

# **OSPRAY**

**AN OPEN, SCALABLE, PARALLEL, RAY TRACING  
BASED RENDERING ENGINE FOR HIGH-FIDELITY  
VISUALIZATION**

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# Chapter 1

## OSPRay Overview

OSPRay is an open source, scalable, and portable ray tracing engine for high-performance, high-fidelity visualization on Intel® Architecture CPUs. OSPRay is released under the permissive [Apache 2.0 license](#).

The purpose of OSPRay is to provide an open, powerful, and easy-to-use rendering library that allows one to easily build applications that use ray tracing based rendering for interactive applications (including both surface- and volume-based visualizations). OSPRay is completely CPU-based, and runs on anything from laptops, to workstations, to compute nodes in HPC systems.

OSPRay internally builds on top of [Embree](#) and [ISPC \(Intel® SPMD Program Compiler\)](#), and fully utilizes modern instruction sets like Intel® SSE4, AVX, AVX2, and AVX-512 to achieve high rendering performance, thus a CPU with support for at least SSE4.1 is required to run OSPRay.

### 1.1 OSPRay Support and Contact

OSPRay is under active development, and though we do our best to guarantee stable release versions a certain number of bugs, as-yet-missing features, inconsistencies, or any other issues are still possible. Should you find any such issues please report them immediately via [OSPRay's GitHub Issue Tracker](#) (or, if you should happen to have a fix for it, you can also send us a pull request); for missing features please contact us via email at [ospray@googlegroups.com](mailto:ospray@googlegroups.com).

For recent news, updates, and announcements, please see our complete [news/updates](#) page.

Join our [mailing list](#) to receive release announcements and major news regarding OSPRay.

### 1.2 Version History

#### 1.2.1 Changes in v1.3.1:

- Improved robustness of OSPRay CMake find\_package config
  - Fixed bugs related to CMake configuration when using the OSPRay SDK from an install
- Fixed issue with Embree library when installing with OSPRAY\_INSTALL\_DEPENDENCIES enabled

#### 1.2.2 Changes in v1.3.0:

- New MPI distributed device to support MPI distributed applications using OSPRay collectively for “in-situ” rendering (currently in “alpha”)

- Enabled via new `mpi_distributed` device type
- Currently only supports raycast renderer, other renderers will be supported in the future
- All API calls are expected to be exactly replicated (object instances and parameters) except scene data (geometries and volumes)
- The original MPI device is now called the `mpi_offload` device to differentiate between the two implementations
- Support of Intel® AVX-512 for next generation Intel® Xeon® processor (codename Skylake), thus new minimum ISPC version is 1.9.1
- Thread affinity of OSPRay’s tasking system can now be controlled via either device parameter `setAffinity`, or commandline parameter `osp:setaffinity`, or environment variable `OSPRAY_SET_AFFINITY`
- Changed behavior of the background color in the SciVis renderer: `bgColor` now includes alpha and is always blended (no `backgroundEnabled` anymore). To disable the background don’t set `bgColor`, or set it to transparent black (0, 0, 0, 0)
- Geometries “spheres” and “cylinders” now support texture coordinates
- The GLUT- and Qt-based demo viewer applications have been replaced by an example viewer with minimal dependencies
  - Building the sample applications now requires GCC 4.9 (previously 4.8) for features used in the C++ standard library; OSPRay itself can still be built with GCC 4.8
  - The new example viewer based on `ospray::sg` (called `ospExampleViewerSg`) is the single application we are consolidating to, `ospExampleViewer` will remain only as a deprecated viewer for compatibility with the old `ospGlutViewer` application
- Deprecated `ospCreateDevice()`; use `ospNewDevice()` instead
- Improved error handling
  - Various API functions now return an `OSPError` value
  - `ospDeviceSetStatusFunc` replaces the deprecated `ospDeviceSetErrorMsgFunc`
  - New API functions to query the last error (`ospDeviceGetLastErrorCode()` and `ospDeviceGetLastErrorMsg()`) or to register an error callback with `ospDeviceSetErrorFunc()`
  - Fixed bug where exceptions could leak to C applications

### 1.2.3 Changes in v1.2.1:

- Various bugfixes related to MPI distributed rendering, ISPC issues on Windows, and other build related issues

### 1.2.4 Changes in v1.2.0:

- Added support for volumes with `voxelType short` (16-bit signed integers). Applications need to recompile, because `OSPDataType` has been re-enumerated
- Removed SciVis renderer parameter `aoWeight`, the intensity (and now color as well) of AO is controlled via “ambient” lights. If `aoSamples` is zero (the default) then ambient lights cause ambient illumination (without occlusion)
- New SciVis renderer parameter `aoTransparencyEnabled`, controlling whether object transparency is respected when computing ambient occlusion (disabled by default, as it is considerable slower)
- Implement normal mapping for SciVis renderer

- Support of emissive (and illuminating) geometries in the path tracer via new material “Luminous”
- Lights can optionally made invisible by using the new parameter `isVisible` (only relevant for path tracer)
- OSPRay Devices are now extendable through modules and the SDK
  - Devices can be created and set current, creating an alternative method for initializing the API
  - New API functions for committing parameters on Devices
- Removed support for the first generation Intel® Xeon Phi™ coprocessor (codename Knights Corner)
- Other minor improvements, updates, and bugfixes:
  - Updated Embree required version to v2.13.0 for added features and performance
  - New API function `ospDeviceSetErrorMsgFunc()` to specify a callback for handling message outputs from OSPRay
  - Add ability to remove user set parameter values with new `ospRemoveParam()` API function
  - The MPI device is now provided via a module, removing the need for having separately compiled versions of OSPRay with and without MPI
  - OSPRay build dependencies now only get installed if `OSPRAY_INSTALL_DEPENDENCIES` CMake variable is enabled

### 1.2.5 Changes in v1.1.2:

- Various bugfixes related to normalization, epsilons and debug messages

### 1.2.6 Changes in v1.1.1:

- Fixed support of first generation Intel Xeon Phi coprocessor (codename Knights Corner) and the COI device
- Fix normalization bug that caused rendering artifacts

### 1.2.7 Changes in v1.1.0:

- New “scivis” renderer features
  - Single sided lighting (enabled by default)
  - Many new volume rendering specific features
    - \* Adaptive sampling to help improve the correctness of rendering high frequency volume data
    - \* Pre-integration of transfer function for higher fidelity images
    - \* Ambient occlusion
    - \* Volumes can cast shadows
    - \* Smooth shading in volumes
    - \* Single shading point option for accelerated shading
- Added preliminary support for adaptive accumulation in the MPI device
- Camera specific features
  - Initial support for stereo rendering with the perspective camera
  - Option `architectural` in perspective camera, rectifying vertical edges to appear parallel
  - Rendering a subsection of the full view with `imageStart/imageEnd` supported by all cameras

- This will be our last release supporting the first generation Intel Xeon Phi coprocessor (codename Knights Corner)
  - Future major and minor releases will be upgraded to the latest version of Embree, which no longer supports Knights Corner
  - Depending on user feedback, patch releases are still made to fix bugs
- Enhanced output statistics in ospBenchmark application
- Many fixes to the OSPRay SDK
  - Improved CMake detection of compile-time enabled features
  - Now distribute OSPRay configuration and ISPC CMake macros
  - Improved SDK support on Windows
- OSPRay library can now be compiled with -Wall and -Wextra enabled
  - Tested with GCC v5.3.1 and Clang v3.8
  - Sample applications and modules have not been fixed yet, thus applications which build OSPRay as a CMake subproject should disable them with -DOSPRAY\_ENABLE\_APPS=OFF and -DOSPRAY\_ENABLE\_MODULES=OFF
- Minor bug fixes, improvements, and cleanups
  - Regard shading normal when bump mapping
  - Fix internal CMake naming inconsistencies in macros
  - Fix missing API calls in C++ wrapper classes
  - Fix crashes on MIC
  - Fix thread count initialization bug with TBB
  - CMake optimizations for faster configuration times
  - Enhanced support for scripting in both ospGlutViewer and ospBenchmark applications

### 1.2.8 Changes in v1.0.0:

- New OSPRay SDK
  - OSPRay internal headers are now installed, enabling applications to extend OSPRay from a binary install
  - CMake macros for OSPRay and ISPC configuration now a part of binary releases
    - \* CMake clients use them by calling `include(${OSPRAY_USE_FILE})` in their CMake code after calling `find_package(ospray)`
  - New OSPRay C++ wrapper classes
    - \* These act as a thin layer on top of OSPRay object handles, where multiple wrappers will share the same underlying handle when assigned, copied, or moved
    - \* New OSPRay objects are only created when a class instance is explicitly constructed
    - \* C++ users are encouraged to use these over the `ospray.h` API
- Complete rework of sample applications
  - New shared code for parsing the commandline
  - Save/load of transfer functions now handled through a separate library which does not depend on Qt
  - Added `ospCvtParaViewTfcn` utility, which enables `ospVolumeViewer` to load color maps from ParaView
  - GLUT based sample viewer updates
    - \* Rename of `ospModelViewer` to `ospGlutViewer`

- \* GLUT viewer now supports volume rendering
  - \* Command mode with preliminary scripting capabilities, enabled by pressing ‘:’ key (not available when using Intel C++ Compiler (icc))
- Enhanced support of sample applications on Windows
- New minimum ISPC version is 1.9.0
- Support of Intel® AVX-512 for second generation Intel Xeon Phi processor (codename Knights Landing) is now a part of the OSPRAY\_BUILD\_ISA CMake build configuration
  - Compiling AVX-512 requires icc to be enabled as a build option
- Enhanced error messages when `ospLoadModule()` fails
- Added `OSP_FB_RGBA32F` support in the `DistributedFrameBuffer`
- Updated Glass shader in the path tracer
- Many miscellaneous cleanups, bugfixes, and improvements

### 1.2.9 Changes in v0.10.1:

- Fixed support of first generation Intel Xeon Phi coprocessor (codename Knights Corner)
- Restored missing implementation of `ospRemoveVolume()`

