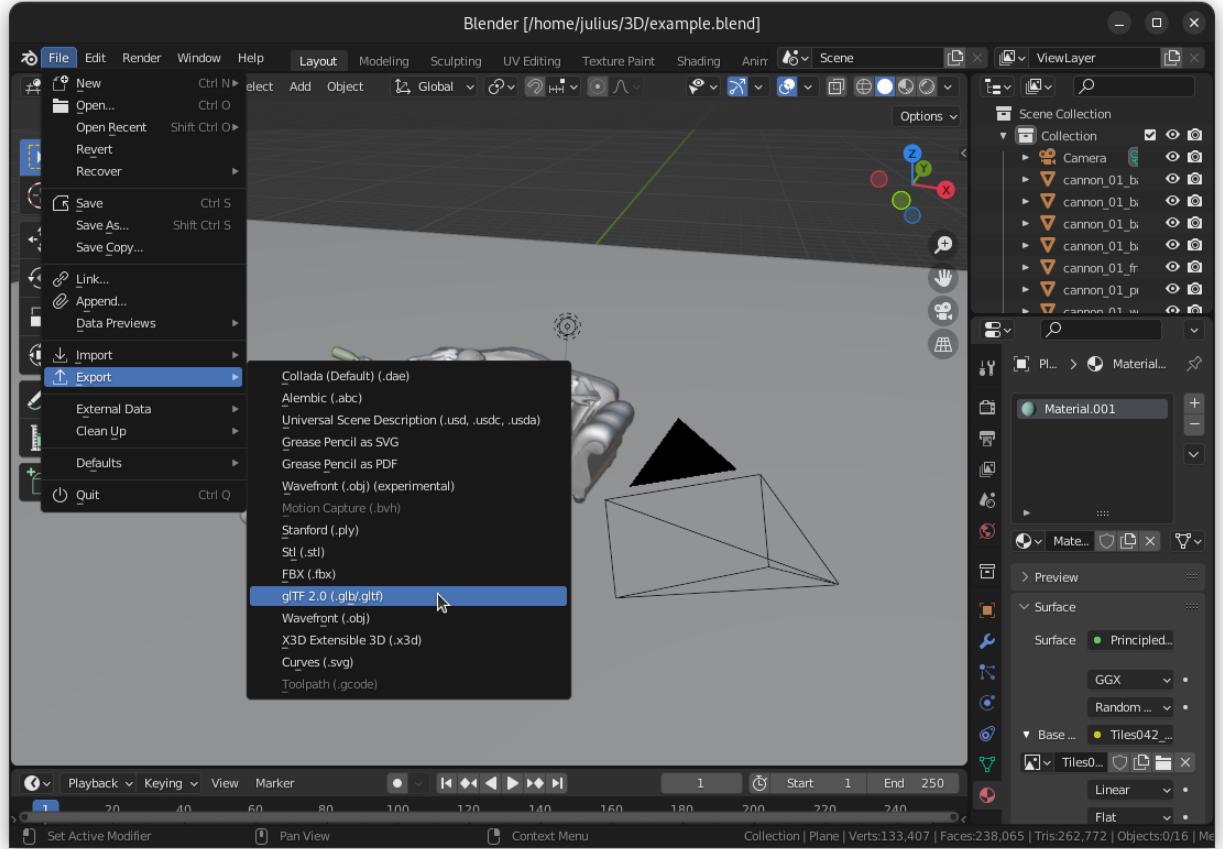


Figure 3.5: Finding the correct export format.

Now, export the model with the settings shown in the image below. You must enable exporting tangents if your scene uses normal maps (and they don't harm you in any case), and cameras and punctual lights. Additionally, lighting mode must be “Unitless” for now.

You can now click the “Export glTF 2.0” button. We are now done with Blender for the extent of this manual.

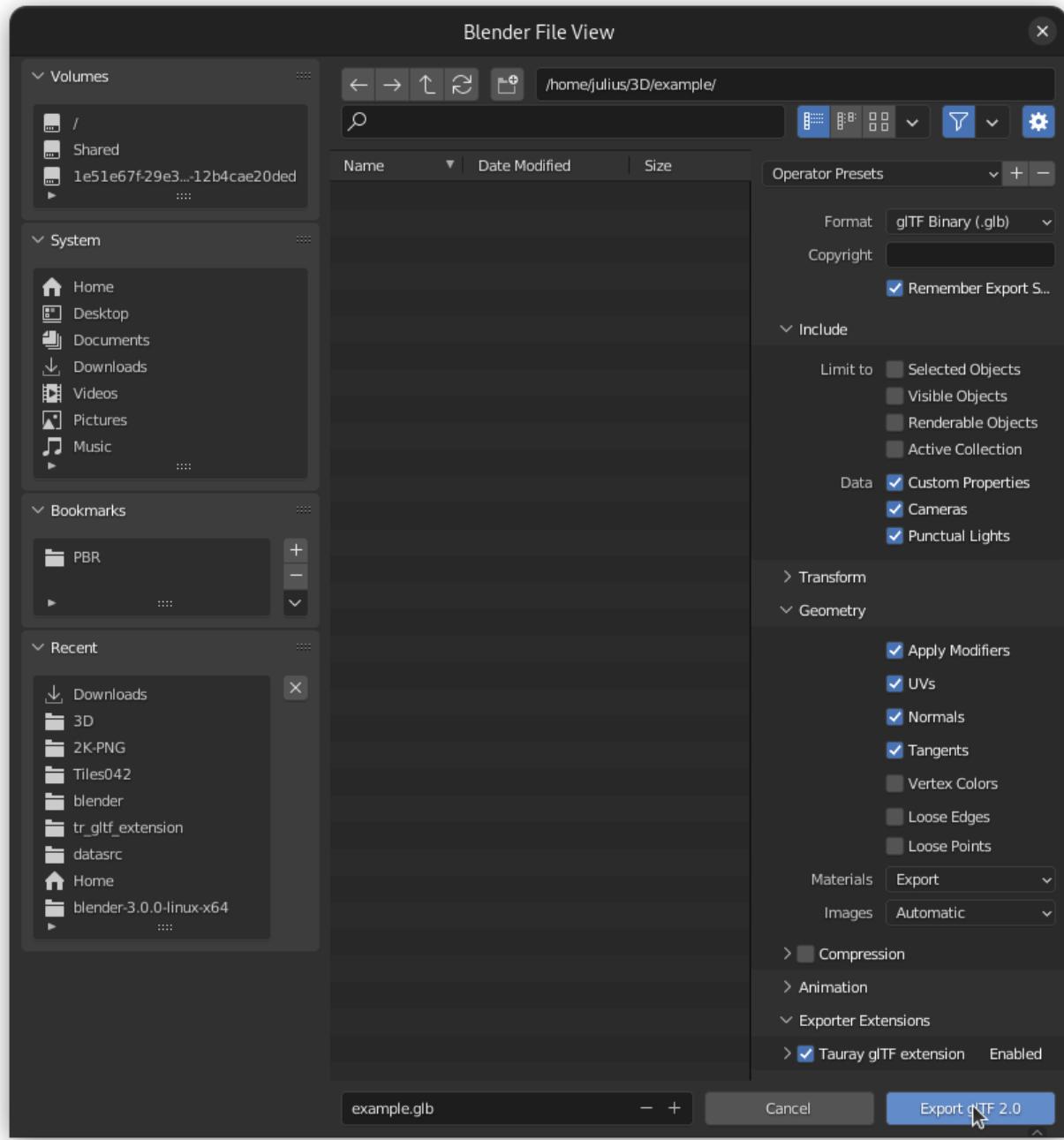


Figure 3.6: You must enable exporting cameras, punctual lights and tangents.

Chapter 4

Interactive rendering

The interactive mode allows you to fly around in your scene in real-time. It is the default mode in Tauray, so you don't have to set any extra parameters to use it!

```
tauray /path/to/example.glb
```

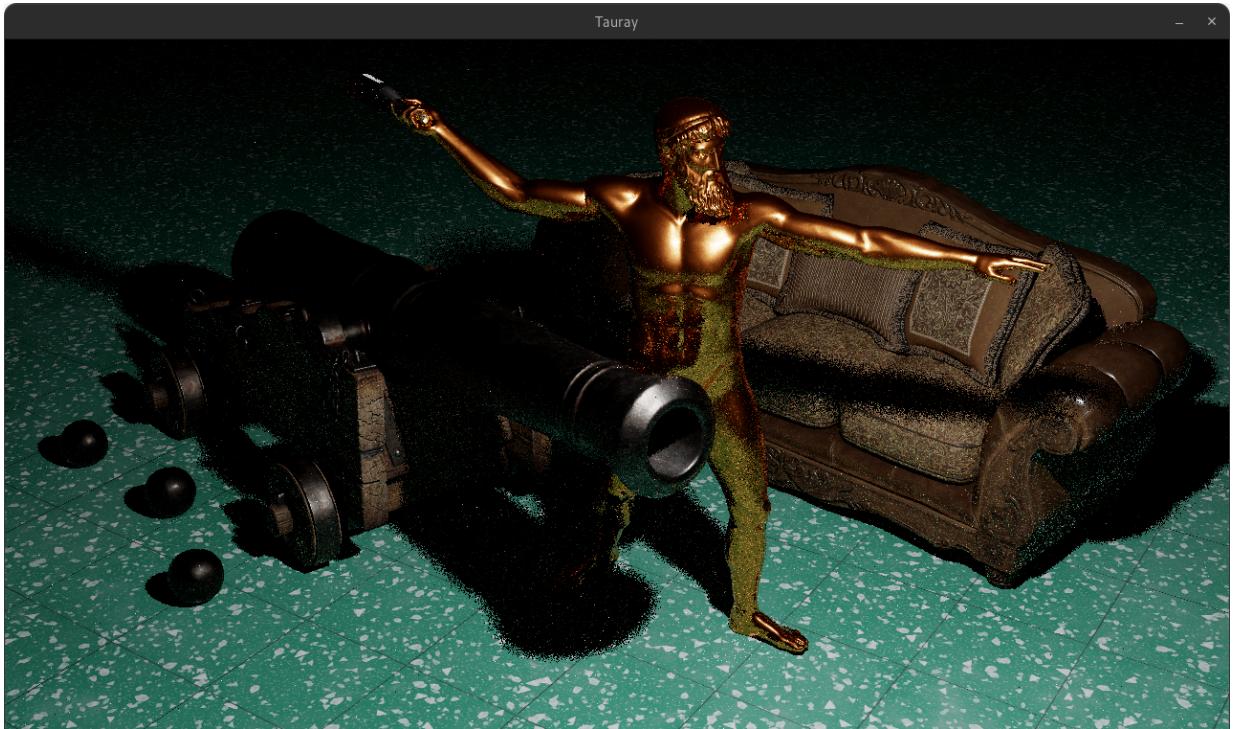


Figure 4.1: Tauray running in interactive mode.

Tauray does not have a loading screen, so large scenes will simply show a black screen until it's done loading.

You can fly around with typical FPS controls. For this reason, Tauray will also grab your cursor while running. The controls are summarized below.

Table 4.1: Controls of Tauray's interactive mode.

Control	Function
Escape	Close the program
W	Fly forwards
S	Fly backwards

Control	Function
A	Fly to the left
D	Fly to the right
Left shift	Descend
Space	Ascend
Mouse move	Turn camera
Scroll up	Speed up flight
Scroll down	Slow down flight
Page up	Switch to next camera
Page down	Switch to previous camera
0	Reset camera to origin
F1	Detach cursor from window
F5	Reload all shaders
T	Print timing info
Return	Pause all animations

You may want to start experimenting with different options now. They are outlined in the Options chapter. Certain (but very few) options are specific to the interactive mode. They are mostly related to windowing.