### 1.2.10 Changes in v0.10.0:

- Added new tasking options: Cilk, Internal, and Debug
  - Provides more ways for OSPRay to interact with calling application tasking systems
    - \* Cilk: Use Intel® Cilk™ Plus language extensions (icc only)
    - \* Internal: Use hand written OSPRay tasking system
    - \* Debug: All tasks are run in serial (useful for debugging)
  - In most cases, Intel Threading Building Blocks (Intel TBB) remains the fastest option
- Added support for adaptive accumulation and stopping
  - `ospRenderFrame` now returns an estimation of the variance in the rendered image if the framebuffer was created with the `OSP_FB_VARIANCE` channel
  - If the renderer parameter `varianceThreshold` is set, progressive refinement concentrates on regions of the image with a variance higher than this threshold
- Added support for volumes with `voxelType ushort` (16-bit unsigned integers)
- `OSPTexture2D` now supports sRGB formats – actually most images are stored in sRGB. As a consequence the API call `ospNewTexture2D()` needed to change to accept the new `OSPTextureFormat` parameter
- Similarly, OSPRay’s framebuffer types now also distinguishes between linear and sRGB 8-bit formats. The new types are `OSP_FB_NONE`, `OSP_FB_RGBA8`, `OSP_FB_SRGBA`, and `OSP_FB_RGBA32F`
- Changed “scivis” renderer parameter defaults
  - All shading (AO + shadows) must be explicitly enabled
- OSPRay can now use a newer, pre-installed Embree enabled by the new `OSPRAY_USE_EXTERNAL_EMBREE` CMake option
- New `ospcommon` library used to separately provide math types and OS abstractions for both OSPRay and sample applications



- Removes extra dependencies on internal Embree math types and utility functions
- `ospray.h` header is now C99 compatible
- Removed loaders module, functionality remains inside of `ospVolumeViewer`
- Many miscellaneous cleanups, bugfixes, and improvements:
  - Fixed data distributed volume rendering bugs when using less blocks than workers
  - Fixes to CMake `find_package()` config
  - Fix bug in `GhostBlockBrickVolume` when using doubles
  - Various robustness changes made in CMake to make it easier to compile OSPRay

### 1.2.11 Changes in v0.9.1:

- Volume rendering now integrated into the “scivis” renderer
  - Volumes are rendered in the same way the “dvr” volume renderer renders them
  - Ambient occlusion works with implicit isosurfaces, with a known visual quality/performance trade-off
- Intel Xeon Phi coprocessor (codename Knights Corner) COI device and build infrastructure restored (volume rendering is known to still be broken)
- New support for CPack built OSPRay binary redistributable packages
- Added support for HDRI lighting in path tracer
- Added `ospRemoveVolume()` API call
- Added ability to render a subsection of the full view into the entire framebuffer in the perspective camera
- Many miscellaneous cleanups, bugfixes, and improvements:
  - The depthbuffer is now correctly populated by in the “scivis” renderer
  - Updated default renderer to be “ao1” in `ospModelViewer`
  - `TriangleMesh postIntersect` shading is now 64-bit safe
  - `Texture2D` has been reworked, with many improvements and bug fixes
  - Fixed bug where MPI device would freeze while rendering frames with Intel TBB
  - Updates to CMake with better error messages when Intel TBB is missing

### 1.2.12 Changes in v0.9.0:

The OSPRay v0.9.0 release adds significant new features as well as API changes.

- Experimental support for data-distributed MPI-parallel volume rendering
- New SciVis-focused renderer (“raytracer” or “scivis”) combining functionality of “obj” and “ao” renderers
  - Ambient occlusion is quite flexible: dynamic number of samples, maximum ray distance, and weight
- Updated Embree version to v2.7.1 with native support for Intel AVX-512 for triangle mesh surface rendering on the Intel Xeon Phi processor (codename Knights Landing)
- OSPRay now uses C++11 features, requiring up to date compiler and standard library versions (GCC v4.8.0)
- Optimization of volume sampling resulting in volume rendering speedups of up to 1.5x

- Updates to path tracer
  - Reworked material system
  - Added texture transformations and colored transparency in OBJ material
  - Support for alpha and depth components of framebuffer
- Added thinlens camera, i.e. support for depth of field
- Tasking system has been updated to use Intel Threading Building Blocks (Intel TBB)
- The `ospGet*( )` API calls have been deprecated and will be removed in a subsequent release

### 1.2.13 Changes in v0.8.3:

- Enhancements and optimizations to path tracer
  - Soft shadows (light sources: sphere, cone, extended spot, quad)
  - Transparent shadows
  - Normal mapping (OBJ material)
- Volume rendering enhancements:
  - Expanded material support
  - Support for multiple lights
  - Support for double precision volumes
  - Added `ospSampleVolume( )` API call to support limited probing of volume values
- New features to support compositing externally rendered content with OSPRay-rendered content
  - Renderers support early ray termination through a maximum depth parameter
  - New OpenGL utility module to convert between OSPRay and OpenGL depth values
- Added panoramic and orthographic camera types
- Proper CMake-based installation of OSPRay and CMake `find_package( )` support for use in external projects
- Experimental Windows support
- Deprecated `ospNewTriangleMesh( )`; use `ospNewGeometry("triangles")` instead
- Bug fixes and cleanups throughout the codebase

### 1.2.14 Changes in v0.8.2:

- Initial support for Intel AVX-512 and the Intel Xeon Phi processor (code-name Knights Landing)
- Performance improvements to the volume renderer
- Incorporated implicit slices and isosurfaces of volumes as core geometry types
- Added support for multiple disjoint volumes to the volume renderer
- Improved performance of `ospSetRegion( )`, reducing volume load times
- Improved large data handling for the `shared_structured_volume` and `block_bricked_volume` volume types
- Added support for DDS horizon data to the seismic module
- Initial support in the Qt viewer for volume rendering
- Updated to ISPC 1.8.2
- Various bug fixes, cleanups and documentation updates throughout the codebase

### 1.2.15 Changes in v0.8.1:

- The volume renderer and volume viewer can now be run MPI parallel (data replicated) using the `--osp:mpi` command line option
- Improved performance of volume grid accelerator generation, reducing load times for large volumes
- The volume renderer and volume viewer now properly handle multiple isosurfaces
- Added small example tutorial demonstrating how to use OSPRay
- Several fixes to support older versions of GCC
- Bug fixes to `ospSetRegion()` implementation for arbitrarily shaped regions and setting large volumes in a single call
- Bug fix for geometries with invalid bounds; fixes streamline and sphere rendering in some scenes
- Fixed bug in depth buffer generation

### 1.2.16 Changes in v0.8.0:

- Incorporated early version of a new Qt-based viewer to eventually unify (and replace) the existing simpler GLUT-based viewers
- Added new path tracing renderer (`ospray/render/pathtracer`), roughly based on the Embree sample path tracer
- Added new features to the volume renderer:
  - Gradient shading (lighting)
  - Implicit isosurfacing
  - Progressive refinement
  - Support for regular grids, specified with the `gridOrigin` and `gridSpacing` parameters
  - New `shared_structured_volume` volume type that allows voxel data to be provided by applications through a shared data buffer
  - New API call to set subregions of volume data (`ospSetRegion()`)
- Added a subsampling-mode, enabled with a negative `spp` parameter; the first frame after scene changes is rendered with reduced resolution, increasing interactivity
- Added multi-target ISA support: OSPRay will now select the appropriate ISA at run time
- Added support for the Stanford SEP file format to the seismic module
- Added `--osp:numthreads <n>` command line option to restrict the number of threads OSPRay creates
- Various bug fixes, cleanups and documentation updates throughout the codebase

### 1.2.17 Changes in v0.7.2:

- Build fixes for older versions of GCC and Clang
- Fixed time series support in `ospVolumeViewer`
- Corrected memory management for shared data buffers
- Updated to ISPC 1.8.1
- Resolved issue in XML parser

# Chapter 2

## Building OSPRay from Source

The latest OSPRay sources are always available at the [OSPRay GitHub repository](#). The default master branch should always point to the latest tested bugfix release.

### 2.1 Prerequisites

OSPRay currently supports Linux, Mac OS X, and Windows. In addition, before you can build OSPRay you need the following prerequisites:

- You can clone the latest OSPRay sources via:

```
git clone https://github.com/ospray/ospray.git
```

- To build OSPRay you need [CMake](#), any form of C++11 compiler (we recommend using GCC, but also support Clang and the [Intel® C++ Compiler \(icc\)](#)), and standard Linux development tools. To build the example viewers, you should also have some version of OpenGL.
- Additionally you require a copy of the [Intel® SPMD Program Compiler \(ISPC\)](#). Please obtain a copy of the latest binary release of ISPC (currently 1.9.1) from the [ISPC downloads page](#). The build system looks for ISPC in the PATH and in the directory right “next to” the checked-out OSPRay sources.<sup>1</sup> Alternatively set the CMake variable ISPC\_EXECUTABLE to the location of the ISPC compiler.
- Per default OSPRay uses the Intel® [Threading Building Blocks \(TBB\)](#) as tasking system, which we recommend for performance and flexibility reasons. Alternatively you can set CMake variable OSPRAY\_TASKING\_SYSTEM to OpenMP, Internal, or Cilk (icc only).
- OSPRay also heavily uses [Embree](#), installing version 2.13 or newer is required. If Embree is not found by CMake its location can be hinted with the variable embree\_DIR.

<sup>1</sup> For example, if OSPRay is in ~/Projects/ospray, ISPC will also be searched in ~/Projects/ispc-v1.9.1-linux

Depending on your Linux distribution you can install these dependencies using yum or apt-get. Some of these packages might already be installed or might have slightly different names.

Type the following to install the dependencies using yum:

```
sudo yum install cmake.x86_64
sudo yum install tbb.x86_64 tbb-devel.x86_64
```

Type the following to install the dependencies using apt-get:

```
sudo apt-get install cmake-curses-gui
sudo apt-get install libtbb-dev
```

Under Mac OS X these dependencies can be installed using [MacPorts](#):

```
sudo port install cmake tbb
```

## 2.2 Compiling OSPRay

Assume the above requisites are all fulfilled, building OSPRay through CMake is easy:

- Create a build directory, and go into it

```
user@mymachine[~/Projects]: mkdir ospray/release
user@mymachine[~/Projects]: cd ospray/release
```

(We do recommend having separate build directories for different configurations such as release, debug, etc).

- The compiler CMake will use will default to whatever the CC and CXX environment variables point to. Should you want to specify a different compiler, run cmake manually while specifying the desired compiler. The default compiler on most linux machines is gcc, but it can be pointed to clang instead by executing the following:

```
user@mymachine[~/Projects/ospray/release]: cmake
-DMAKE_CXX_COMPILER=clang++ -DCMAKE_C_COMPILER=clang ..
```

CMake will now use Clang instead of GCC. If you are ok with using the default compiler on your system, then simply skip this step. Note that the compiler variables cannot be changed after the first cmake or cmake run.

- Open the CMake configuration dialog

```
user@mymachine[~/Projects/ospray/release]: cmake ..
```

- Make sure to properly set build mode and enable the components you need, etc; then type 'c'onfigure and 'g'enerate. When back on the command prompt, build it using

```
user@mymachine[~/Projects/ospray/release]: make
```

- You should now have libospray.so as well as a set of example application. You can test your version of OSPRay using any of the examples on the [OSPRay Demos and Examples](#) page.

# Chapter 3

## OSPRay API

To access the OSPRay API you first need to include the OSPRay header

```
#include "ospray/ospray.h"
```

where the API is compatible with C99 and C++.