Chapter 5

Offline rendering

Offline rendering means that instead of an interactive session, you want to leave the computer rendering high-quality images over a long time, ranging from seconds to days. This is what you want to do when you wish to generate datasets, for example.

Offline rendering can be done with the headless mode. This mode does not open a window and doesn't even require a desktop session to exist - it's very suitable for running on a server.

This command will render the same example image as in interactive mode, but as a still image.

```
tauray /path/to/example.glb --filetype/png --headless=output
```

You may want to start experimenting with different options now. They are outlined in the Options chapter. Certain (but very few) options are specific to the headless mode. They are mostly related to the output format and animations.

Chapter 6

Configuration

Configuration of Tauray can be done in three ways: command-line parameters, configuration files and the command-line interface.

The command-line parameters you've already seen earlier in this document: `--filetype/png` is one of these. In general, most command-line parameters start with `--` and have an equals-sign for specifying the value. There's also no whitespace. Then there's also the short flags: `-f`, enables fullscreen mode, for example.

Configuration files have all of the same parameters available, but they use a slightly different syntax. Preceding dashes are omitted, and the equals sign is optional. Whitespace is allowed! Short flags also do not exist in configuration files, so you'll need to use their long names instead (e.g. `fullscreen` instead of `f`). An example configuration file could look as follows:

```
# Let's call this file my_config.cfg
# This is a comment!
film blackman-harris
force-double-sided on
max-ray-depth 5
accumulation on
renderer path-tracer
sampler sobol-z3
samples-per-pixel 1
regularization 0.2

# Config files are also allowed to load each other like this, but please avoid
# creating cycles.
config base_config.cfg
```

If you saved this file as `my_config.cfg`, you can load it in Tauray using the `--config=my_config.cfg` parameter.

Finally, there's the command-line interface (CLI). It is only available in interactive mode. You can access it by detaching control of the Tauray window with F1 and alt-tabbing to the console/terminal where you launched Tauray. Now, you can type in commands with the same syntax as in the configuration files, but they will take place while the program is running!

You can use the CLI to experiment with options without having to restart Tauray constantly. There's also some extra features in the CLI that are not present elsewhere: you can get help for one specific command with the `help command-name` command, close the program with `quit` and print current configuration with `dump`.

A few parameters cannot be changed while the program is running; generally, these are related to windowing or how the scene is loaded. You cannot switch into headless mode, re-select involved GPUs, change display type, etc. without restarting Tauray.

Chapter 7

Options

Tauray has a **lot** of options and most things are customizable. Here, we've gathered the most important ones with example images of their function where applicable. Remember that you can always get the most up-to-date information with `tauray --help`.

In general, options are documented with a list of possible values for them. For example, `--some-algorithm-selection=<algo-a|algo-b|algo-c>` means that `--some-algorithm-selection=algo-b` would select the `algo-b` option of the listed three. Boolean flags (`--some-boolean-flag=<on|off>`) also have a short form: You can simply use `--some-boolean-flag` to set the value to `on`.

While everything here is documented with the command-line parameter syntax (with the `--`, etc.), these options are also usable in configuration files. Just drop the `--` and replace the equals-sign with a space.

7.1 Presets

`--preset=<preset-name>` loads the given preset. “Presets” are configuration files that are shipped with Tauray (in `data/presets/preset-name.cfg`) and can be loaded with a shorthand name.

Preset	Image
<code>accumulation:</code> Interactive renderer that slowly reduces noise when not moving.	
<code>ddish-gi:</code> Interactive rendering with a fast global illumination approximation.	

Preset	Image
denoised : Interactive renderer that produces denoised images.	 A rendering of a golden statue standing next to a couch. The rendering is relatively smooth but shows some noise or artifacts, particularly in the shadows and highlights.
direct : Interactive renderer that computes direct light references.	 A rendering of the same scene using a direct light reference renderer. The lighting is more direct and less diffused than in the denoised version, creating sharper shadows and highlights.
quality : Offline renderer that creates high-quality images fairly quickly.	 A rendering of the scene using an offline quality renderer. This version appears to be the most complete and visually appealing, with highly detailed lighting, sharp highlights, and deep shadows.

Preset	Image
reference: Reference renderer that avoids biased images.	
restir-hybrid: Hybrid renderer between ddish-gi and restir.	

Presets are subject to minor changes every now and then, so don't rely on specific behaviour (except for the **reference** preset).

7.2 Fullscreen

-f or **--fullscreen=<on|off>** enable fullscreen mode. Runs the interactive Tauray session in fullscreen at the native resolution. By default, Tauray runs in a window instead.

7.3 Output resolution

-h=<integer> and **--height=<integer>** set the output height, **-w=<integer>** and **--width=<integer>** set the output width. The default output size is 1280x720. The output size is the window size in interactive mode and the output image file size in offline rendering.

7.4 Replay mode

-r or **--replay=<on|off>** enable the replay mode. This means that even in the interactive mode, the user does not have camera control. Instead, it follows the animation, if present. This option is also forced on by the headless rendering mode.

7.5 Silent

--silent disables all printing except errors and timing data (if the latter is requested).

7.6 Timing

`-t` or `--timing=<on|off>` make Tauray print timing information on every frame. If you are benchmarking Tauray performance, please only use this with interactive mode. If you need to use headless mode regardless, ensure that its output filetype is `none`, so that your benchmark doesn't end up just measuring your disk speed instead.

By default, Tauray uses its own timing format, as presented below:

```
FRAME 617:
DEVICE 0:
[skinning] 0.001856 ms
[scene update] 0.051872 ms
[light BLAS update] 0.026624 ms
[path tracing (1 viewports)] 1.55018 ms
[distribution frame from host] 0.283552 ms
[stitch (1 viewports)] 0.047136 ms
[tonemap (1 viewports)] 0.032608 ms
DEVICE 1:
[skinning] 0.001568 ms
[scene update] 0.050688 ms
[light BLAS update] 0.02576 ms
[path tracing (1 viewports)] 1.1321 ms
[distribution frame to host] 1.26109 ms
HOST: 3.64286 ms
```

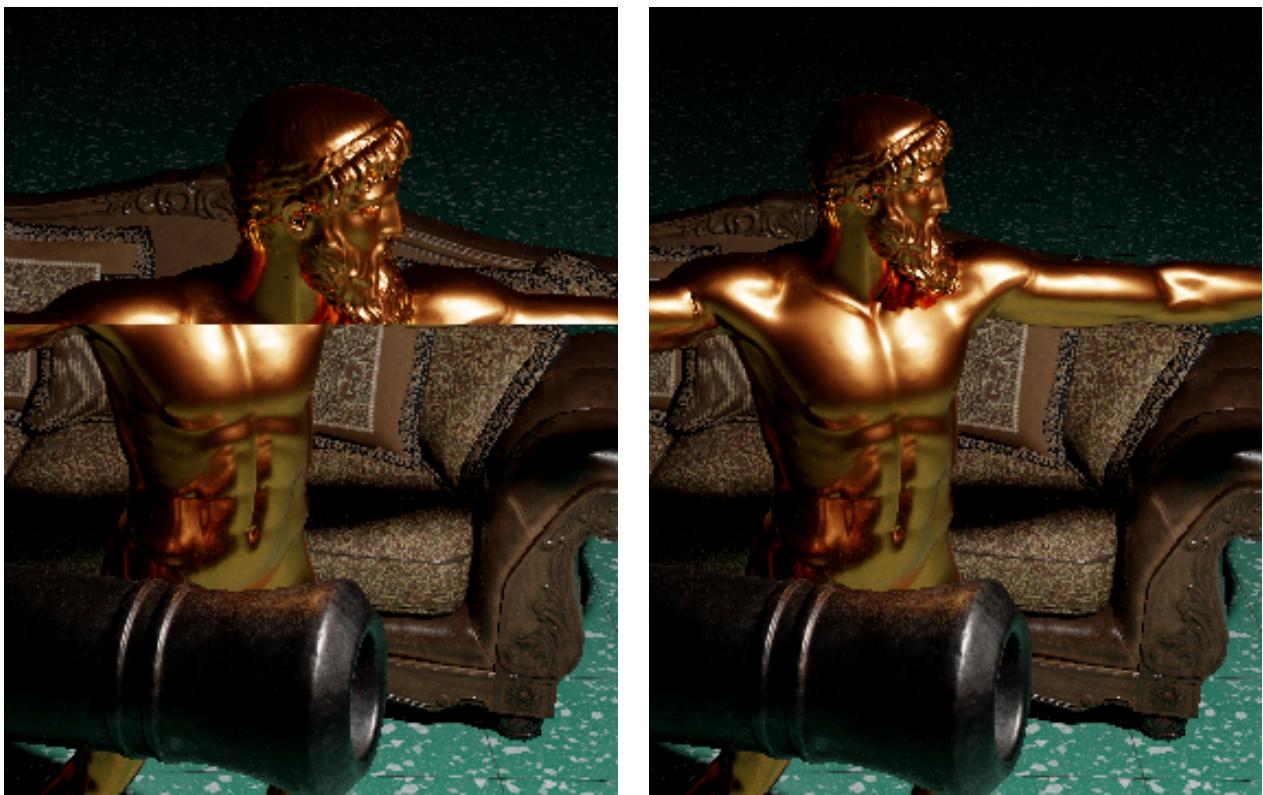
Additionally, you can change the timing output format into “Trace Event Format” with `--trace=trace-event-format`. The output can be viewed in Chrome’s `about://tracing`. This is particularly useful with `--timing-output=<filename>`, which forwards output to another file.

You get the frame index (the first frame is `FRAME 0`) and timing for each rendering stage on every device. The `HOST` timing means the overall frametime as measured on the CPU: this is what you want to use for benchmarks, excluding the first and last few values which wind the in-flight frames up and down.

You can also press the `T` key while Tauray is running to print the same timing info for one frame only.

7.7 Vertical synchronization

`-s` or `--vsync=<on|off>` can be used to enable vertical synchronization. This is only meaningful in interactive mode and is used to combat display tearing artifacts occurring in motion:



Tearing with `--vsync=off.`

No tearing with `--vsync=on`

These artifacts are not any Tauray-specific issue, they occur in any program that doesn't do vertical synchronization. It's caused by the image being only partially updated when the display is refreshing.

Important! Do not benchmark Tauray with vertical sync enabled! It intentionally limits the framerate!

7.8 Throttle

`--throttle=<framerate>`

can be used to force Tauray's framerate to be below the given rate, in interactive modes. This is useful for debugging issues that are hard to see at high framerates, and can help conserve battery life when running on a laptop.

7.9 Validation

`--validation=<on|off>` sets whether Vulkan validation layers are enabled or not. They're good for debugging and reporting issues, but bad when benchmarking. Most presets explicitly disable validation for performance reasons.

7.10 Progress bar

`-p` can be used to display an ASCII progress bar, which estimates how long the rendering is going to take at the current rate. It is only available in conjunction with `--headless`.

7.11 Renderer

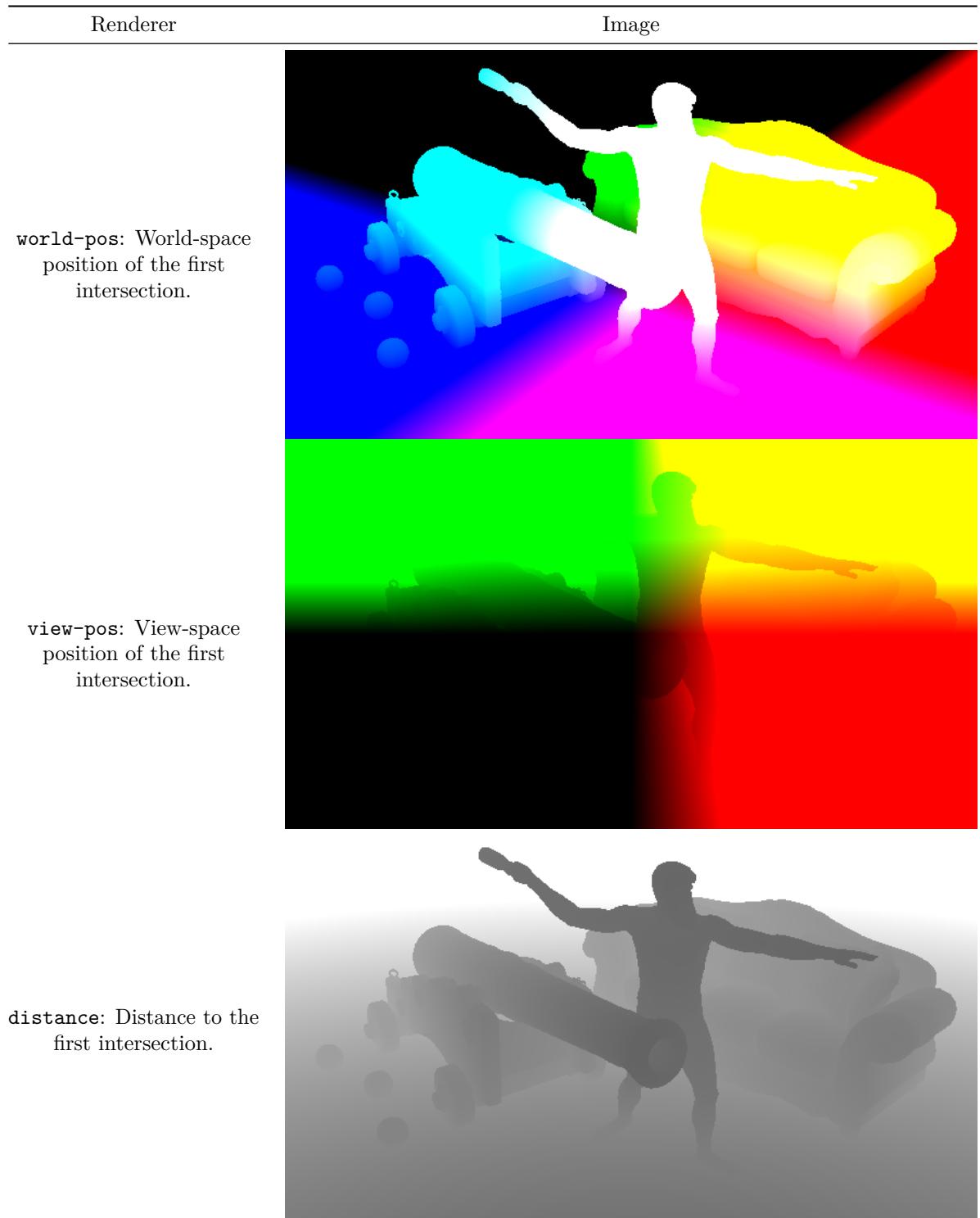
`--renderer=<renderer-name>` sets the renderer used by Tauray. Tauray comes with many different renderers. Below is a table of each, with example images. The default renderer is the path tracer.

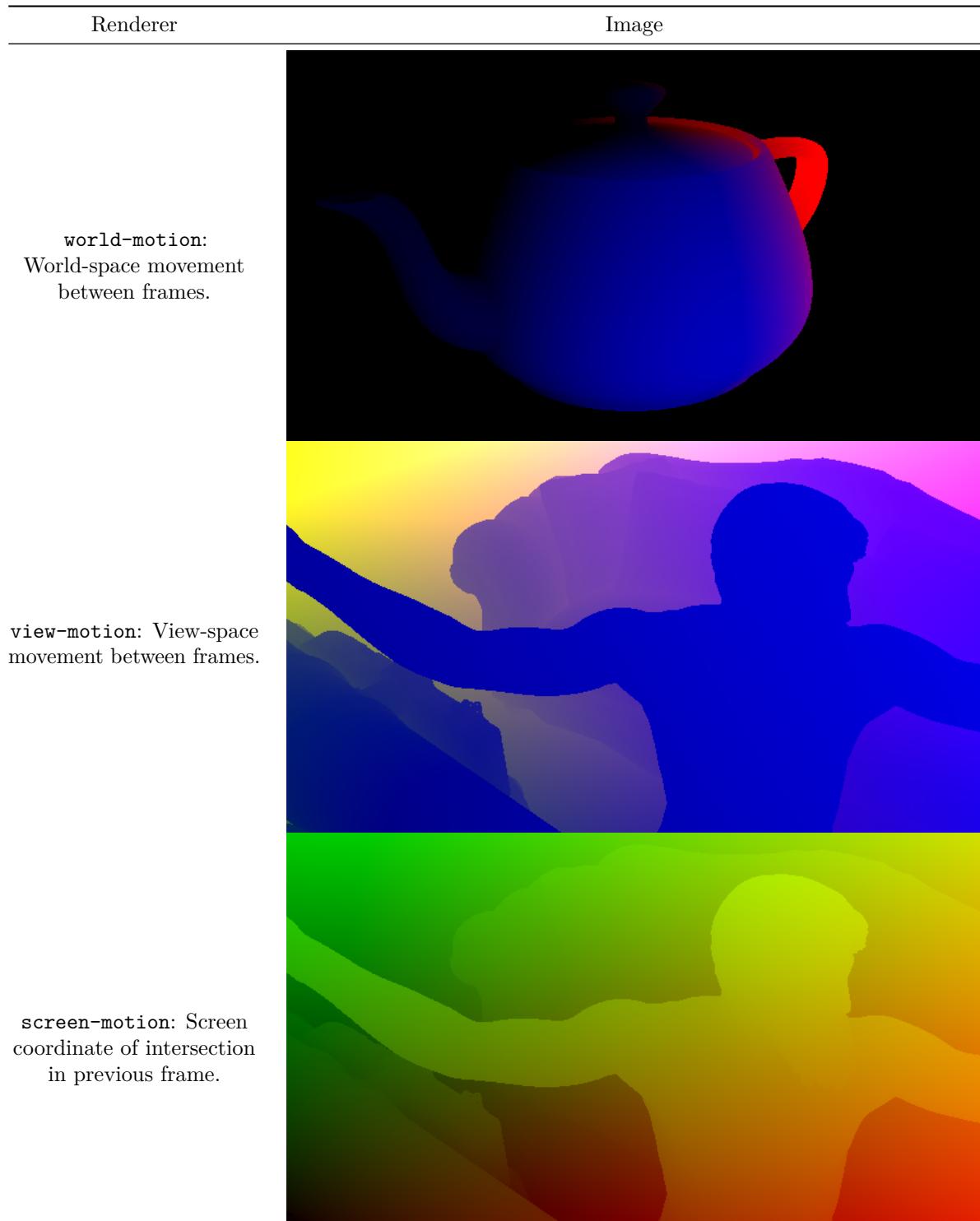
Table 7.3: Summary of renderers included in Tauray.

Renderer	Image
path-tracer: Photorealistic algorithm susceptible to noise.	
direct: Ray traced direct light only.	
raster: Naive rasterization with shadow mapping.	

Renderer	Image
dshgi: DDISH-GI.	
restir: ReSTIR DI/PT for real-time rendering.	
restir-hybrid: ReSTIR hybridized with DDISH-GI.	

Renderer	Image
albedo: Albedo of the first intersection.	
world-normal: World-space of the first intersection.	
view-normal: View-space normal of the first intersection.	





Renderer	Image
<pre>instance-id: Color channels are geometry-dependent IDs.</pre>	

7.11.1 Primary renderers

These are the `path-tracer`, `restir`, `raster` and `dshgi` renderers. Many further options only affect some of these renderers.

There's two that you'll most likely be interested in. `restir` is an implementation of the state-of-the-art ReSTIR DI/GI/PT algorithms, and has very low noise levels (by real-time rendering standards). These methods are unbiased by default.

For offline rendering or simpler real-time rendering needs, you'll want to be running `path-tracer`, which is just a very normal forward path tracer with MIS, NEE and BSDF importance sampling.

If you can't run Tauray normally due to missing ray tracing support, you may still be able to run the `raster` renderer. But in that case, there's hardly any reason to be running Tauray, anyway...

`dshgi` is the underlying renderer for DDISH-GI. Note that when creating scenes for DDISH-GI (`dshgi`), you should place an "Irradiance Volume" that covers the scene in Blender. DDISH-GI will use this volume for its probe placement. The resolution selected in Blender for the irradiance volume will also be used by Tauray.

7.11.2 ReSTIR DI / GI / PT

The ReSTIR implementation in Tauray is extremely configurable, to the point that all three big variants can be achieved with simple configuration variables. See "A Gentle Introduction to ReSTIR¹ to learn further details of what these parameters do.

The implementation acts as ReSTIR DI if `--max-ray-depth=2`, otherwise it's PT. The special `restir-hybrid` renderer is similar to ReSTIR GI. It only does one bounce, after which lighting is gathered from DDISH-GI probes and punctual lights. Direct explicit lighting uses shadow maps also, as this helps with performance and isn't always noticeable if PCSS is configured properly.

`--restir.max-confidence=<int>` sets the maximum confidence of a reservoir. Large values have generally lower noise, but increase correlation between temporal frames. The default is 16, and you probably shouldn't go any higher. While even large confidences don't technically cause bias over time, overconfidence can backfire via large correlated areas:

¹<https://intro-to-restir.cwyman.org/>



Too high confidence can cause VPL or MLT-like artefacts, depending on the selected shift mapping.

`--restir.temporal-reuse=<on|off>` is on by default. It enables the temporal feedback loop, which makes ReSTIR do its party trick, the explosively increasing sample quality. It's also the cause of temporal correlation, and is generally harmful if you want to accumulate and converge an image.

`--restir.canonical-samples=<int>` sets the number of canonical samples, e.g. number of new samples injected into the feedback loop per frame. It's somewhat similar to SPP in a path tracer. Higher numbers = less noise but the performance cost is linear.

`--restir.spatial-samples=<int>` sets the amount of neighbors considered for spatial reuse. 0 disables spatial reuse. The default is 2, which is quite low for ReSTIR literature, but it's pretty good for real-time still.

`--restir.passes=<int>` defaults to one. It's the number of successive spatial reuse passes per frame. It can help good samples cover a large distance even without temporal reuse.

`--restir.sample-spatial-disk=<on|off>` selects how the spatial neighbors are searched. It's enabled by default, and searches from a surface-aligned disk. If disabled, the search area is a screen-space disk.

`--restir.shift-mapping-type=<reconnection-shift|random-replay-shift|hybrid-shift>` defaults to `reconnection-shift`.

`reconnection-shift` is the fastest and works quite well in scenes with fairly high roughnesses, but performs no better than a regular path tracer with mirror-like surfaces.

`random-replay-shift` is a general method that produces higher noise levels and is the slowest, but kind of deals with any light transport issues. Its weaknesses are somewhat similar to Kelemen-style MLT.

`hybrid-shift` aims to combine the good noise level and performance of `reconnection-shift` and robustness `random-replay-shift`. It's generally good, and just a bit slower than `reconnection-shift` (depending on scene). There's a scene-dependent parameter though, `--restir.reconnection-scale=<float>`, which controls the minimum ray length considered for reconnection. You may need to adjust it if you see artifacting in concave corners.