### 3.1 Initialization

In order to use the API, OSPRay must be initialized with a “device”. A device is the object which implements the API. Creating and initializing a device can be done in either of two ways: command line arguments or manually instantiating a device.

#### 3.1.1 Command Line Arguments

The first is to do so by giving OSPRay the command line from `main()` by calling

```
OSPError ospInit(int *argc, const char **argv);
```

OSPRay parses (and removes) its known command line parameters from your application’s main function. For an example see the [tutorial](#). For possible error codes see section [Error Handling and Status Messages](#). It is important to note that the arguments passed to `ospInit()` are processed in order they are listed. The following parameters (which are prefixed by convention with “--osp:”) are understood:

#### 3.1.2 Manual Device Instantiation

The second method of initialization is to explicitly create the device yourself, and possibly set parameters. This method looks almost identical to how other [objects](#) are created and used by OSPRay (described in later sections). The first step is to create the device with

```
OSPDevice ospNewDevice(const char *type);
```

where the type string maps to a specific device implementation. OSPRay always provides the “default” device, which maps to a local CPU rendering device. If it is enabled in the build, you can also use “mpi” to access the MPI multi-node rendering device (see [Parallel Rendering with MPI](#) section for more information). Once a device is created, you can call

```
void ospDeviceSet1i(OSPDevice, const char *id, int val);
```

Table 3.1 – Command line parameters accepted by OSPRay’s ospInit.

| Parameter             | Description   |
|-----------------------|---|
| --osp:debug           | enables various extra checks and debug output, and disables multi-threading   |
| --osp:numthreads <n>  | use n threads instead of per default using all detected hardware threads  |
| --osp:loglevel <n>    | set logging level, default 0; increasing n means increasingly verbose log messages  |
| --osp:verbose         | shortcut for --osp:loglevel 1   |
| --osp:vv              | shortcut for --osp:loglevel 2   |
| --osp:module:<name>   | load a module during initialization; equivalent to calling ospLoadModule(name)  |
| --osp:mpi             | enables MPI mode for parallel rendering with the mpi_offload device, to be used in conjunction with mpirun; this will automatically load the “mpi” module if it is not yet loaded or linked                         |
| --osp:mpi-offload     | same as --osp:mpi   |
| --osp:mpi-distributed | same as --osp:mpi, but will create an mpi_distributed device instead; Note that this will likely require application changes to work properly   |
| --osp:logoutput <dst> | convenience for setting where error/status messages go; valid values for dst are cerr and cout  |
| --osp:device:<name>   | use name as the type of device for OSPRay to create; e.g. --osp:device:default gives you the default local device; Note if the device to be used is defined in a module, remember to pass --osp:module:<name> first |
| --osp:setaffinity <n> | if 1, bind software threads to hardware threads; 0 disables binding; default is 1 on KNL and 0 otherwise  |

or

```
void ospDeviceSetString(OSPDevice, const char *id, const char *val);
```

to set parameters on the device. The following parameters can be set on all devices:

Table 3.2 – Parameters shared by all devices.

| Type | Name        | Description   |
|------|-------------|---|
| int  | numThreads  | number of threads which OSPRay should use   |
| int  | logLevel    | logging level   |
| int  | debug       | set debug mode; equivalent to logLevel=2 and numThreads=1   |
| int  | setAffinity | bind software threads to hardware threads if set to 1; 0 disables binding omitting the parameter will let OSPRay choose |

Once parameters are set on the created device, the device must be committed with

```
void ospDeviceCommit(OSPDevice);
```

To use the newly committed device, you must call

```
void ospSetCurrentDevice(OSPDevice);
```

This then sets the given device as the object which will respond to all other OSPRay API calls.

Users can change parameters on the device after initialization (from either method above), by calling

```
OSPDevice ospGetCurrentDevice();
```

This function returns the handle to the device currently used to respond to OSPRay API calls, where users can set/change parameters and recommit the device. If changes are made to the device that is already set as the current device, it does not need to be set as current again.

### 3.1.3 Environment Variables

Finally, OSPRay’s generic device parameters can be overridden via environment variables for easy changes to OSPRay’s behavior without needing to change the application (variables are prefixed by convention with “OSPRAY\_”):

| Variable            | Description                                  |
|---------------------|--|
| OSPRAY_THREADS      | equivalent to <code>--osp:numthreads</code>  |
| OSPRAY_LOG_LEVEL    | equivalent to <code>--osp:loglevel</code>    |
| OSPRAY_LOG_OUTPUT   | equivalent to <code>--osp:logoutput</code>   |
| OSPRAY_DEBUG        | equivalent to <code>--osp:debug</code>       |
| OSPRAY_SET_AFFINITY | equivalent to <code>--osp:setaffinity</code> |

**Table 3.3** – Environment variables interpreted by OSPRay.

### 3.1.4 Error Handling and Status Messages

The following errors are currently used by OSPRay:

| Name                  | Description   |
|-----------------------|---|
| OSP_NO_ERROR          | no error occurred                                     |
| OSP_UNKNOWN_ERROR     | an unknown error occurred                             |
| OSP_INVALID_ARGUMENT  | an invalid argument was specified                     |
| OSP_INVALID_OPERATION | the operation is not allowed for the specified object |
| OSP_OUT_OF_MEMORY     | there is not enough memory to execute the command     |
| OSP_UNSUPPORTED_CPU   | the CPU is not supported (minimum ISA is SSE4.1)      |

**Table 3.4** – Possible error codes, i.e. valid named constants of type `OSPError`.

These error codes are either directly return by some API functions, or are recorded to be later queried by the application via

```
OSPError ospDeviceGetLastErrorCode(OSPDevice);
```

A more descriptive error message can be queried by calling

```
const char* ospDeviceGetLastErrorMsg(OSPDevice);
```

Alternatively, the application can also register a callback function of type

```
typedef void (*OSPErrorFunc)(OSPError, const char* errorDetails);
```

via

```
void ospDeviceSetErrorFunc(OSPDevice, OSPErrorFunc);
```



to get notified when errors occur.

Applications may be interested in messages which OSPRay emits, whether for debugging or logging events. Applications can call

```
void ospDeviceSetStatusFunc(OSPDevice, OSPStatusFunc);
```

in order to register a callback function of type

```
typedef void (*OSPStatusFunc)(const char* messageText);
```

which OSPRay will use to emit status messages. By default, OSPRay uses a callback which does nothing, so any output desired by an application will require that a callback is provided. Note that callbacks for C++ `std::cout` and `std::cerr` can be alternatively set through `ospInit()` or the `OSPRAY_LOG_OUT-PUT` environment variable.

### 3.1.5 Loading OSPRay Extensions at Runtime

OSPRay's functionality can be extended via plugins, which are implemented in shared libraries. To load plugin name from `libospray_module_<name>.so` (on Linux and Mac OS X) or `ospray_module_<name>.dll` (on Windows) use

```
OSPError ospLoadModule(const char *name);
```

Modules are searched in OS-dependent paths, which include the application directory. `ospLoadModule` returns `OSP_NO_ERROR` if the plugin could be successfully loaded.

## 3.2 Objects

All entities of OSPRay (the renderer, volumes, geometries, lights, cameras, ...) are a specialization of `OSPObject` and share common mechanism to deal with parameters and lifetime.

An important aspect of object parameters is that parameters do not get passed to objects immediately. Instead, parameters are not visible at all to objects until they get explicitly committed to a given object via a call to

```
void ospCommit(OSPObject);
```

at which time all previously additions or changes to parameters are visible at the same time. If a user wants to change the state of an existing object (e.g., to change the origin of an already existing camera) it is perfectly valid to do so, as long as the changed parameters are recommitted.

The commit semantic allow for batching up multiple small changes, and specifies exactly when changes to objects will occur. This is important to ensure performance and consistency for devices crossing a PCI bus, or across a network. In our MPI implementation, for example, we can easily guarantee consistency among different nodes by MPI barrier'ing on every commit.

Note that OSPRay uses reference counting to manage the lifetime of all objects, so one cannot explicitly "delete" any object. Instead, to indicate that the application does not need and does not access the given object anymore, call

```
void ospRelease(OSPObject);
```

This decreases its reference count and if the count reaches 0 the object will automatically get deleted.

### 3.2.1 Parameters

Parameters allow to configure the behavior of and to pass data to objects. However, objects do *not* have an explicit interface for reasons of high flexibility and a more stable compile-time API. Instead, parameters are passed separately to objects in an arbitrary order, and unknown parameters will simply be ignored. The following functions allow adding various types of parameters with name `id` to a given object:

```
// add a C-string (zero-terminated char *) parameter
void ospSetString(OSPObject, const char *id, const char *s);

// add an object handle parameter to another object
void ospSetObject(OSPObject, const char *id, OSPObject object);

// add an untyped pointer -- this will *ONLY* work in local rendering!
void ospSetVoidPtr(OSPObject, const char *id, void *v);

// add scalar and vector integer and float parameters
void ospSetf (OSPObject, const char *id, float x);
void ospSet1f (OSPObject, const char *id, float x);
void ospSet1i (OSPObject, const char *id, int32_t x);
void ospSet2f (OSPObject, const char *id, float x, float y);
void ospSet2fv(OSPObject, const char *id, const float *xy);
void ospSet2i (OSPObject, const char *id, int x, int y);
void ospSet2iv(OSPObject, const char *id, const int *xy);
void ospSet3f (OSPObject, const char *id, float x, float y, float z);
void ospSet3fv(OSPObject, const char *id, const float *xyz);
void ospSet3i (OSPObject, const char *id, int x, int y, int z);
void ospSet3iv(OSPObject, const char *id, const int *xyz);
void ospSet4f (OSPObject, const char *id, float x, float y, float z, float w);
void ospSet4fv(OSPObject, const char *id, const float *xyzw);

// additional functions to pass vector integer and float parameters in C++
void ospSetVec2f(OSPObject, const char *id, const vec2f &v);
void ospSetVec2i(OSPObject, const char *id, const vec2i &v);
void ospSetVec3f(OSPObject, const char *id, const vec3f &v);
void ospSetVec3i(OSPObject, const char *id, const vec3i &v);
void ospSetVec4f(OSPObject, const char *id, const vec4f &v);
```

Users can also remove parameters that have been explicitly set via an `ospSet` call. Any parameters which have been removed will go back to their default value during the next commit unless a new parameter was set after the parameter was removed. The following API function removes the named parameter from the given object:

```
void ospRemoveParam(OSPObject, const char *id);
```

### 3.2.2 Data

There is also the possibility to aggregate many values of the same type into an array, which then itself can be used as a parameter to objects. To create such a new data buffer, holding `numItems` elements of the given type, from the initialization data pointed to by `source` and optional creation flags, use

```
OSPData ospNewData(size_t numItems,
                  OSPDataType,
                  const void *source,
                  const uint32_t dataCreationFlags = 0);
```