`--restir.max-search-radius=<float>` controls the maximum distance for spatial neighbor search.
`--restir.min-search-radius=<float>` controls the minimum distance (this should be non-zero to avoid sampling the original pixel itself).

By default, the implementation is unbiased and all `assume-*` are off. You can enable specific biases / assumptions for increased performance.

`--restir.assume-unchanged-material=<on|off>` assumes that the material has not changed between frames in temporal reuse, saving some bandwidth in material storage and reading.

`--restir.assume-unchanged-acceleration-structure=<on|off>` assumes that geometry in the acceleration structures has not changed between frames. If there are moving objects in the scene, this introduces brightening and darkening bias near them.

`--restir.assume-unchanged-reconnection-radiance=<on|off>` lets the temporal reuse assume that radiance incoming to the reconnection vertex has not changed. This saves re-tracing the rest of the path in temporal reuse, and helps quite a bit with performance. Of course, it biases with movement or lighting changes.

`--restir.assume-unchanged-temporal-visibility=<on|off>` lets the temporal reuse assume that reconnection will not be blocked when shifting previous samples to the new frame. Again, this breaks with movement and sometimes also with rounding errors from the selection of the previous pixel.

7.11.3 Feature buffer / AOV renderers

These are the `albedo`, `world-normal`, `view-normal`, `world-pos`, `view-pos`, `distance`, `world-motion`, `view-motion`, `screen-motion`, and `instance-id` renderers. They all use a common backend, which is why most options affecting feature buffers tend to affect all of them equally.

In the table above, many color channels appear black or extremely bright. This is because the PNG files cannot preserve the entire range of values. Feature buffers are internally rendered to floating-point buffers, so you probably don't want to be using `.png` files for feature buffer datasets.

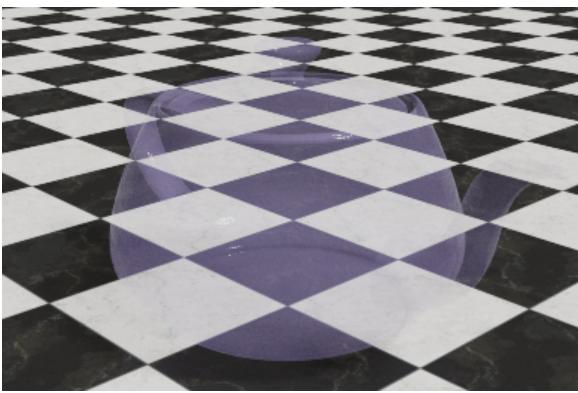
Instead, use `.exr`, which preserves negative and values larger than 1. `.exr` is the default image type in Tauray so that you wouldn't accidentally lose data if you forgot to specify the filetype.

Particularly, the `instance-id` renderer places the instance ID in the red color channel, triangle index in the green color channel, and mesh index in the blue color channel. They are all integers, so `.png` will not suffice!

7.12 Alpha to transmittance

`--alpha-to-transmittance=<on|off>`

A crude approximation that turns alpha + albedo color into colored transmittance for all materials in the scene whose constant alpha factor is below 1.0. It is disabled by default. You can use this to get transmittance with some `.glb` files that have not been exported with Tauray's Blender plugin.



A scene with an alpha blended teapot.



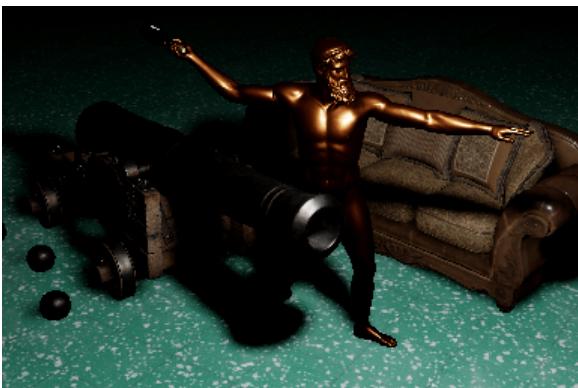
The same scene with
--alpha-to-transmittance.

--transmittance-to-alpha=<number> is simply the inverse operation, but it has very few use cases. The value is the minimum alpha assigned to materials converted this way.

7.13 Ambient

--ambient=<r,g,b>

The **raster** renderer does not properly estimate surrounding indirect lighting. Instead, it applies a constant light, called “ambient light”, to every surface in the scene. You can adjust that ambient light’s color and intensity with this parameter.



raster rendering with --ambient=0,0,0.



The same scene with --ambient=0.1,0.2,0.4.

Setting ambient to zero is equivalent to simulating direct light only. Note that this parameter does nothing in the **dshgi** or **path-tracer** renderers, as they don’t use an ambient light.

7.14 Animation

--animation or --animation=<name>

Tauray supports animations, but they are not running by default. You can add the **--animation** flag to play animations. Without a string parameter, the flag just plays the first found animation for everything in the scene. If you give a string, it tries to play animations with that name.

Both rigid and skeletal animations are supported. The camera and lights can be animated as well. Note that camera animation will not work in interactive mode, because the camera is controlled by the user instead. If you want to preview an animation, you can use the **-r** flag (replay mode) to forego user control of the camera.

By default, `headless` mode (offline rendering) will render all frames of the full animation with this flag specified. You can limit the number of frames to something lower with `--frames=<integer>`.

If your animation render is interrupted without finishing, you can easily continue from the frame you left off with `--skip-frames=<integer>`. Also, you can skip all rendering entirely with `--skip-render`. That way, you can save camera logs without having to actually render or save images.

In replay and offline rendering modes, you can set the simulated framerate for the animation with `--framerate=<number>`. It defaults to 60 fps.

7.15 Aspect ratio

`--aspect-ratio=<number>`

By default, Tauray assumes that pixels are square. If you want them to be something else, you can force the image aspect ratio with `--aspect-ratio`.



The default aspect ratio, which is 1.5 in this case.



The same scene with `--aspect-ratio=0.75`.

7.16 Camera

There's many ways to modify the camera included in a scene with command line options, because it's often faster to compare different views this way instead of re-exporting the scene with a different camera from Blender.

7.16.1 Camera selection

`--camera=<name>`

If there are multiple cameras in the scene, you can choose which one to use by specifying `--camera=nameofthecamera`. The default camera is the first one.

7.16.2 Camera position

`--camera-offset=<x,y,z>`

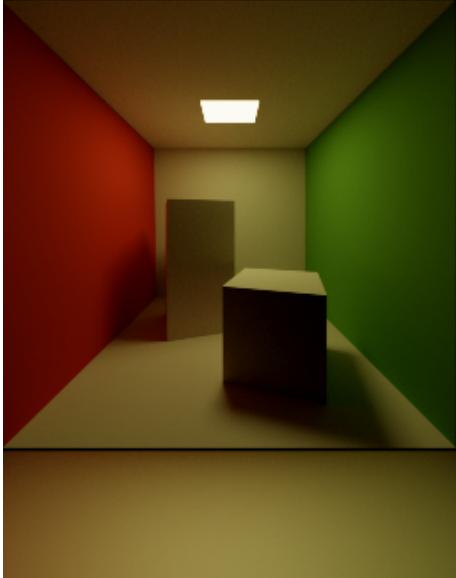
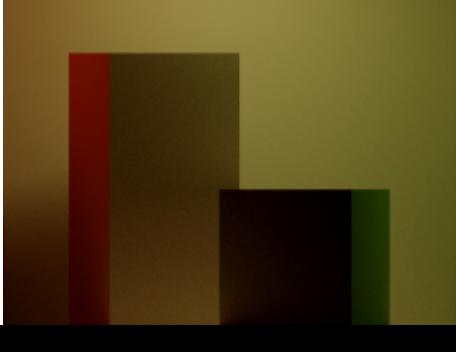
You can also move the camera a bit from its original position with `--camera-offset=<x,y,z>`.

7.16.3 Camera projection

`--force-projection=<perspective|orthographic|equirectangular>`

It's possible to force a different camera projection than specified in the scene. Note that the `equirectangular` projection only works with ray tracing!

Table 7.8: Summary of available camera projections.

Projection	Image
<code>perspective</code>	
<code>orthographic</code>	
<code>equirectangular</code>	

7.16.4 Camera clip range

`--camera-clip-range=<near,far>`

This parameter forces specific near and far planes for the camera. Things outside of that depth range will be clipped/culled in rasterization-based renderers.

7.16.5 Field of view (FOV)

`--fov=<number>`

If you want to force a different field of view than the original, you can do so with `--fov`. Adjusting FOV is

just like adjusting zoom on a camera. Lower FOV = more zoomed in.



7.16.6 Camera grid / simple light fields

```
--camera-grid=<w,h,x,y>
--camera-grid-roll=<degrees>
--camera-recentering-distance=<distance>
```

If you want to render a grid of views instead of just one, you can easily turn one camera into many with the `--camera-grid` option. It takes four numbers: `w` and `h` specify the view grid size horizontally and vertically; `x` and `y` specify the distance between views horizontally and vertically. If you want the grid to be rotated (without rotating the cameras themselves!), you can use `--camera-grid-roll=<degrees>`.

`--camera-recentering-distance` is used to set the distance to the zero-disparity plane. In other words, objects at that depth appear at the exact same screen coordinates on all cameras of the grid. This parameter is commonly needed for VR and light field setups.

7.16.7 Camera logging

```
--camera-log=<path-to-log>
```

You can write a log of camera matrices from an animation using this flag. The data will be in the JSON format.

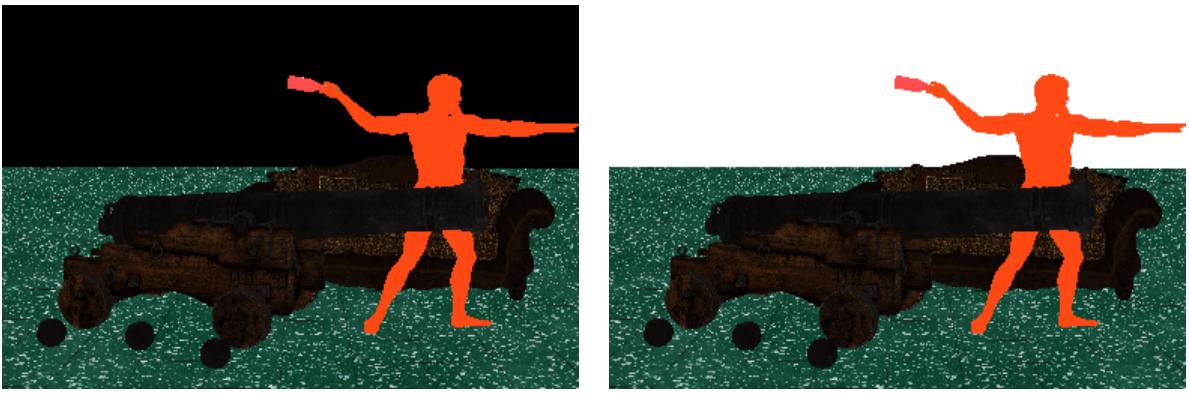
7.17 Networking

There are certain setups in Tauray that require networking. There's always a server and a client. The server will bind to a port (default is 3333, you can set it with `--port=<integer>`). The client will connect to a server with an address that can be specified with `--connect=<address:port>` (default is localhost:3333).

7.18 Default value

```
--default-value=<number>
```

You can set the default value to be used in feature renderers when the ray misses geometry. The default is NaN, which can be stored and detected in .exr images.



An albedo render, with `--default-value=0`.

The same scene, with `--default-value=1`.

7.19 Denoising

`--denoiser=<none|svgf|bmfr>`

Denoising can be used with the `path-tracer` renderer in order to reduce noise from the images. You basically only want this when very few samples per pixel are taken, which causes massive noise.

While the SVGF denoiser somewhat corresponds to the “Spatiotemporal Variance Guided Filtering” paper, it has been upgraded quite a bit, and is pretty close to state-of-the-art in real-time denoising.



A path traced rendering with `--denoiser=none`.

The same scene, with `--denoiser=svgf`.

You may want to use `--warmup-frames=<number>` for offline rendering use cases in order to get some temporal history before starting actual rendering. Doing so will reduce noise. Usually, you also use denoising in conjunction with temporal anti aliasing.

7.19.1 SVGF parameters

`--svgf=<atrous-diff-iter,atrous-spec-iter,atrous-kernel-radius,sigma-l,sigma-z,sigma-n,min-alpha-color>`

This sets the parameters for the SVGF denoiser. Note that the defaults are quite general, and it's unlikely that you'll gain much by changing these parameters. `atrous-diffuse-iter` sets number of iterations of the A-Trous filter for the diffuse contribution, while `atrous-spec-iter` sets them for the specular contribution. `atrous-kernel-radius` sets the A-Trous filter size. `sigma-l` controls the luminance weight, `sigma-z` controls the depth weight, and `sigma-n` controls the normal weight. `min-alpha-color` controls the temporal accumulation speed for color data, and `min-alpha-moments` controls the accumulation speed for moments used to drive the variance guidance.

7.20 Multi-device rendering

`--devices=<int,int,...>`

You can define which devices to use with the `--devices` argument. By default, it uses all ray tracing-capable GPUs that are found. If you only want one GPU, you can use `--devices=-1` (which picks the default GPU) or `--devices=0` (which picks the first one) and so on. You can also give a list of integers to define a subset of GPUs to use.

If you only have one GPU, but want to debug multi-GPU stuff, you can use the `--fake-devices=<N>` option, which creates N logical devices for each physical device.

7.20.1 Distribution strategy

`--distribution-strategy=<duplicate|scanline|shuffled-strips>` determines how the rendering workload is distributed to multiple GPUs. `duplicate` does all calculations on each GPU and is not useful. `scanline` distributes scanlines evenly across all GPUs, and is a good choice when the GPUs are identical. `shuffled-strips` is the default, as it dynamically adjusts to uneven GPU performance.

7.20.2 Workload distribution

With the `shuffled-strips` strategy, Tauray distributes the rendering workload dynamically based on how long each GPU took to render earlier frames. To set the initial distribution (e.g. for single-frame offline rendering), you can use `--workload=<gpu1-share,gpu2-share,...>` to set the ratio of workload given to each GPU.

7.21 Display

`--display=<headless|window|openxr|looking-glass|frame-server|frame-client>`

Display type. If you use `--headless`, the `headless` display is forced on. Otherwise, you can pick whether you want to output to a window, to a VR HMD with OpenXR or a Looking Glass light field display. `frame-server` and `frame-client` are special, see frame streaming.

7.21.1 Looking Glass

`--lkg-params=<viewports,midplane,depthiness,relative_view_distance>`

You can set the parameters for rendering to a Looking Glass display with the `--lkg-params` option. `viewports` is the number of discrete viewports to render, this would usually be between 48 to 128. `midplane` is the plane of convergence, i.e. which scene depth corresponds to the actual physical distance of the display from the viewer's eye. `depthiness` can be used to adjust the distance between viewports, and `relative_view_distance` is the distance of the user's eye relative to the size of the display (this is needed for the Y axis, as the Looking Glass displays only have multiple horizontal views.)

Additionally, if your Looking Glass isn't connected via USB to the computer running Tauray, you can still use it. In that case, you'll need to use the `--lkg-calibration=<...>` parameter. Read further instructions from `tauray --help`.

7.21.2 Frame streaming

Tauray supports a really simple form of frame streaming. This can be used to have an interactive session on a render farm, although you really should run it at a very low resolution, because the frames are sent uncompressed!

You need two instances of Tauray for this. They can, and probably should be, on different computers. One of them acts as the server and is given the flag `--display=frame-server`, while the other is the client, which is given `--display=frame-client`.

The frame server does the entire rendering, while the frame-client sends its inputs over to the server and receives frames from the server. You can set the port for the server with `--port=<port-number>`, and the client can then specify the address via `--connect=url:port`.

7.22 Environment map

```
--envmap=<path-to-envmap>
```

Environment maps are among one of the only things that glTF 2.0 files cannot contain. If you want your scene to have a “background image” instead of floating in an infinite black void, you need to specify an environment map with the `--envmap` parameter. You can find free CC0-licensed environment maps from Poly Haven².



A path traced rendering with no envmap.



The same scene, with an environment map.

Environment maps make it easier to generate realistic-looking images of individual objects, as you don’t have to model proper surrounding geometry. They are also nice in larger scenes as well.

By default, environment maps are importance sampled. This has a noticeable performance impact and you may want to disable the importance sampling sometimes. You can do this with `--sample-envmap=off`. Note that this importance sampling is basically required if your environment map includes the sun or any other small and bright light source:



`--sample-envmap=off`



`--sample-envmap=on` (default)

7.23 Tone mapping

```
--tonemap=<filmic|gamma-correction|linear|reinhard|reinhard-luminance>
```

```
--gamma=<number>
```

```
--exposure=<number>
```

If you want to affect the final look of the render, you can adjust the tonemapping parameters. Firstly, you’ll want to pick a tonemapping operator with `--tonemap`.

²<https://polyhaven.com/hdris>

Table 7.14: Summary of available tonemapping operators.

Operator	Image
<code>filmic</code> : Looks generally good, but has relatively stark contrast for an HDR operator.	
<code>gamma-correction</code> : Plain and susceptible to clipping, but sometimes required for science.	
<code>linear</code> : Looks wrong on regular displays, but is useful if you intend to do math with the output.	

Operator	Image
reinhard: A bit plain, but works well with HDR. Often seen in literature.	
reinhard-luminance: Reinhard done on luminance instead of color channels. Technically incorrect, but preserves saturation better.	

Then, you can adjust `gamma`, to change the gamma curve³. It affects every operator except `linear`. It's usually best to leave this as the default value 2.2 unless your display expects a different gamma value.



Filmic tonemapping with `--gamma=1.5`.

The same scene, with `--gamma=2.5`.

³https://en.wikipedia.org/wiki/Gamma_correction

`exposure` should be used to adjust the overall brightness of the image. It works just like adjusting exposure on a real camera, although it's defined in relative terms. `--exposure=1` is the default exposure that is expected by glTF files. `--exposure=2` doubles the brightness *before* tonemapping.



Filmic tonemapping with `--exposure=0.5`.

The same scene, with `--exposure=2.0`.

7.24 Output file

7.24.1 File format

`--filetype=<exr|png|bmp|hdr|raw|none>`

You can change the file format for the output data of headless mode with `--filetype`. The default is .EXR, which may be hard to view without an EXR viewer application, but it will not lose data. If you intend to generate images just to be looked at, you probably want to specify `--filetype/png` instead. Tauray's PNG output is limited to 8-bits-per-channel color, clipped between 0 to 1.

The `raw` file format just dumps 4 floating point numbers per pixel to the disk as-is. This can be easy to load in your own programs consuming Tauray data, as you don't have to deal with image formats. However, you must know the size of the image yourself, as no metadata is included.

The `none` format just means that no output is actually written. This can be useful for benchmarking Tauray on a server, so you don't end up benchmarking disk and EXR compression speed instead.

7.24.2 Pixel format

`--format=<rgb16|rgb32|rgba16|rgba32>`

This flag sets the pixel format for EXR files. All are floating point formats, you can only choose whether you want 3 (`rgb`) or 4 (`rgba`) color channels and half floating point values (16) or regular floating point values (32).

7.24.3 Compression

`--compression=<zip|zips|rle|piz|none>`

Currently, this parameter only sets the compression scheme for the EXR format. All schemes are lossless, but may not be supported by every EXR viewer. For example, a 384x256 image of the example scene used in this manual takes 594 kilobytes with `--compression=none`, and 403 kilobytes with `--compression=piz`. The PIZ compression scheme is used by default.

7.25 Anti-aliasing

There's many parameters controlling how anti-aliasing is done, as it's generally a bit different between path tracing and rasterization-based methods. By default, anti-aliasing is **disabled** because it makes it harder to post-process images afterwards. However, if you just want to show pretty pictures, you most definitely want to enable it.

7.25.1 Rasterization

In rasterization (i.e. `raster` and `dshgi` renderers), two related anti-aliasing methods are available: MSAA⁴ and SSAA⁵.

Both are enabled by setting `--samples-per-pixel=<integer>`, where the integer is a power-of-two number between 1 and 8. 1 corresponds to no anti-aliasing and is the default, whereas 8 is the slowest and prettiest anti-aliasing.

MSAA is used by default. It only anti-aliases geometric edges, so shading details such as sharp shadows may still appear aliased. SSAA is enabled by setting `--sample-shading=on`. This method is very slow, as it linearly increases the workload by your `--samples-per-pixel` value. However, it generally works the best.

Table 7.17: Comparison between anti-aliasing methods for rasterization.

Anti-aliasing mode	Image
No anti-aliasing	
8 x MSAA	
8 x SSAA	

⁴https://en.wikipedia.org/wiki/Multisample_anti-aliasing

⁵<https://en.wikipedia.org/wiki/Supersampling>

7.25.2 Path tracing

```
--film=<point|box|blackman-harris>
```

With `path-tracer`, you can set the film filtering scheme. This jitters the origin of the ray according to a filter function, in order to cause anti-aliasing with a method that is fairly physically correct. You can set the filter shape with `--film`. `box` looks like the anti-aliasing methods available in rasterization, but `blackman-harris` has fewer artifacts and is recommended instead. `point` is the default, which means that all rays start from the center of the pixel and there is no anti-aliasing.

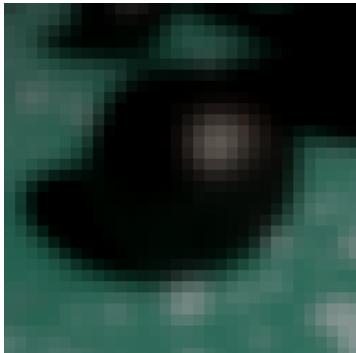
```
--film-radius=<number>
```

For the `box` and `blackman-harris` filters, you can set the filter radius `--film-radius`. The default is usually good, but you can make the image appear even less aliased (and blurrier) if needed. Higher radius = blurrier image.

Note that the anti-aliasing starts to appear once you have multiple samples per pixel. So you'll want to set `--samples-per-pixel` to something higher than 1.

Table 7.18: Comparison between film filters for anti-aliasing path traced images.

Film filtering	Image	Explanation
point		No anti-aliasing.
box		Anti-aliased. This case doesn't show major issues with the box filter.
blackman-harris		Less blurry than <code>box</code> but still well anti-aliased.

Film filtering	Image	Explanation
<code>blackman-harris with --film-radius=4</code>		Who smudged the lens?