The call returns an `OSPData` handle to the created array. The flag `OSP_DATA_SHARED_BUFFER` indicates that the buffer can be shared with the application. In this case the calling program guarantees that the source pointer will remain valid for the duration that this data array is being used. The enum type `OSPDataType` describes the different data types that can be represented in OSPRay; valid constants are listed in the table below.

| Type/Name                          | Description                                   |
|------------------------------------|---|
| <code>OSP_DEVICE</code>            | API device object reference                   |
| <code>OSP_VOID_PTR</code>          | void pointer                                  |
| <code>OSP_DATA</code>              | data reference                                |
| <code>OSP_OBJECT</code>            | generic object reference                      |
| <code>OSP_CAMERA</code>            | camera object reference                       |
| <code>OSP_FRAMEBUFFER</code>       | framebuffer object reference                  |
| <code>OSP_LIGHT</code>             | light object reference                        |
| <code>OSP_MATERIAL</code>          | material object reference                     |
| <code>OSP_TEXTURE</code>           | texture object reference                      |
| <code>OSP_RENDERER</code>          | renderer object reference                     |
| <code>OSP_MODEL</code>             | model object reference                        |
| <code>OSP_GEOMETRY</code>          | geometry object reference                     |
| <code>OSP_VOLUME</code>            | volume object reference                       |
| <code>OSP_TRANSFER_FUNCTION</code> | transfer function object reference            |
| <code>OSP_PIXEL_OP</code>          | pixel operation object reference              |
| <code>OSP_STRING</code>            | C-style zero-terminated character string      |
| <code>OSP_CHAR</code>              | 8 bit signed character scalar                 |
| <code>OSP_UCHAR</code>             | 8 bit unsigned character scalar               |
| <code>OSP_UCHAR[234]</code>        | ... and [234]-element vector                  |
| <code>OSP_USHORT</code>            | 16 bit unsigned integer scalar                |
| <code>OSP_INT</code>               | 32 bit signed integer scalar                  |
| <code>OSP_INT[234]</code>          | ... and [234]-element vector                  |
| <code>OSP_UINT</code>              | 32 bit unsigned integer scalar                |
| <code>OSP_UINT[234]</code>         | ... and [234]-element vector                  |
| <code>OSP_LONG</code>              | 64 bit signed integer scalar                  |
| <code>OSP_LONG[234]</code>         | ... and [234]-element vector                  |
| <code>OSP_ULONG</code>             | 64 bit unsigned integer scalar                |
| <code>OSP_ULONG[234]</code>        | ... and [234]-element vector                  |
| <code>OSP_FLOAT</code>             | 32 bit single precision floating point scalar |
| <code>OSP_FLOAT[234]</code>        | ... and [234]-element vector                  |
| <code>OSP_FLOAT3A</code>           | ... and aligned 3-element vector              |
| <code>OSP_DOUBLE</code>            | 64 bit double precision floating point scalar |

**Table 3.5** – Valid named constants for `OSPDataType`.

To add a data array as parameter named `id` to another object call

```
void ospSetData(OSPObject, const char *id, OSPData);
```

### 3.3 Volumes

Volumes are volumetric datasets with discretely sampled values in 3D space, typically a 3D scalar field. To create a new volume object of given type `type` use

```
OSPVolume ospNewVolume(const char *type);
```

The call returns NULL if that type of volume is not known by OSPRay, or else an OSPVolume handle.

#### 3.3.1 Structured Volume

Structured volumes only need to store the values of the samples, because their addresses in memory can be easily computed from a 3D position. A common type of structured volumes are regular grids. OSPRay supports two variants that differ in how the volumetric data for the regular grids is specified.

The first variant shares the voxel data with the application. Such a volume type is created by passing the type string “shared\_structured\_volume” to `ospNewVolume`. The voxel data is laid out in memory in XYZ order and provided to the volume via a [data](#) buffer parameter named “voxelData”.

The second regular grid variant is optimized for rendering performance: data locality in memory is increased by arranging the voxel data in smaller blocks. This volume type is created by passing the type string “block\_bricked\_volume” to `ospNewVolume`. Because of this rearrangement of voxel data it cannot be shared the with the application anymore, but has to be transferred to OSPRay via

```
OSPError ospSetRegion(OSPVolume, void *source,
                      const vec3i &regionCoords,
                      const vec3i &regionSize);
```

The voxel data pointed to by `source` is copied into the given volume starting at position `regionCoords`, must be of size `regionSize` and be placed in memory in XYZ order. Note that OSPRay distinguishes between volume data and volume parameters. This function must be called only after all volume parameters (in particular dimensions and `voxelType`, see below) have been set and *before* `ospCommit(volume)` is called. If necessary then memory for the volume is allocated on the first call to this function.

The common parameters understood by both structured volume variants are summarized in the table below. If `voxelRange` is not provided for a volume OSPRay will compute it based on the voxel data, which may result in slower data updates.

#### 3.3.2 Transfer Function

Transfer functions map the scalar values of volumes to color and opacity and thus they can be used to visually emphasize certain features of the volume. To create a new transfer function of given type `type` use

```
OSPTransferFunction ospNewTransferFunction(const char *type);
```

The call returns NULL if that type of transfer functions is not known by OSPRay, or else an OSPTransferFunction handle to the created transfer function. That handle can be assigned to a volume as parameter “transferFunction” using `ospSetObject`.

One type of transfer function that is built-in in OSPRay is the linear transfer function, which interpolates between given equidistant colors and opacities. It is create by passing the string “piecewise\_linear” to `ospNewTransferFunction` and it is controlled by these parameters:

Table 3.6 – Parameters to configure a structured volume.

| Type   | Name                    | Default   | Description   |
|--------|-------------------------|-----------|---|
| vec3i  | dimensions              |           | number of voxels in each dimension ( $x, y, z$ )  |
| string | voxelType               |           | data type of each voxel, currently supported are:<br>“uchar” (8 bit unsigned integer)<br>“short” (16 bit signed integer)<br>“ushort” (16 bit unsigned integer)<br>“float” (32 bit single precision floating point)<br>“double” (64 bit double precision floating point) |
| vec2f  | voxelRange              |           | minimum and maximum of the scalar values  |
| vec3f  | gridOrigin              | (0, 0, 0) | origin of the grid in world-space   |
| vec3f  | gridSpacing             | (1, 1, 1) | size of the grid cells in world-space   |
| bool   | gradientShadingEnabled  | false     | volume is rendered with surface shading wrt. to normalized gradient   |
| bool   | preIntegration          | false     | use pre-integration for <a href="#">transfer function</a> lookups   |
| bool   | singleShade             | true      | shade only at the point of maximum intensity  |
| bool   | adaptiveSampling        | true      | adapt ray step size based on opacity  |
| float  | adaptiveScalar          | 15        | modifier for adaptive step size   |
| float  | adaptiveMaxSamplingRate | 2         | maximum sampling rate for adaptive sampling   |
| float  | samplingRate            | 0.125     | sampling rate of the volume (this is the minimum step size for adaptive sampling)   |
| vec3f  | specular                | gray 0.3  | specular color for shading  |
| vec3f  | volumeClippingBoxLower  | disabled  | lower coordinate (in object-space) to clip the volume values  |
| vec3f  | volumeClippingBoxUpper  | disabled  | upper coordinate (in object-space) to clip the volume values  |

| Type    | Name       | Description                                   |
|---------|------------|---|
| vec3f[] | colors     | <a href="#">data</a> array of RGB colors      |
| float[] | opacities  | <a href="#">data</a> array of opacities       |
| vec2f   | valueRange | domain (scalar range) this function maps from |

Table 3.7 – Parameters accepted by the linear transfer function.

## 3.4 Geometries

Geometries in OSPRay are objects that describe surfaces. To create a new geometry object of given type `type` use

```
OSPGeometry ospNewGeometry(const char *type);
```

The call returns NULL if that type of geometry is not known by OSPRay, or else an OSPGeometry handle.

### 3.4.1 Triangle Mesh

A traditional triangle mesh (indexed face set) geometry is created by calling `ospNewGeometry` with type string “triangles”. Once created, a triangle mesh recognizes the following parameters:

| Type               | Name            | Description  |
|--------------------|-----------------|--|
| vec3f(a)[]         | vertex          | <a href="#">data</a> array of vertex positions                 |
| vec3f(a)[]         | vertex.normal   | <a href="#">data</a> array of vertex normals                   |
| vec4f[] / vec3fa[] | vertex.color    | <a href="#">data</a> array of vertex colors (RGBA/RGB)         |
| vec2f[]            | vertex.texcoord | <a href="#">data</a> array of vertex texture coordinates       |
| vec3i(a)[]         | index           | <a href="#">data</a> array of triangle indices (into vertex.*) |

**Table 3.8** – Parameters defining a triangle mesh geometry.

### 3.4.2 Spheres

A geometry consisting of individual spheres, each of which can have an own radius, is created by calling `ospNewGeometry` with type string “spheres”. The spheres will not be tessellated but rendered procedurally and are thus perfectly round. To allow a variety of sphere representations in the application this geometry allows a flexible way of specifying the data of center position and radius within a [data](#) array:

**Table 3.9** – Parameters defining a spheres geometry.

| Type                    | Name             | Default | Description   |
|-------------------------|------------------|---------|---|
| float                   | radius           | 0.01    | radius of all spheres (if <code>offset_radius</code> is not used)   |
| OSPData                 | spheres          | NULL    | memory holding the spatial <a href="#">data</a> of all spheres  |
| int                     | bytes_per_sphere | 16      | size (in bytes) of each sphere within the spheres array   |
| int                     | offset_center    | 0       | offset (in bytes) of each sphere’s “vec3f center” position (in object-space) within the spheres array         |
| int                     | offset_radius    | -1      | offset (in bytes) of each sphere’s “float radius” within the spheres array (-1 means disabled and use radius) |
| vec4f[] /<br>vec3f(a)[] | color            | NULL    | <a href="#">data</a> array of colors (RGBA/RGB), color is constant for each sphere                            |
| vec2f[]                 | texcoord         | NULL    | <a href="#">data</a> array of texture coordinates, coordinate is constant for each sphere                     |

### 3.4.3 Cylinders

A geometry consisting of individual cylinders, each of which can have an own radius, is created by calling `ospNewGeometry` with type string “cylinders”. The cylinders will not be tessellated but rendered procedurally and are thus perfectly round. To allow a variety of cylinder representations in the application this geometry allows a flexible way of specifying the data of offsets for start position, end position and radius within a [data](#) array. All parameters are listed in the table below.

For texturing each cylinder is seen as a 1D primitive, i.e. a line segment: the 2D texture coordinates at its vertices `v0` and `v1` are linearly interpolated.

### 3.4.4 Streamlines

A geometry consisting of multiple stream lines of constant radius is created by calling `ospNewGeometry` with type string “streamlines”. The stream lines are

Table 3.10 – Parameters defining a cylinders geometry.

| Type                              | Name               | Default | Description   |
|-----------------------------------|--------------------|---------|---|
| float                             | radius             | 0.01    | radius of all cylinders (if <code>offset_radius</code> is not used)   |
| OSPData                           | cylinders          | NULL    | memory holding the spatial <a href="#">data</a> of all cylinders  |
| int                               | bytes_per_cylinder | 24      | size (in bytes) of each cylinder within the <code>cylinders</code> array  |
| int                               | offset_v0          | 0       | offset (in bytes) of each cylinder’s “ <code>vec3f v0</code> ” position (the start vertex, in object-space) within the <code>cylinders</code> array |
| int                               | offset_v1          | 12      | offset (in bytes) of each cylinder’s “ <code>vec3f v1</code> ” position (the end vertex, in object-space) within the <code>cylinders</code> array   |
| int                               | offset_radius      | -1      | offset (in bytes) of each cylinder’s “float radius” within the <code>cylinders</code> array (-1 means disabled and use <code>radius</code> instead) |
| <code>vec4f[] / vec3f(a)[]</code> | color              | NULL    | <a href="#">data</a> array of colors (RGBA/RGB), color is constant for each cylinder  |
| OSPData                           | texcoord           | NULL    | <a href="#">data</a> array of texture coordinates, in pairs (each a <code>vec2f</code> at vertex <code>v0</code> and <code>v1</code> )              |

internally assembled from connected (and rounded) cylinder segments and are thus perfectly round. The parameters defining this geometry are listed in the table below.

| Type                  | Name         | Description  |
|-----------------------|--------------|--|
| float                 | radius       | radius of all stream lines, default 0.01                               |
| <code>vec3fa[]</code> | vertex       | <a href="#">data</a> array of all vertices for <i>all</i> stream lines |
| <code>vec4f[]</code>  | vertex.color | <a href="#">data</a> array of corresponding vertex colors (RGBA)       |
| <code>int32[]</code>  | index        | <a href="#">data</a> array of indices to the first vertex of a link    |

Table 3.11 – Parameters defining a streamlines geometry.

Each stream line is specified by a set of (aligned) `vec3fa` control points in `vertex`; all vertices belonging to the same logical stream line are connected via [cylinders](#) of a fixed radius `radius`, with additional [spheres](#) at each vertex to make for a smooth transition between the cylinders.

A streamlines geometry can contain multiple disjoint stream lines, each streamline is specified as a list of linear segments (or links) referenced via `index`: each entry `e` of the `index` array points the first vertex of a link (`vertex[index[e]]`) and the second vertex of the link is implicitly the directly following one (`vertex[index[e]+1]`). For example, two stream lines of vertices (A-B-C-D) and (E-F-G), respectively, would internally correspond to five links (A-B, B-C, C-D, E-F, and F-G), and would be specified via an array of vertices `[A,B,C,D,E,F,G]`, plus an array of link indices `[0,1,2,4,5]`.

### 3.4.5 Isosurfaces

OSPRay can directly render multiple isosurfaces of a volume without first tessellating them. To do so create an isosurfaces geometry by calling `ospNewGeometry` with type string “`isosurfaces`”. Each isosurface will be colored according to the provided volume’s [transfer function](#).

### 3.4.6 Slices

One tool to highlight interesting features of volumetric data is to visualize 2D cuts (or slices) by placing planes into the volume. Such a slices geometry is created

| Type      | Name      | Description  |
|-----------|-----------|--|
| float[]   | isovalues | <a href="#">data</a> array of isovalues                |
| OSPVolume | volume    | handle of the <a href="#">volume</a> to be isosurfaced |

**Table 3.12** – Parameters defining an iso-surfaces geometry.

by calling `ospNewGeometry` with type string “slices”. The planes are defined by the coefficients  $(a, b, c, d)$  of the plane equation  $ax + by + cz + d = 0$ . Each slice is colored according to the provided volume’s [transfer function](#).

| Type      | Name   | Description   |
|-----------|--------|---|
| vec4f[]   | planes | <a href="#">data</a> array with plane coefficients for all slices |
| OSPVolume | volume | handle of the <a href="#">volume</a> that will be sliced          |

**Table 3.13** – Parameters defining a slices geometry.

### 3.4.7 Instances

OSPRay supports instancing via a special type of geometry. Instances are created by transforming another given [model](#) `modelToInstantiate` with the given affine transformation `transform` by calling

```
OSPGeometry ospNewInstance(OSPModel modelToInstantiate, const affine3f &transform);
```

## 3.5 Renderer

A renderer is the central object for rendering in OSPRay. Different renderers implement different features and support different materials. To create a new renderer of given type `type` use

```
OSPRenderer ospNewRenderer(const char *type);
```

The call returns NULL if that type of renderer is not known, or else an `OSPRenderer` handle to the created renderer. General parameters of all renderers are

| Type       | Name              | Description  |
|------------|-------------------|--|
| OSPModel   | model             | the <a href="#">model</a> to render  |
| OSPCamera  | camera            | the <a href="#">camera</a> to be used for rendering                                    |
| OSPLight[] | lights            | <a href="#">data</a> array with handles of the <a href="#">lights</a>                  |
| float      | epsilon           | ray epsilon to avoid self-intersections, relative to scene diameter, default $10^{-6}$ |
| int        | spp               | samples per pixel, default 1   |
| int        | maxDepth          | maximum ray recursion depth  |
| float      | varianceThreshold | threshold for adaptive accumulation  |

**Table 3.14** – Parameters understood by all renderers.

OSPRay’s renderers support a feature called adaptive accumulation, which accelerates progressive [rendering](#) by stopping the rendering and refinement of image regions that have an estimated variance below the `varianceThreshold`. This feature requires a [framebuffer](#) with an `OSP_FB_VARIANCE` channel.



### 3.5.1 SciVis Renderer

The SciVis renderer is a fast ray tracer for scientific visualization which supports volume rendering and ambient occlusion (AO). It is created by passing the type string “scivis” or “raytracer” to `ospNewRenderer`. In addition to the [general parameters](#) understood by all renderers the SciVis renderer supports the following special parameters:

**Table 3.15** – Special parameters understood by the SciVis renderer.

| Type                  | Name                  | Default            | Description  |
|-----------------------|-----------------------|--------------------|--|
| bool                  | shadowsEnabled        | false              | whether to compute (hard) shadows  |
| int                   | aoSamples             | 0                  | number of rays per sample to compute ambient occlusion                             |
| float                 | aoDistance            | $10^{20}$          | maximum distance to consider for ambient occlusion                                 |
| bool                  | aoTransparencyEnabled | false              | whether object transparency is respected when computing ambient occlusion (slower) |
| bool                  | oneSidedLighting      | true               | if true back-facing surfaces (wrt. light source) receive no illumination           |
| float / vec3f / vec4f | bgColor               | black, transparent | background color and alpha (RGBA)  |
| OSPTexture2D          | maxDepthTexture       | NULL               | screen-sized float <a href="#">texture</a> with maximum far distance per pixel     |

Note that the intensity (and color) of AO is controlled via an [ambient light](#). If `aoSamples` is zero (the default) then ambient lights cause ambient illumination (without occlusion).

Per default the background of the rendered image will be transparent black, i.e. the alpha channel holds the opacity of the rendered objects. This facilitates transparency-aware blending of the image with an arbitrary background image by the application. The parameter `bgColor` can be used to already blend with a constant background color (and alpha) during rendering.

The SciVis renderer supports depth composition with images of other renderers, for example to incorporate help geometries of a 3D UI that were rendered with OpenGL. The screen-sized [texture](#) `maxDepthTexture` must have format `OSP_TEXTURE_R32F` and flag `OSP_TEXTURE_FILTER_NEAREST`. The fetched values are used to limit the distance of primary rays, thus objects of other renderers can hide objects rendered by OSPRay.

### 3.5.2 Path Tracer

The path tracer supports soft shadows, indirect illumination and realistic materials. In addition to the [general parameters](#) understood by all renderers the path tracer supports the following special parameters:

### 3.5.3 Model

Models are a container of scene data. They can hold the different [geometries](#) and [volumes](#) as well as references to (and [instances](#) of) other models. A model is associated with a single logical acceleration structure. To create an (empty) model call

```
OSPModel ospNewModel();
```

The call returns an `OSPModel` handle to the created model. To add an already created geometry or volume to a model use

Table 3.16 – Special parameters understood by the path tracer.

| Type         | Name            | Default  | Description   |
|--------------|-----------------|----------|---|
| float        | minContribution | 0.01     | sample contributions below this value will be neglected to speed-up rendering   |
| float        | maxContribution | $\infty$ | samples are clamped to this value before they are accumulated into the framebuffer  |
| OSPTexture2D | backplate       | NULL     | <a href="#">texture</a> image used as background, replacing visible lights in infinity (e.g. the <a href="#">HDRI light</a> ) |

```
void ospAddGeometry(OSPModel, OSPGeometry);
void ospAddVolume(OSPModel, OSPVolume);
```

An existing geometry or volume can be removed from a model with

```
void ospRemoveGeometry(OSPModel, OSPGeometry);
void ospRemoveVolume(OSPModel, OSPVolume);
```

### 3.5.4 Lights

To let the given renderer create a new light source of given type type use

```
OSPLight ospNewLight(OSPRenderer renderer, const char *type);
```

The call returns NULL if that type of camera is not known by the renderer, or else an OSPLight handle to the created light source. All light sources<sup>1</sup> accept the following parameters:

<sup>1</sup>The [HDRI Light](#) is an exception, it knows about intensity, but not about color.

| Type     | Name      | Default | Description                            |
|----------|-----------|---------|--|
| vec3f(a) | color     | white   | color of the light                     |
| float    | intensity | 1       | intensity of the light (a factor)      |
| bool     | isVisible | true    | whether the light can be directly seen |

Table 3.17 – Parameters accepted by the all lights.

The following light types are supported by most OSPRay renderers.

#### 3.5.4.1 Directional Light / Distant Light

The distant light (or traditionally the directional light) is thought to be very far away (outside of the scene), thus its light arrives (almost) as parallel rays. It is created by passing the type string “distant” to ospNewLight. In addition to the [general parameters](#) understood by all lights the distant light supports the following special parameters:

| Type     | Name            | Description                                  |
|----------|-----------------|--|
| vec3f(a) | direction       | main emission direction of the distant light |
| float    | angularDiameter | apparent size (angle in degree) of the light |

Table 3.18 – Special parameters accepted by the distant light.

Setting the angular diameter to a value greater than zero will result in soft shadows when the renderer uses stochastic sampling (like the [path tracer](#)). For instance, the apparent size of the sun is about 0.53°.