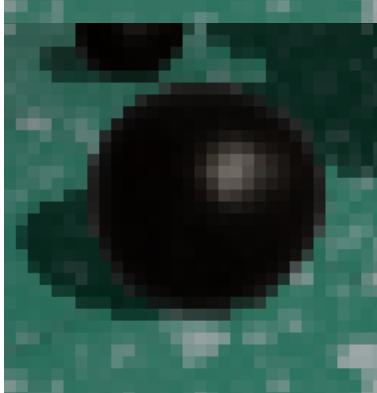
7.25.3 Temporal anti-aliasing

`--taa=<sequence-length,edge-dilation,anti-shimmer>`

Tauray also implements Temporal Anti-Aliasing⁶. This works with all renderers, but isn't recommended with path tracing unless you also use a denoiser. The `sequence-length` corresponds to the equivalent SSAA sample quality that it aims for, and refers to the jittering sequence length. `edge-dilation` is enabled by default, it helps with tracking motion of anti-aliased edges.

TAA can cause some flickering in shiny edges. `anti-shimmer` is a hack that aims to reduce this, but it is not enabled by default.

Table 7.19: Comparison between supersampling anti-aliasing with temporal anti-aliasing.

Anti-aliasing mode	Image	Explanation
8 x SSAA		The aimed quality of SSAA.
8 x TAA		TAA generally works well when there is little motion.

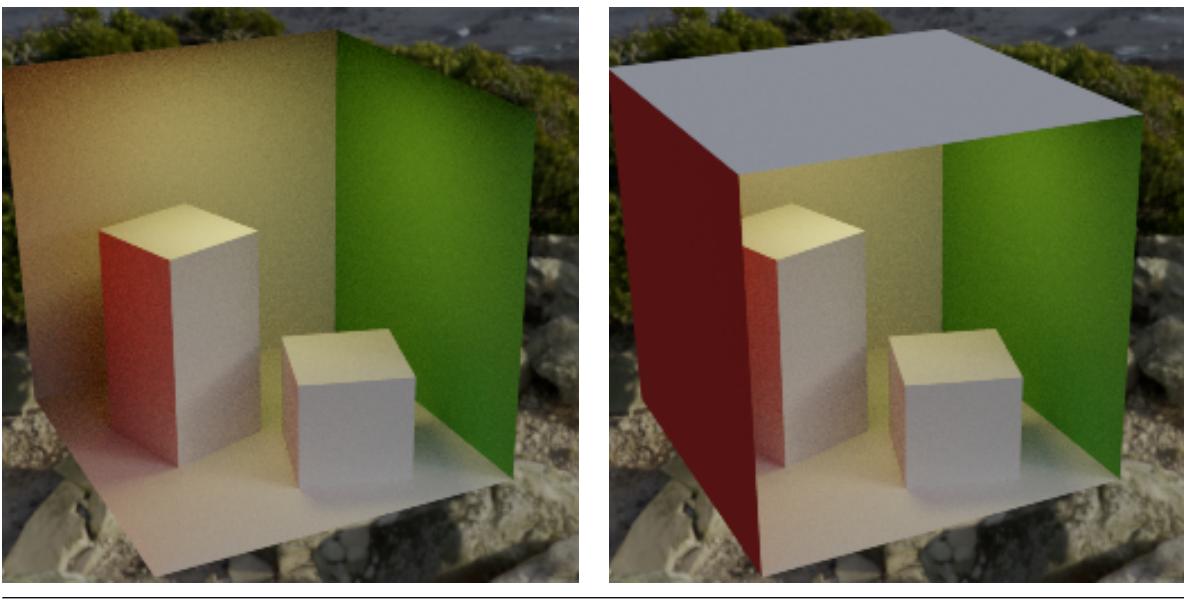
⁶https://en.wikipedia.org/wiki/Temporal_anti-aliasing

7.26 Sidedness

```
--force-double-sided=<on|off>  
--force-single-sided=<on|off>
```

Usually, Tauray follows what each glTF 2.0 material has specified as the “sidedness” of the surface. Many models are marked as single-sided, simply because that is faster in rasterization-based methods. However, this is not true in ray tracing, where double-sided surfaces are faster. The options `--force-double-sided` and `--force-single-sided` can be used to force the desired kind of sidedness.

Single-sided surfaces are also known as **Backface culling**.



Cornell box with the original single-sided behaviour.

The same scene with `--force-double-sided`

If you want to improve ray tracing performance, use `--force-double-sided`!

7.27 Pre-transformed vertices

`--pre-transform-vertices=<on|off>` is yet another performance option. Enabling it consumes more memory, but is likely faster in multi-bounce path tracing due to only calculating vertex transforms once instead of on each bounce on every pixel.

7.28 HDR

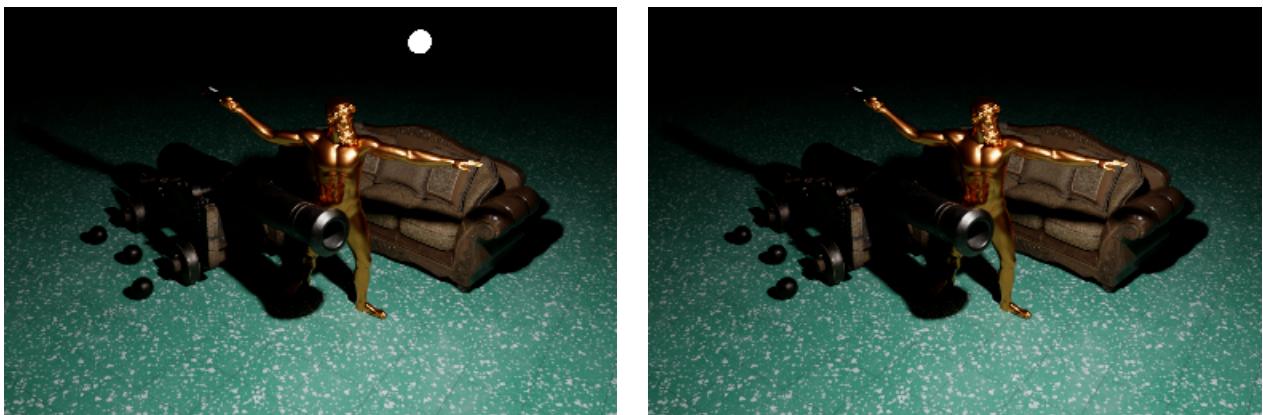
```
--hdr=<on|off>
```

If you have an HDR display, you can make use of it with `--hdr`. You probably want to use a tonemapping that doesn't target values between 0 to 1, so you probably should simply use `--tonemap=gamma-correction`.
note: VR HMDs usually specify HDR support and you want to enable this with them!

7.29 Hide lights

```
--hide-lights=<on|off>
```

In path tracing, light sources are also rendered. For example, a spherical light will appear as a bright sphere. You can disable this from primary rays with `--hide-lights`.



Note how the light source is visible.

With `--hide-lights`, it's hidden!

7.30 Firefly mitigation (path space regularization & indirect clamping)

`--regularization=<number>` `--indirect-clamping=<number>`

If your image suffers from fireflies, you have two ways to get rid of them: path space regularization with `--regularization` and indirect clamping with `--indirect-clamping`.

Path space regularization is the recommended way to do this. It biases the image by strategically adjusting roughness for indirect bounces such that fireflies cannot occur. Good values for real-time renders are between 0.1-0.5. Higher values make caustics appear blurrier.

Indirect clamping is the older but powerful way to reduce or remove fireflies. However, it's a fairly aggressive method that causes more biasing and loss of energy than path space regularization. Usually, good indirect clamping values are around 10-100, lower values start to affect the image too much.



Fireflies can be seen in the cannon's shadow.

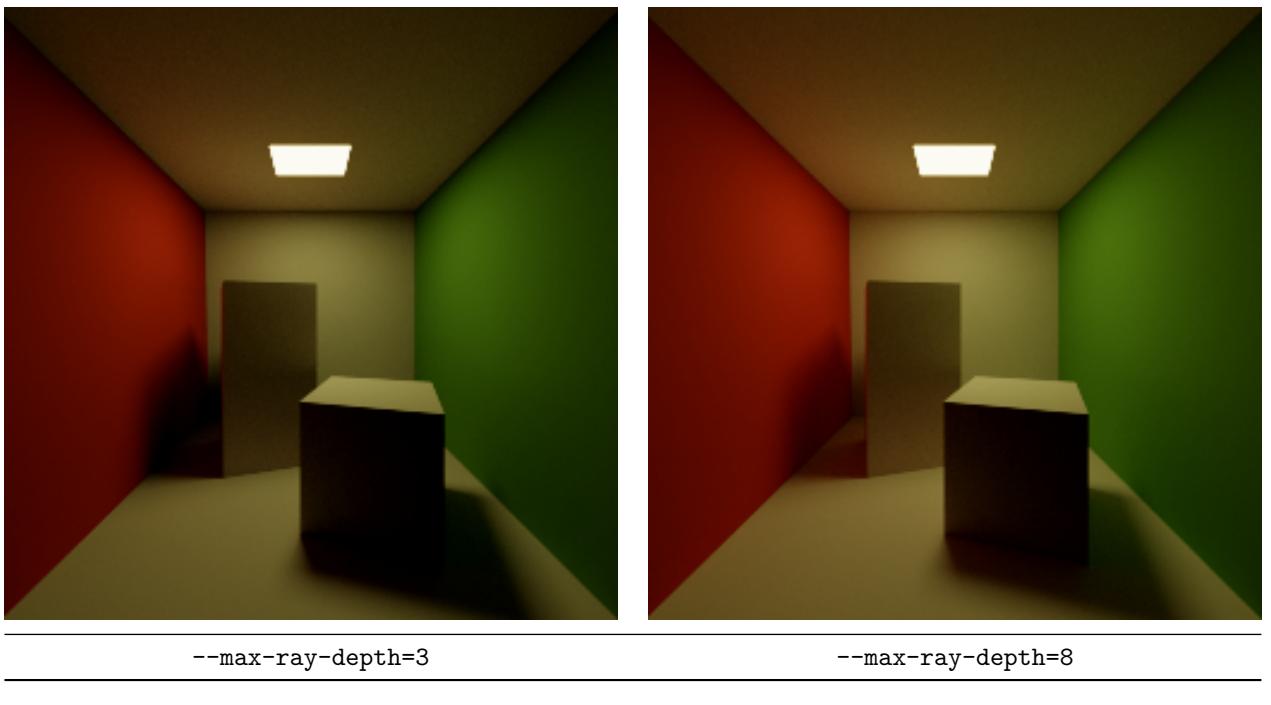
The same scene with `--indirect-clamping=5`.

The same scene with `--regularization=0.5`.

7.31 Ray bounces

`--max-ray-depth=<integer>`

This parameter sets the maximum number of edges in a path, in ray tracers. The number of bounces is one less. Higher numbers are generally slower, but are more realistic and brighter. While the default is 8, you should usually be fine with just 3-4. Especially in bright outdoor areas, you can get away with a low number of bounces. 2 is direct light only (camera->surface->light). 1 shows only emissive objects (camera->light)



7.32 Minimum ray distance

`--min-ray-dist=<number>`

To prevent self-intersections, rays must have a minimum distance that they will travel. You can set the distance with this flag. In massive scenes, you may encounter precision issues if it's too small, and in small scenes, you may see light leaking a short distance past walls. The default value of 0.0001 is generally fairly good.

7.33 Acceleration structure strategy

`--as-strategy=<per-material|per-model|static-merged-dynamic-per-model|all-merged>`

This parameter sets how geometry is assigned to BLASes. `per-material` creates a unique BLAS for every material primitive of each object, and is very inefficient. `per-model` creates one BLAS per model, which is quite straightforward.

`static-merged-dynamic-per-model` is the default, which merges all static (non-animated) meshes into a single BLAS, and creates one BLAS for each dynamic model. This is a good tradeoff between ray tracing and acceleration structure building performance.

`all-merged` is the fastest option for offline rendering, as it just dumps all geometry in one BLAS. It is a bit slow to update though, so this is not recommended for real-time rendering.