### 3.5.4.2 Point Light / Sphere Light

The sphere light (or the special case point light) is a light emitting uniformly in all directions. It is created by passing the type string “sphere” to `ospNewLight`. In addition to the [general parameters](#) understood by all lights the sphere light supports the following special parameters:

| Type     | Name     | Description                                    |
|----------|----------|--|
| vec3f(a) | position | the center of the sphere light, in world-space |
| float    | radius   | the size of the sphere light                   |

**Table 3.19** – Special parameters accepted by the sphere light.

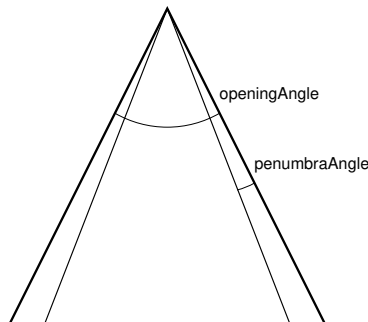
Setting the radius to a value greater than zero will result in soft shadows when the renderer uses stochastic sampling (like the [path tracer](#)).

### 3.5.4.3 Spot Light

The spot light is a light emitting into a cone of directions. It is created by passing the type string “spot” to `ospNewLight`. In addition to the [general parameters](#) understood by all lights the spot light supports the special parameters listed in the table.

**Table 3.20** – Special parameters accepted by the spot light.

| Type     | Name          | Description   |
|----------|---------------|---|
| vec3f(a) | position      | the center of the spot light, in world-space  |
| vec3f(a) | direction     | main emission direction of the spot   |
| float    | openingAngle  | full opening angle (in degree) of the spot; outside of this cone is no illumination   |
| float    | penumbraAngle | size (angle in degree) of the “penumbra”, the region between the rim (of the illumination cone) and full intensity of the spot; should be smaller than half of openingAngle |
| float    | radius        | the size of the spot light, the radius of a disk with normal direction  |



**Figure 3.1** – Angles used by SpotLight.

Setting the radius to a value greater than zero will result in soft shadows when the renderer uses stochastic sampling (like the [path tracer](#)).

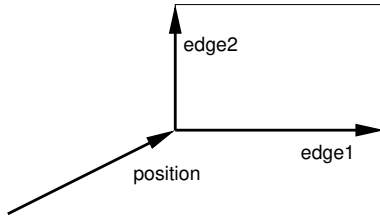
### 3.5.4.4 Quad Light

The quad<sup>2</sup> light is a planar, procedural area light source emitting uniformly on one side into the half space. It is created by passing the type string “quad” to `ospNewLight`. In addition to the [general parameters](#) understood by all lights the spot light supports the following special parameters:

<sup>2</sup> actually a parallelogram

| Type     | Name     | Description  |
|----------|----------|--|
| vec3f(a) | position | world-space position of one vertex of the quad light |
| vec3f(a) | edge1    | vector to one adjacent vertex                        |
| vec3f(a) | edge2    | vector to the other adjacent vertex                  |

**Table 3.21** – Special parameters accepted by the quad light.



**Figure 3.2** – Defining a Quad Light.

The emission side is determined by the cross product of  $\text{edge1} \times \text{edge2}$ . Note that only renderers that use stochastic sampling (like the path tracer) will compute soft shadows from the quad light. Other renderers will just sample the center of the quad light, which results in hard shadows.

#### 3.5.4.5 HDRI Light

The HDRI light is a textured light source surrounding the scene and illuminating it from infinity. It is created by passing the type string “hri” to `ospNewLight`. In addition to the [parameter intensity](#) the HDRI light supports the following special parameters:

**Table 3.22** – Special parameters accepted by the HDRI light.

| Type         | Name | Description  |
|--------------|------|--|
| vec3f(a)     | up   | up direction of the light in world-space   |
| vec3f(a)     | dir  | direction to which the center of the texture will be mapped to (analog to <a href="#">panoramic camera</a> ) |
| OSPTexture2D | map  | environment map in latitude / longitude format   |

Note that the currently only the [path tracer](#) supports the HDRI light.

#### 3.5.4.6 Ambient Light

The ambient light surrounds the scene and illuminates it from infinity with constant radiance (determined by combining the [parameters color and intensity](#)). It is created by passing the type string “ambient” to `ospNewLight`.

Note that the [SciVis renderer](#) uses ambient lights to control the color and intensity of the computed ambient occlusion (AO).

#### 3.5.4.7 Emissive Objects

The [path tracer](#) will consider illumination by [geometries](#) which have a light emitting material assigned (for example the [Luminous](#) material).

### 3.5.5 Materials

Materials describe how light interacts with surfaces, they give objects their distinctive look. To let the given renderer create a new material of given type type call

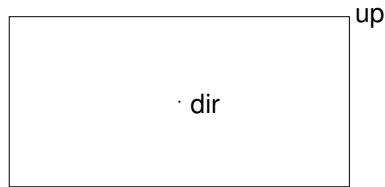


Figure 3.3 – Orientation and Mapping of an HDRI Light.

```
OSPMaterial ospNewMaterial(OSPRenderer, const char *type);
```

The call returns NULL if the material type is not known by the renderer, or else an OSPMaterial handle to the created material. The handle can then be used to assign the material to a given geometry with

```
void ospSetMaterial(OSPGeometry, OSPMaterial);
```

### 3.5.5.1 OBJ Material

The OBJ material is the workhorse material supported by both the [SciVis renderer](#) and the [path tracer](#). It offers widely used common properties like diffuse and specular reflection and is based on the [MTL material format](#) of Lightwave’s OBJ scene files. To create an OBJ material pass the type string “OBJMaterial” to `ospNewMaterial`. Its main parameters are

| Type         | Name     | Default   | Description                                       |
|--------------|----------|-----------|---|
| vec3f        | Kd       | white 0.8 | diffuse color                                     |
| vec3f        | Ks       | black     | specular color                                    |
| float        | Ns       | 10        | shininess (Phong exponent), usually in $[2-10^4]$ |
| float        | d        | opaque    | opacity   |
| vec3f        | Tf       | black     | transparency filter color                         |
| OSPTexture2D | map_Bump | NULL      | normal map  |

Table 3.23 – Main parameters of the OBJ material.

In particular when using the path tracer it is important to adhere to the principle of energy conservation, i.e. that the amount of light reflected by a surface is not larger than the light arriving. Therefore the path tracer issues a warning and renormalizes the color parameters if the sum of Kd, Ks, and Tf is larger than one in any color channel. Similarly important to mention is that almost all materials of the real world reflect at most only about 80% of the incoming light. So even for a white sheet of paper or white wall paint do better not set Kd larger than 0.8; otherwise rendering times are unnecessary long and the contrast in the final images is low (for example, the corners of a white room would hardly be discernible).

Note that currently only the path tracer implements colored transparency with Tf.

Normal mapping can simulate small geometric features via the texture `map_Bump`. The normals  $n$  in the normal map are wrt. the local tangential shading coordinate system and are encoded as  $1/2(n + 1)$ , thus a texel  $(0.5, 0.5, 1)$ <sup>3</sup> represents the unperturbed shading normal  $(0, 0, 1)$ . Because of this encoding an sRGB gamma [texture](#) format is ignored and normals are always fetched as linear from a normal map. Note that the orientation of normal maps is important for a visually consistent look: by convention OSPRay uses a coordinate system with the origin in the lower left corner; thus a convexity will look green towards the top of the texture image (see also the example image of a normal map). If this is not the case flip the normal map vertically or invert its green channel.

<sup>3</sup> respectively  $(127, 127, 255)$  for 8 bit textures

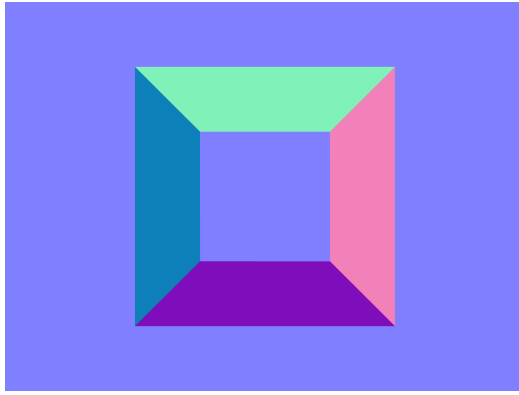


Figure 3.4 – Normal map representing an exalted square pyramidal frustum.

All parameters (except `Tf`) can be textured by passing a [texture](#) handle, prefixed with “map\_”. The fetched texels are multiplied by the respective parameter value. Texturing requires [geometries](#) with texture coordinates, e.g. a [triangle mesh](#) with `vertex.texcoord` provided. The color textures `map_Kd` and `map_Ks` are typically in one of the sRGB gamma encoded formats, whereas textures `map_Ns` and `map_d` are usually in a linear format (and only the first component is used). The path tracer additionally supports [texture transformations](#) for all textures.

### 3.5.5.2 Glass

The [path tracer](#) offers a realistic a glass material, supporting refraction and volumetric attenuation (i.e. the transparency color varies with the geometric thickness). To create a Glass material pass the type string “Glass” to `ospNewMaterial`. Its parameters are

| Type               | Name                             | Default | Description                        |
|--------------------|----------------------------------|---------|------------------------------------|
| float              | <code>eta</code>                 | 1.5     | index of refraction                |
| <code>vec3f</code> | <code>attenuationColor</code>    | white   | resulting color due to attenuation |
| float              | <code>attenuationDistance</code> | 1       | distance affecting attenuation     |

Table 3.24 – Parameters of the Glass material.

For convenience, the rather counterintuitive physical attenuation coefficients will be calculated from the user inputs in such a way, that the `attenuationColor` will be the result when white light traveled trough a glass of thickness `attenuationDistance`.

### 3.5.5.3 Luminous

The [path tracer](#) supports the Luminous material which emits light uniformly in all directions and which can thus be used to turn any geometric object into a light source. It is created by passing the type string “Luminous” to `ospNewMaterial`. The amount of constant radiance that is emitted is determined by combining the general parameters of lights: [color and intensity](#).

## 3.5.6 Texture

To create a new 2D texture of size `size` (in pixels) and with the given format and flags use

```
OSPTexture2D ospNewTexture2D(const vec2i &size,
                             const OSPTextureFormat,
                             void *source = NULL,
                             const uint32_t textureCreationFlags = 0);
```

The call returns NULL if the texture could not be created with the given parameters, or else an OSPTexture2D handle to the created texture. The supported texture formats are:

| Name                | Description   |
|---------------------|---|
| OSP_TEXTURE_RGBA8   | 8 bit [0–255] linear components red, green, blue, alpha     |
| OSP_TEXTURE_SRGBA   | 8 bit sRGB gamma encoded color components, and linear alpha |
| OSP_TEXTURE_RGBA32F | 32 bit float components red, green, blue, alpha             |
| OSP_TEXTURE_RGB8    | 8 bit [0–255] linear components red, green, blue            |
| OSP_TEXTURE_SRGB    | 8 bit sRGB gamma encoded components red, green, blue        |
| OSP_TEXTURE_RGB32F  | 32 bit float components red, green, blue                    |
| OSP_TEXTURE_R8      | 8 bit [0–255] linear single component                       |
| OSP_TEXTURE_R32F    | 32 bit float single component                               |

**Table 3.25** – Supported texture formats by ospNewTexture2D, i.e. valid constants of type OSPTextureFormat.

The texel data addressed by source starts with the texels in the lower left corner of the texture image, like in OpenGL. Similar to [data](#) buffers the texel data can be shared by the application by specifying the OSP\_TEXTURE\_SHARED\_BUFFER flag. Per default a texture fetch is filtered by performing bi-linear interpolation of the nearest 2×2 texels; if instead fetching only the nearest texel is desired (i.e. no filtering) then pass the OSP\_TEXTURE\_FILTER\_NEAREST flag. Both texture creating flags can be combined with a bitwise OR.

### 3.5.7 Texture Transformations

Many materials with textures also offer to manipulate the placement of these textures with the help of texture transformations. If so, this convention shall be used. The following parameters (prefixed with “texture\_name.”) are combined into one transformation matrix:

| Type  | Name        | Description   |
|-------|-------------|---|
| vec4f | transform   | interpreted as 2×2 matrix (linear part), column-major |
| float | rotation    | angle in degree, counterclock-wise, around center     |
| vec2f | scale       | enlarge texture, relative to center (0.5, 0.5)        |
| vec2f | translation | move texture in positive direction (right/up)         |

**Table 3.26** – Parameters to define texture coordinate transformations.

The transformations are applied in the given order. Rotation, scale and translation are interpreted “texture centric”, i.e. their effect seen by an user are relative to the texture (although the transformations are applied to the texture coordinates).

### 3.5.8 Cameras

To create a new camera of given type type use

```
OSPCamera ospNewCamera(const char *type);
```

The call returns NULL if that type of camera is not known, or else an OSPCamera handle to the created camera. All cameras accept these parameters:

| Type     | Name       | Description                               |
|----------|------------|---|
| vec3f(a) | pos        | position of the camera in world-space     |
| vec3f(a) | dir        | main viewing direction of the camera      |
| vec3f(a) | up         | up direction of the camera                |
| float    | nearClip   | near clipping distance                    |
| vec2f    | imageStart | start of image region (lower left corner) |
| vec2f    | imageEnd   | end of image region (upper right corner)  |

**Table 3.27** – Parameters accepted by all cameras.

The camera is placed and oriented in the world with `pos`, `dir` and `up`. The region of the camera sensor that is rendered to the image can be specified in normalized screen-space coordinates with `imageStart` (lower left corner) and `imageEnd` (upper right corner). This can be used, for example, to crop the image or to achieve asymmetrical view frusta. Note that values outside the default range of `[0–1]` are valid, which is useful to easily realize overscan or film gate, or to emulate a shifted sensor.

### 3.5.8.1 Perspective Camera

The perspective camera implements a simple thinlens camera for perspective rendering, supporting optionally depth of field and stereo rendering, but no motion blur. It is created by passing the type string “perspective” to `ospNewCamera`. In addition to the [general parameters](#) understood by all cameras the perspective camera supports the special parameters listed in the table below.

**Table 3.28** – Parameters accepted by the perspective camera.

| Type  | Name                   | Description  |
|-------|------------------------|--|
| float | fovy                   | the field of view (angle in degree) of the frame’s height              |
| float | aspect                 | ratio of width by height of the frame                                  |
| float | apertureRadius         | size of the aperture, controls the depth of field                      |
| float | focusDistance          | distance at where the image is sharpest when depth of field is enabled |
| bool  | architectural          | vertical edges are projected to be parallel                            |
| int   | stereoMode             | 0: no stereo (default), 1: left eye, 2: right eye, 3: side-by-side     |
| float | interpupillaryDistance | distance between left and right eye when stereo is enabled             |

Note that when setting the aspect ratio a non-default image region (using `imageStart` & `imageEnd`) needs to be regarded.

In architectural photography it is often desired for aesthetic reasons to display the vertical edges of buildings or walls vertically in the image as well, regardless of how the camera is tilted. Enabling the `architectural` mode achieves this by internally leveling the camera parallel to the ground (based on the `up` direction) and then shifting the lens such that the objects in direction `dir` are centered in the image. If finer control of the lens shift is needed use `imageStart` & `imageEnd`. Because the camera is now effectively leveled its image plane and thus the plane of focus is oriented parallel to the front of buildings, the whole façade appears sharp, as can be seen in the example images below.

### 3.5.8.2 Orthographic Camera

The orthographic camera implements a simple camera with orthographic projection, without support for depth of field or motion blur. It is created by passing the





Figure 3.5 – Example image created with the perspective camera, featuring depth of field.



Figure 3.6 – Enabling the architectural flag corrects the perspective projection distortion, resulting in parallel vertical edges.

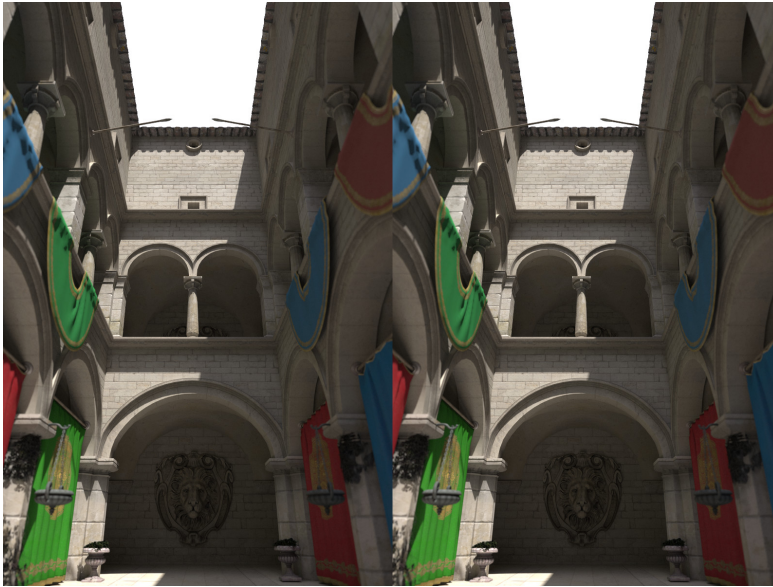


Figure 3.7 – Example 3D stereo image using stereoMode side-by-side.

type string “orthographic” to `ospNewCamera`. In addition to the [general parameters](#) understood by all cameras the orthographic camera supports the following special parameters:

| Type  | Name   | Description   |
|-------|--------|---|
| float | height | size of the camera’s image plane in y, in world coordinates |
| float | aspect | ratio of width by height of the frame                       |

Table 3.29 – Parameters accepted by the orthographic camera.

For convenience the size of the camera sensor, and thus the extent of the scene that is captured in the image, can be controlled with the `height` parameter. The same effect can be achieved with `imageStart` and `imageEnd`, and both methods can be combined. In any case, the aspect ratio needs to be set accordingly to get an undistorted image.

### 3.5.8.3 Panoramic Camera

The panoramic camera implements a simple camera without support for motion blur. It captures the complete surrounding with a latitude / longitude mapping and thus the rendered images should best have a ratio of 2:1. A panoramic camera is created by passing the type string “panoramic” to `ospNewCamera`. It is placed and oriented in the scene by using the [general parameters](#) understood by all cameras.

## 3.5.9 Picking

To get the world-space position of the geometry (if any) seen at [0–1] normalized screen-space pixel coordinates `screenPos` use

```
void ospPick(OSPPickResult*, OSPRenderer, const vec2f &screenPos);
```

The result is returned in the provided `OSPPickResult` struct:

```
typedef struct {
    vec3f position; // the position of the hit point (in world-space)
    bool hit;       // whether or not a hit actually occurred
} OSPPickResult;
```



Figure 3.8 – Example image created with the orthographic camera.



Figure 3.9 – Latitude / longitude map created with the panoramic camera.

Note that `ospPick` considers exactly the same camera of the given renderer that is used to render an image, thus matching results can be expected. If the camera supports depth of field then the center of the lens and thus the center of the circle of confusion is used for picking.

## 3.6 Framebuffer

The framebuffer holds the rendered 2D image (and optionally auxiliary information associated with pixels). To create a new framebuffer object of given size (in pixels), color format, and channels use

```
OSPFramebuffer ospNewFramebuffer(const vec2i &size,
                                const OSPFramebufferFormat format = OSP_FB_SRGBA,
                                const uint32_t framebufferChannels = OSP_FB_COLOR);
```

The parameter `format` describes the format the color buffer has *on the host*, and the format that `ospMapFramebuffer` will eventually return. Valid values are:

| Name           | Description   |
|----------------|---|
| OSP_FB_NONE    | framebuffer will not be mapped by the application           |
| OSP_FB_RGBA8   | 8 bit [0–255] linear component red, green, blue, alpha      |
| OSP_FB_SRGBA   | 8 bit sRGB gamma encoded color components, and linear alpha |
| OSP_FB_RGBA32F | 32 bit float components red, green, blue, alpha             |

**Table 3.30** – Supported color formats of the framebuffer that can be passed to `ospNewFramebuffer`, i.e. valid constants of type `OSPFramebufferFormat`.

The parameter `framebufferChannels` specifies which channels the framebuffer holds, and can be combined together by bitwise OR from the values of `OSPFramebufferChannel` listed in the table below.

| Name            | Description   |
|-----------------|---|
| OSP_FB_COLOR    | RGB color including alpha   |
| OSP_FB_DEPTH    | euclidean distance to the camera ( <i>not</i> to the image plane) |
| OSP_FB_ACCUM    | accumulation buffer for progressive refinement                    |
| OSP_FB_VARIANCE | estimate of the current variance, see <a href="#">rendering</a>   |

**Table 3.31** – Framebuffer channels constants (of type `OSPFramebufferChannel`), naming optional information the framebuffer can store. These values can be combined by bitwise OR when passed to `ospNewFramebuffer` or `ospClearFramebuffer`.

If a certain channel value is *not* specified, the given buffer channel will not be present. Note that `ospray` makes a very clear distinction between the *external* format of the framebuffer and the internal one: The external format is the format the user specifies in the `format` parameter; it specifies what color format `OSPRay` will eventually *return* the framebuffer to the application (when calling `ospMapFramebuffer`): no matter what `OSPRay` uses internally, it will simply return a 2D array of pixels of that format, with possibly all kinds of reformatting, compression/decompression, etc, going on in-between the generation of the *internal* framebuffer and the mapping of the externally visible one.