7.34 Shadow mapping

In the `raster` and `dshgi` renderers, shadows are implemented using shadow mapping⁷. There are multiple parameters controlling them.

7.34.1 Percentage Closer Filtering

`--pcf=<integer>`

The Percentage Closer Filtering (PCF) technique makes shadows appear smoother. You can set the number of PCF samples taken. Low values have more noise but are faster. `--pcf=0` disables PCF and uses bilinear

⁷https://en.wikipedia.org/wiki/Shadow_mapping

interpolation instead. It's set to 64 by default, which is pretty slow, but mostly noise-free. Without PCSS, PCF uses a constant blur radius relative to the size of the light source.

Table 7.24: Images visualizing the effects of increasing PCF samples.

PCF	Image
--pcf=0	
--pcf=1	
--pcf=8	

PCF	Image
--pcf=64	

7.34.2 Percentage Closer Soft Shadows

--pcss=<integer>

Percentage Closer Soft Shadows (PCSS) works in conjunction with Percentage Closer Filtering in order to create realistic shadow penumbrae. --pcss=0 disables it, low values are noisy, the default is 32. Note that you have to have --pcf as something other than 0 for PCSS to work!

Unfortunately, PCSS only works with directional lights (like the sun), so point lights do not work. For the table below, the point light in the scene has been swapped for a directional light.

Table 7.25: Images visualizing the effects of increasing PCSS samples.

PCSS	Image
--pcss=0	



If you want to avoid ever going too sharp with the PCSS shadows, you can use `--pcss-minimum-radius=<number>` to force a minimum radius instead of being arbitrarily sharp.

7.34.3 Shadow map bias

`--shadow-map-bias=<number>`

Shadow map biasing is a technique that removes the “shadow acne” artefacts caused by precision issues. High bias values remove the acne effectively, but also cause “peter panning”, i.e. shadows detached from their casters. The default is 0.05.

Table 7.26: Comparison of a few different bias values. Note how the highest bias causes notable peter panning (i.e. shadow detached from caster) and the lowest bias causes “shadow acne.”

PCSS	Image
Bias = 0.0	
Bias = 0.05	
Bias = 0.5	

7.34.4 Shadow map cascades

`--shadow-map-cascades=<integer>`

Tauray implement cascaded shadow maps for directional lights. This means that the same shadow map is rendered at multiple different zoom levels. Nearby areas are shown with the highest zoom level, while areas further away get successively less precise shadow maps. This lets the shadow map cover very large distances.

For small scenes, you may want to disable cascades by setting `--shadow-map-cascades=1`.

7.34.5 Shadow map depth

--shadow-map-depth=<number>

If your scene is very large, the default shadow map distance range of 100 may not be enough. If you notice that the shadow cuts off, you should increase the range.

7.34.6 Shadow map radius

--shadow-map-radius=<number>

You usually don't have to change this unless you want to disable shadow map cascades. If so, you'll have to find a radius that is large enough to cover your scene. Lower radius values let you distribute the shadow map resolution to a smaller area, which makes it look more precise.

7.34.7 Shadow map resolution

--shadow-map-resolution=<integer>

In Tauray, shadow maps are simply square images. You can set the size of the square with this parameter. Higher resolutions allows you to preserve more details in the shadows, but are also slower to render. Lower resolutions are also more susceptible to shadow acne.

Table 7.27: Effects of resolution to shadow map quality. Bias was manually adjusted to barely avoid shadow acne in each case.

Resolution	Image
256	
1024	

Resolution	Image
4096	

7.35 Sampling

7.35.1 Random number seed

--rng-seed=<integer>

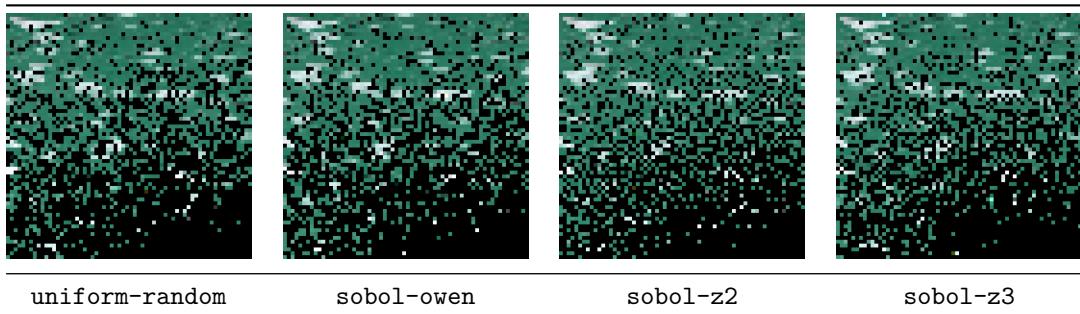
Typically, Tauray renders are reproducible in that the RNG seed will always be the same. If you want to have different noise in the otherwise same render, you should set the random number generator seed with --rng-seed.

7.35.2 Sampler

--sampler=<uniform-random|sobol-owen|sobol-z2|sobol-z3>

A sampler picks the samples for Monte Carlo integration in the path tracer. `uniform-random` is just regular random values, `sobol-owen` implements Practical Hash-based Owen Scrambling⁸. `sobol-z2` and `sobol-z3` are related to Screen-Space Blue-Noise Diffusion of Monte Carlo Sampling Error via Hierarchical Ordering of Pixels⁹. The difference between them is that `sobol-z2` is using a typical 2D Morton curve, while `sobol-z3` is using a 3D Morton curve where frame index/time is the third axis.

`sobol-z3` is the default, as it seems to perform fairly well in most cases. For low-spp renders, you may want to go for `sobol-z2` instead. For maximum performance, `uniform-random` is the fastest.



7.35.3 Russian roulette sampling

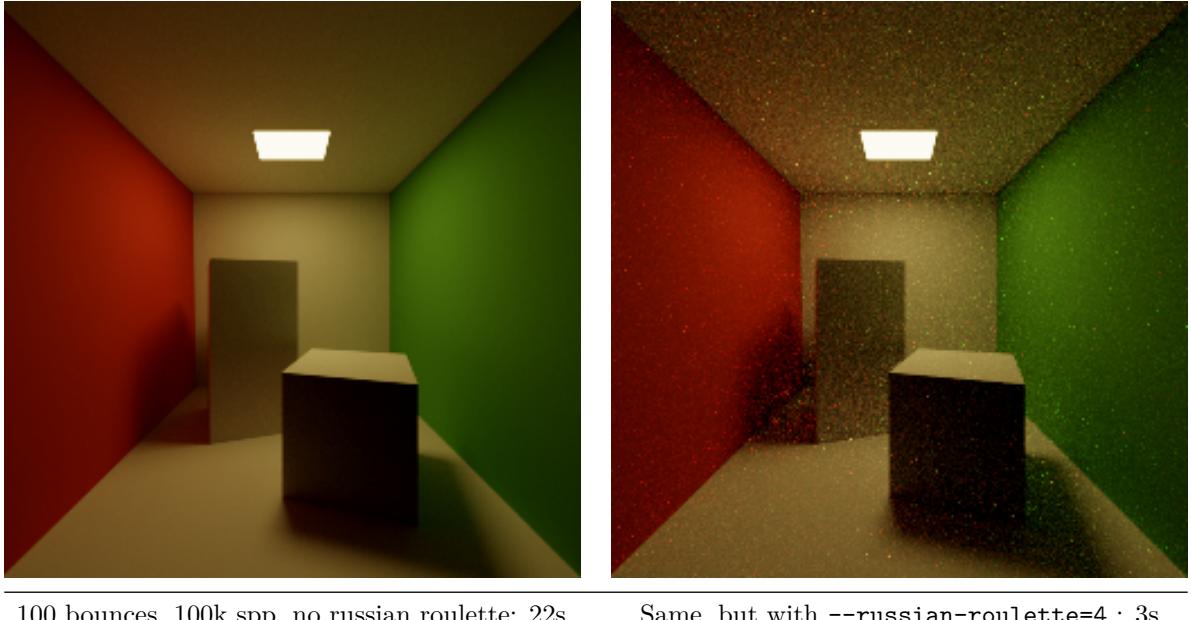
--russian-roulette=<number>

Russian Roulette sampling is a method that randomly kills off deep rays in the scene. It is typically used when you need lots of light bounces, but still want to render the image reasonably quickly. Higher numbers

⁸<https://jcgtr.org/published/0009/04/01/>

⁹<http://abdallagafar.com/publications/zsampler/>

raise the odds of rays losing the roulette. You can think of the number as the number of chambers in the revolver, and only one of them *doesn't* have a bullet...



100 bounces, 100k spp, no russian roulette: 22s

Same, but with **--russian-roulette=4 : 3s**

Note: because this method relies on causing certain samples to have higher weight than usual, it responds poorly to **--indirect-clamping**!

7.35.4 BSDF sampling

--bounce-mode=<hemisphere|cosine|material>

This parameter selects how path tracer & ReSTIR select the next bounce. By default, it's set to **material**, which is based on GGX VNDF importance sampling. **hemisphere** samples direction uniformly from the hemisphere, and **cosine** samples a cosine hemisphere. The latter two are mostly available for educational purposes, as they cause significantly increased noise levels.

7.35.5 Multiple importance sampling (MIS)

--multiple-importance-sampling=<off|balance|power>

This parameter sets the MIS type for the path tracer. It's set to **power** by default, as it's usually the lowest-noise approach. Disabling MIS is also possible with **off**, but that's mostly useful for educational purposes, as the image will be full of fireflies for any non-trivial scene.

Note that ReSTIR always uses the balance heuristic regardless of this setting.

7.35.6 Point lights

--sample-point-lights=<float> can be used to set the relative weight of sampling point lights in next event estimation. Higher values emphasize point lights more than other light types. 0 disables next event estimation of point lights.

7.35.7 Directional lights

--sample-directional=<float> can be used to set the relative weight of sampling directional lights in next event estimation. Higher values emphasize directional lights more than other light types. 0 disables next event estimation of directional lights.

7.35.8 Environment maps / infinite area lights

`--sample-envmap=<float>` can be used to set the relative weight of sampling directions from the environment map in next event estimation. Higher values emphasize envmaps over other light types. 0 disables next event estimation of envmaps. Envmap sampling is implemented via alias tables, so it's O(1) regardless of the environment map resolution.

7.35.9 Triangle area lights

`--sample-emissive-triangles=<float>` can be used to set the relative weight of sampling emissive triangles in next event estimation. Higher values emphasize triangle lights more than other light types. 0 disables next event estimation of emissive triangles.

`--tri-light-mode=<area|solid-angle|hybrid>` controls how triangular area lights are sampled. The `area` method is robust, but noisy. `solid-angle` has less noise, but is also less robust to very small triangles. `hybrid` should be robust and low-noise, but it is also slower.

7.35.10 Samples per pixel

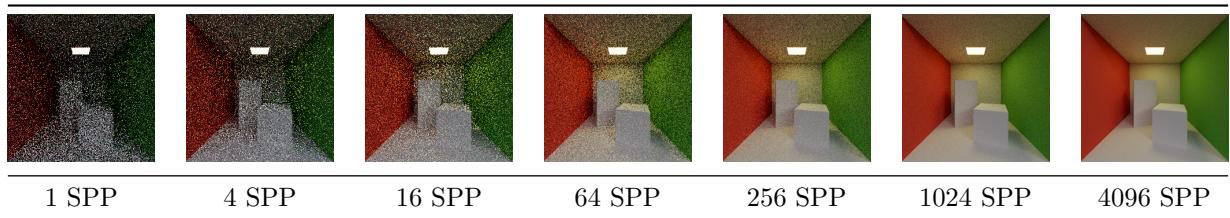
`--samples-per-pixel=<integer>`

This flag has two meanings depending on the renderer, but they are both somewhat related. For rasterization-based renderers (such as `raster` and `dshgi`), it's the number of anti-aliasing samples to take per pixel.