In particular, `OSP_FB_NONE` is a perfectly valid pixel format for a framebuffer that an application will never map. For example, an application driving a display wall may well generate an intermediate framebuffer and eventually transfer its pixel to the individual displays using an `OSPPixelOp` [pixel operation](#).

A framebuffer can be freed again using

```
void ospFreeFramebuffer(OSPFramebuffer);
```

Because OSPRay uses reference counting internally the framebuffer may not immediately be deleted at this time.

The application can map the given channel of a framebuffer – and thus access the stored pixel information – via

```
const void *ospMapFramebuffer(OSPFramebuffer,
                               const OSPFramebufferChannel = OSP_FB_COLOR);
```

Note that only `OSP_FB_COLOR` or `OSP_FB_DEPTH` can be mapped. The origin of the screen coordinate system in OSPRay is the lower left corner (as in OpenGL), thus the first pixel addressed by the returned pointer is the lower left pixel of the image.

A previously mapped channel of a framebuffer can be unmapped by passing the received pointer mapped to

```
void ospUnmapFramebuffer(const void *mapped, OSPFramebuffer);
```

The individual channels of a framebuffer can be cleared with

```
void ospFramebufferClear(OSPFramebuffer, const uint32_t framebufferChannels);
```

When selected, `OSP_FB_COLOR` will clear the color buffer to black (0, 0, 0, 0), `OSP_FB_DEPTH` will clear the depth buffer to inf, `OSP_FB_ACCUM` will clear the accumulation buffer to black, resets the accumulation counter `accumID` and also clears the variance buffer (if present) to inf.

## Pixel Operation

A pixel operation are functions that are applied to every pixel that gets written into a framebuffer. Examples include post-processing, filtering, blending, tone mapping, or sending tiles to a display wall. To create a new pixel operation of given type type use

```
OSPPIXelOp ospNewPixelOp(const char *type);
```

The call returns NULL if that type is not known, or else an `OSPPIXelOp` handle to the created pixel operation.

To set a pixel operation to the given framebuffer use

```
void ospSetPixelOp(OSPFramebuffer, OSPPIXelOp);
```

## 3.7 Rendering

To render a frame into the given framebuffer with the given renderer use

```
float ospRenderFrame(OSPFramebuffer, OSPRenderer,
                    const uint32_t framebufferChannels = OSP_FB_COLOR);
```

The third parameter specifies what channel(s) of the framebuffer is written to<sup>4</sup>. What to render and how to render it depends on the renderer's parameters. If the framebuffer supports accumulation (i.e. it was created with `OSP_FB_ACCUM`) then successive calls to `ospRenderFrame` will progressively refine the rendered image. If additionally the framebuffer has an `OSP_FB_VARIANCE` channel then `ospRenderFrame` returns an estimate of the current variance of the rendered image, otherwise `inf` is returned. The estimated variance can be used by the application as a quality indicator and thus to decide whether to stop or to continue progressive rendering.

<sup>4</sup> This is currently not implemented, i.e. all channels of the framebuffer are always updated.



# Chapter 4

## Parallel Rendering with MPI

OSPRay has the ability to scale to multiple nodes in a cluster via MPI. This enables applications to take advantage of larger compute and memory resources when available.

### 4.1 Prerequisites for MPI Mode

In addition to the standard build requirements of OSPRay, you must have the following items available in your environment in order to build&run OSPRay in MPI mode:

- An MPI enabled multi-node environment, such as an HPC cluster
- An MPI implementation you can build against (i.e. Intel MPI, MVAPICH2, etc...)

### 4.2 Enabling the MPI module in your build

To build the MPI module the CMake variable `OSPRAY_MODULE_MPI` must be enabled, which can be done directly on the command line (with `-D...`) or through a configuration dialog (`ccmake`, `cmake-gui`), see also [Compiling OSPRay].

This will trigger CMake to go look for an MPI implementation in your environment. You can then inspect the CMake value of `MPI_LIBRARY` to make sure that CMake found your MPI build environment correctly.

This will result in an OSPRay module being built. To enable using it, applications will need to either link `libospray_module_mpi`, or call

```
ospLoadModule("mpi");
```

before initializing OSPRay.

### 4.3 Modes of using OSPRay's MPI features

OSPRay provides two ways of using MPI to scale up rendering: offload and distributed.

The “offload” rendering mode is where a single (not-distributed) calling application treats the OSPRay API the same as with local rendering. However, OSPRay uses multiple MPI connected nodes to evenly distribute frame rendering work, where each node contains a full copy of all scene data. This method is most effective for scenes which can fit into memory, but are very expensive to render: for example, path tracing with many samples-per-pixel is very compute heavy, making it a good situation to use the offload feature. This can be done

with any application which already uses OSPRay for local rendering without the need for any code changes.

The “distributed” rendering mode is where a MPI distributed application (such as a scientific simulation) uses OSPRay collectively to render frames. In this case, the API expects all calls (both created objects and parameters) to be the same on every application rank, except each rank can specify arbitrary geometries and volumes. Each renderer will have its own limitations on the topology of the data (i.e. overlapping data regions, concave data, etc.), but the API calls will only differ for scene objects. Thus all other calls (i.e. setting camera, creating framebuffer, rendering frame, etc.) will all be assumed to be identical, but only rendering a frame and committing the model must be in lock-step. This mode targets using all available aggregate memory for very large scenes and for “in-situ” visualization where the data is already distributed by a simulation app.

## 4.4 Running an application with the “offload” device

As an example, our sample viewer can be run as a single application which offloads rendering work to multiple MPI processes running on multiple machines.

The example apps are setup to be launched in two different setups. In either setup, the application must initialize OSPRay with the offload device. This can be done by creating an “mpi\_offload” device and setting it as the current device (via the `ospSetCurrentDevice()` function), or passing either “`--osp:mpi`” or “`--osp:mpi-offload`” as a command line parameter to `ospInit()`. Note that passing a command line parameter will automatically call `ospLoadModule("mpi")` to load the MPI module, while the application will have to load the module explicitly if using `ospNewDevice()`.

### Option 1: single MPI launch

OSPRay is initialized with the `ospInit()` function call which takes command line arguments in and configures OSPRay based on what it finds. In this setup, the app is launched across all ranks, but workers will never return from `ospInit()`, essentially turning the application into a worker process for OSPRay. Here’s an example of running the `ospVolumeViewer` data-replicated, using `c1-c4` as compute nodes and `localhost` the process running the viewer itself:

```
% mpirun -perhost 1 -hosts localhost,c1,c2,c3,c4 ./ospExampleViewer [scene_file] --osp:mpi
```

### Option 2: separate app/worker launches

The second option is to explicitly launch the app on rank 0 and worker ranks on the other nodes. This is done by running `ospray_mpi_worker` on worker nodes and the application on the display node. Here’s the same example above using this syntax:

```
% mpirun -perhost 1 -hosts localhost ./ospExampleViewer [scene_file] --osp:mpi \
: -hosts c1,c2,c3,c4 ./ospray_mpi_worker --osp:mpi
```

This method of launching the application and OSPRay worker separately works best for applications which do not immediately call `ospInit()` in their `main()` function, or for environments where application dependencies (such as GUI libraries) may not be available on compute nodes.

## 4.5 Running an application with the “distributed” device

Applications using the new distributed device should initialize OSPRay by creating (and setting current) an “mpi\_distributed” device or pass “--osp:mpi-distributed” as a command line argument to `ospInit()`. Note that due to the semantic differences the distributed device gives the OSPRay API, it is not expected for applications which can already use the offload device to correctly use the distributed device without changes to the application.



# Chapter 5

## Examples

### 5.1 Tutorial

A minimal working example demonstrating how to use OSPRay can be found at `apps/ospTutorial.cpp`<sup>1</sup>. On Linux build it in the build directory with

<sup>1</sup> A C99 version is available at `apps/ospTutorial.c`.

```
g++ ../apps/ospTutorial.cpp -I ../ospray/include -I .. ./libospray.so -Wl,-rpath,. -o ospTutorial
```

On Windows build it in the `build_directory\Configuration` with

```
cl ../apps/ospTutorial.cpp /EHsc -I ../ospray/include -I ..\.. ospray.lib
```

Running `ospTutorial` will create two images of two triangles, rendered with the Scientific Visualization renderer with full Ambient Occlusion. The first image `firstFrame.ppm` shows the result after one call to `ospRenderFrame` – jagged edges and noise in the shadow can be seen. Calling `ospRenderFrame` multiple times enables progressive refinement, resulting in antialiased edges and converged shadows, shown after ten frames in the second image `accumulatedFrames.png`.

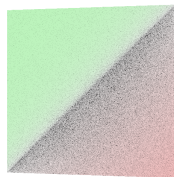


Figure 5.1 – First frame.

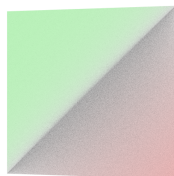


Figure 5.2 – After accumulating ten frames.

## 5.2 Example Viewer

OSPRay also includes an exemplary viewer application `ospExampleViewerSg`, showcasing all features of OSPRay. The Example Viewer uses the ImGui library for user interface controls. The viewer is based on a prototype OSPRay scene-graph interface where its nodes are displayed in the GUI and can be manipulated interactively. For instance, simply run it as `ospExampleViewerSg teapot.obj`.

This application also functions as an OSPRay state debugger – invalid values will be shown in red up the hierarchy and won't change the viewer until corrected. You can also add new nodes where appropriate: for example, when “lights” is expanded right clicking on “lights” and typing in a light type, such as “point”, will add it to the scene. Similarly, right clicking on “world” and creating an “Importer” node will add a new scene importer from a file. Changing the filename to an appropriate file will load the scene and propagate the resulting state.

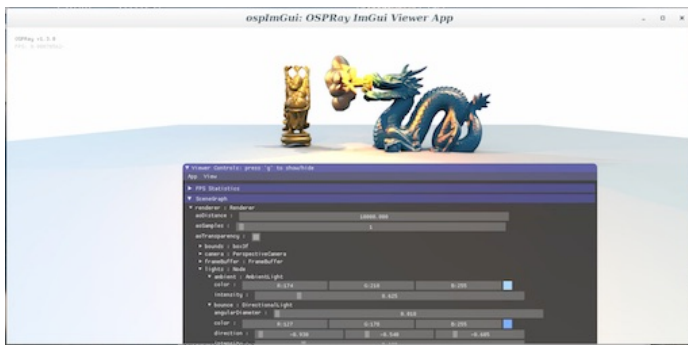


Figure 5.3 – Screenshot of ospExampleViewerSg

## 5.3 Demos

Several ready-to-run demos, models and data sets for OSPRay can be found at the [OSPRay Demos and Examples](#) page.

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