For path tracing, it's the number of Monte Carlo samples to take. Lower numbers are fast, but noisy. High numbers are slow, but don't have much noise.

Usually, `--samples-per-pixel=4096` is suitable for offline rendering with path tracing. The default value is 1, which is suitable real-time use in all contexts.

Table 7.30: Effects of samples per pixel (SPP) counts to noise in path tracing.



For performance, you may consider setting `--samples-per-pass=8` or so. This parameter makes one shader pass calculate more samples, reducing overall overhead. However, too high values can cause driver timeouts, as their watchdogs bite Tauray if it takes too many seconds to run one pass.

7.36 DDISH-GI

Many parameters affect DDISH-GI (`--renderer=dshgi`) alone.

7.36.1 Temporal reuse

`--dshgi-temporal-ratio=<number>`

To adjust the temporal reuse, which affects visible flickering in probe data, you can use the `--dshgi-temporal-ratio` parameter. The argument is between 0 and 1, where 1 means all data comes from the current frame and values approaching zero use increasingly more data from previous frames.

7.36.2 Samples per probe

`--samples-per-probe=<integer>`

This parameter adjusts how many paths are traced per probe during each frame. Higher values make the update slower, but reduce flickering.

7.36.3 Spherical harmonics order

```
--sh-order=<integer>
```

By default, spherical harmonics up to L2 are used for the probe data. You can select orders between 1 and 4. Higher orders store more detailed information, which can be visible in reflections, but are increasingly slower.



DDISH-GI with `--sh-order=2`.



Same, but with `--sh-order=4`.

7.36.4 Probe visibility approximation

```
--use-probe-visibility=<on|off>
```

This flag can reduce light leaking from probes, but can also cause odd artefacts and slow down rendering significantly. It's disabled by default.



DDISH-GI with `--use-probe-visibility=off`.



Same, but with `--use-probe-visibility=on`.

7.37 Reprojection

Reprojection can be used with path tracing to re-use data from previous frames or other viewports. These are the *temporal* and *spatial* reprojection, respectively.

7.37.1 Spatial reprojection

```
--spatial-reprojection=<int,int,...>
```

This type of reprojection is only useful for light-field rendering. You list the viewport indices that are rendered, and the rest are then reprojected from those.

7.37.2 Temporal reprojection

```
--temporal-reprojection=<number>
```

Temporal reprojection can be used with regular renders as well, though it's most useful in interactive mode. This method re-uses pixel values from the previous frame to deliver a more noise-free image. The given number affects the ratio of data re-used from the previous frame, where 0 is no re-use and 0.5 is 50/50 new and old frame.

7.38 Accumulation

```
--accumulation=<on|off>
```

Enables accumulation in the interactive path tracer, meaning that new frames are blended with previous frames until you move. This lets you quickly and interactively preview scenes with high SPP counts, as you can fly around normally, then stop to accumulate a high-SPP image. Do not use accumulation in headless mode.

7.39 Transparent background

```
--transparent-background=<on|off>
```

If you want to render cut-out images where the background is transparent, you can use `--transparent-background` to achieve just that.

7.40 Depth of field

```
--depth-of-field=<f-stop,distance,sensor-size,sides,angle>.
```

You can enable simulation of a simplistic non-pinhole camera with the thin-lens model, by using the `--depth-of-field` option. `f-stop` controls the aperture size¹⁰, `distance` sets the distance to the plane of focus, `sensor-size` sets the camera sensor size (default: 0.036), `sides` sets the shape of the aperture (0 = circle, 3 and above: polygonal), `angle` sets the angle of a polygonal aperture.

7.41 Force white albedo for first bounce

```
--use-white-albedo-on-first-bounce=<on|off>
```

This flag has a very specific use case in mind: denoising research. You can force the albedo of every material to be white on the first intersection, which lets you observe the lighting arriving at the surface without meddling textures. On further bounces, the materials are back to their usual colors, so you still get color bleeding!

7.42 Up axis

```
--up-axis=<x|y|z>
```

This rotates the scene such that the given axis points up. By default, the Y-axis points up.

¹⁰<https://en.wikipedia.org/wiki/F-number>

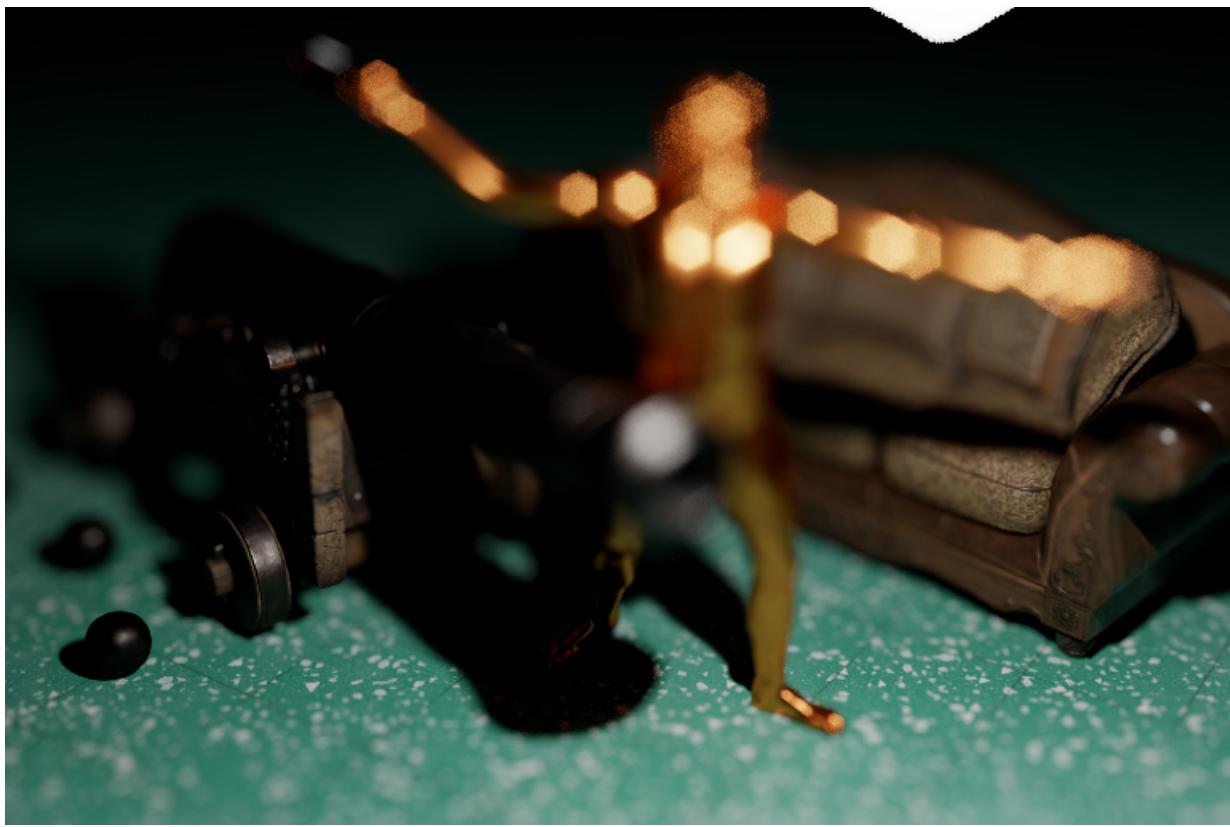


Figure 7.1: The usual scene, but with `--depth-of-field=0.05,10,0.036,6`.

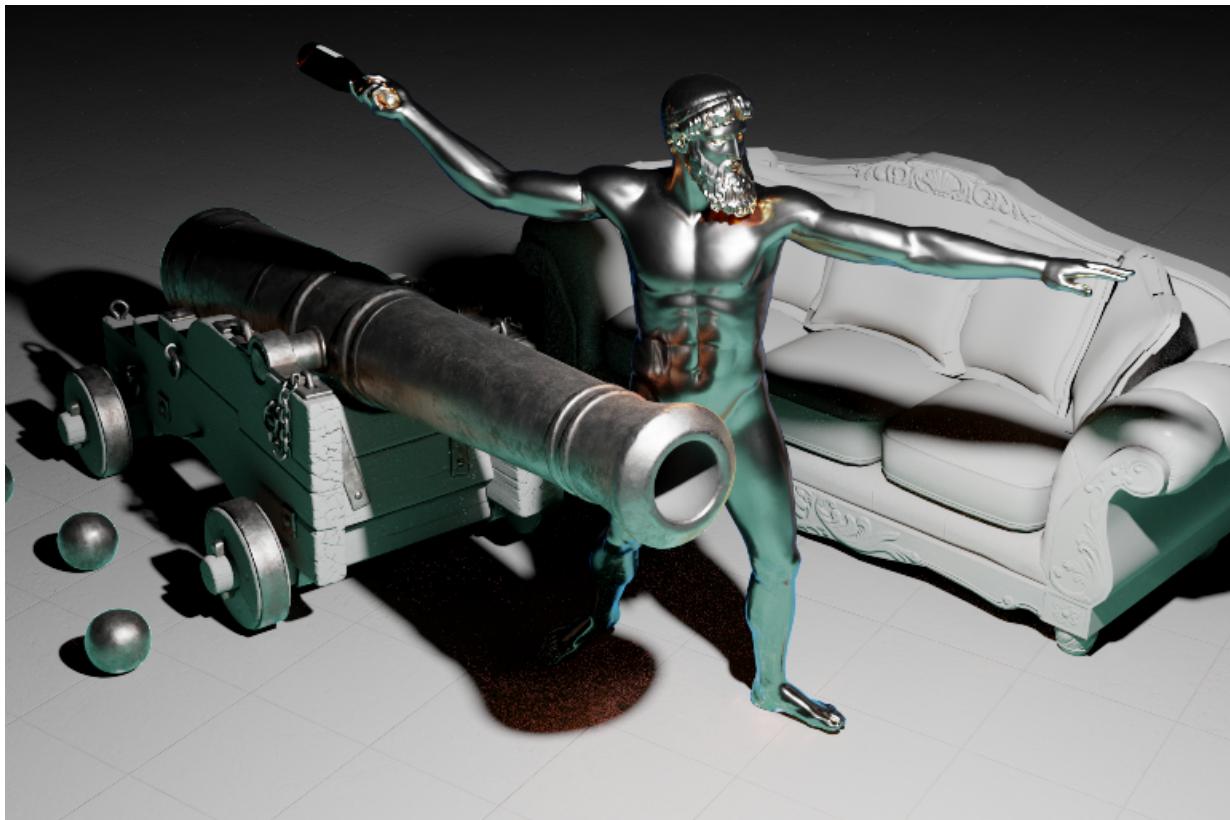


Figure 7.2: The usual scene, but with `--use-white-albedo-on-first-bounce`.

Chapter 8

Limitations

There are things that Tauray does not handle well. In such cases, you may want to use some other tool instead. This list of limitations may also change in the future, as we work on implementing more missing features. Namely:

- Morph target animations are not supported.
- Advanced material models are not yet supported, only the basic GGX metallic-roughness + transmission.
- Scenes requiring complex light transport - while ReSTIR may be able to resolve some caustics, it's still nowhere near as robust as VCM, for example.

Chapter 9

Conclusion

Thank you for using Tauray.