Oculus Rift Developer Guide

Version 0.6.0.0

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Contents

LibOVR Integration

The Oculus SDK is designed to be as easy to integrate as possible. This guide outlines a basic Oculus integration with a C/C++ game engine or application.

We'll discuss initializing the LibOVR, HMD device enumeration, head tracking, frame timing, and rendering for the Rift.

Many of the code samples below are taken directly from the OculusRoomTiny demo source code (available in `Oculus/LibOVR/Samples/OculusRoomTiny`). OculusRoomTiny and OculusWorldDemo are great places to view sample integration code when in doubt about a particular system or feature.

Overview of the SDK

There are three major phases when using the SDK: setup, the game loop, and shutdown.

To add Oculus support to a new application, do the following:

1. Initialize LibOVR through `ovr_Initialize`.
2. Enumerate Oculus devices, create the `ovrHmd` object, and start sensor input.
    - See: `ovrHmd_Create` and `ovrHmd_ConfigureTracking`.
3. Integrate head-tracking into your application's view and movement code. This involves:
    a. Obtaining predicted headset orientation for the frame through a combination of the `ovrHmd_GetFrameTiming` and `ovrHmd_GetTrackingState` calls.
    b. Applying Rift orientation and position to the camera view, while combining it with other application controls.
    c. Modifying movement and game play to consider head orientation.
4. Initialize rendering for the HMD.
    a. Select rendering parameters such as resolution and field of view based on HMD capabilities.
        - See: `ovrHmd_GetFovTextureSize` and`ovrHmd_GetRenderDesc`.
    b. Configure rendering by creating D3D/OpenGL-specific swap texture sets to present data to the headset.
        - See: `ovrHmd_CreateSwapTextureSetD3D11` and`ovrHmd_CreateSwapTextureSetGL`.
5. Modify application frame rendering to integrate HMD support and proper frame timing:
    a. Make sure your engine supports rendering stereo views.
    b. Add frame timing logic into the render loop to obtain correctly predicted eye render poses.
    c. Render each eye's view to intermediate render targets.
    d. Submit the rendered frame to the headset by calling `ovrHmd_SubmitFrame`.
6. Customize UI screens to work well inside of the headset.
7. Destroy the created resources during shutdown.
    - See: `ovrHmd_Destroy` and`ovr_Shutdown`.

A more complete summary of rendering details is provided in the *Rendering Setup Outline* on page 15 section.

Integrating LibOVR

To add Oculus support to a new application, do the following:

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2. Enumerate Oculus devices, create the `ovrHmd` object, and start sensor input.
3. Integrate head-tracking into your application's view and movement code. This involves:
    a. Obtaining predicted headset orientation for the frame through a combination of the `ovrHmd_GetFrameTiming` and `ovrHmd_GetTrackingState` calls.
    b. Applying Rift orientation and position to the camera view, while combining it with other application controls.
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4. Initialize rendering for the HMD.
    a. Select rendering parameters such as resolution and field of view based on HMD capabilities.
    b. Configure rendering by creating D3D/OpenGL-specific swap texture sets to present data to the headset.
5. Modify application frame rendering to integrate HMD support and proper frame timing:
    a. Make sure your engine supports rendering stereo views.
    b. Add frame timing logic into the render loop to ensure that motion prediction and timewarp work correctly.
    c. Render each eye's view to intermediate render targets.
    d. Submit the rendered frame to the headset by calling `ovrHmd_SubmitFrame`. This and other details of frame rendering are covered later in the section on Frame Rendering.
6. Customize UI screens to work well inside of the headset.

Initialization and Sensor Enumeration

This example initializes LibOVR and requests information about the first available HMD.

Review the following code:

```
// Include the OculusVR SDK
#include <OVR_CAPI_0_6_0.h>

void Application()
{
    if (ovr_Initialize(nullptr) == ovrSuccess)
    {
        ovrHmd    hmd    = nullptr;
        ovrResult result = ovrHmd_Create(0, &hmd);

        if (result == ovrSuccess)
        {
            // Get more details about the HMD.
            ovrSizei resolution = hmd->Resolution;
            ...

            // Do something with the HMD.
            ...
            ovrHmd_Destroy(hmd);
        }

        ovr_Shutdown();
    }
}
```

As you can see, `ovr_Initialize` is called before any other API functions and `ovr_Shutdown` is called to shut down the library before you exit the program. In between these function calls, you are free to create HMD objects, access tracking state, and perform application rendering.

In this example, `ovrHmd_Create(0, &hmd)` creates the first available HMD. `ovrHmd_Create` accesses HMDs by index, which is an integer ranging from 0 to the value returned by `ovrHmd_Detect`. Users can call `ovrHmd_Detect` any time after library initialization to re-enumerate the connected Oculus devices. Finally, `ovrHmd_Destroy` must be called to clear the HMD before shutting down the library.

If no Rift is plugged in during detection, `ovrHmd_Create(0, &hmd)` fills in a null handle. In this case, you can use `ovrHmd_CreateDebug` to create a virtual HMD of the specified type. Although the virtual HMD will not provide any sensor input, it can be useful for debugging Rift-compatible rendering code and for general development without a physical device.

The`ovrHmd` handle is actually a pointer to an `ovrHmdDesc` struct that contains information about the HMD and its capabilities, which is used to set up rendering. The following table describes the fields:

Field	Type	Description
`Type`	ovrHmdType	Type of the HMD, such as `ovrHmd_DK1` or `ovrHmd_DK2` .
`ProductName`	const char*	Name of the product as a string.
`Manufacturer`	const char*	Name of the manufacturer.
`VendorId`	short	Vendor ID reported by the headset USB device.
`ProductId`	short	Product ID reported by the headset USB device.

Field	Type	Description
`SerialNumber`	char[]	Serial number string reported by the headset USB device.
`FirmwareMajor`	short	The major version of the sensor firmware.
`FirmwareMinor`	short	The minor version of the sensor firmware.
`CameraFrustumHFovInRadians`	float	The horizontal FOV of the position tracker frustum.
`CameraFrustumVFovInRadians`	float	The vertical FOV of the position tracker frustum.
`CameraFrustumNearZInMeters`	float	The distance from the position tracker to the near frustum bounds.
`CameraFrustumNearZInMeters`	float	The distance from the position tracker to the far frustum bounds.
`HmdCaps`	unsigned int	HMD capability bits described by `ovrHmdCaps`.
`TrackingCaps`	unsigned int	Tracking capability bits describing whether orientation, position tracking, and yaw drift correction are supported.
`DefaultEyeFov`	ovrFovPort[]	Recommended optical field of view for each eye.
`MaxEyeFov`	ovrFovPort[]	Maximum optical field of view that can be practically rendered for each eye.
`EyeRenderOrder`	ovrEyeType[]	Preferred eye rendering order for best performance. Using this value can help reduce latency on sideways scanned screens.
`Resolution`	ovrSizei	Resolution of the full HMD screen (both eyes) in pixels.

Head Tracking and Sensors

The Oculus Rift hardware contains a number of micro-electrical-mechanical (MEMS) sensors including a gyroscope, accelerometer, and magnetometer.

Starting with DK2, there is also a tracker to track headset position. The information from each of these sensors is combined through the sensor fusion process to determine the motion of the user's head in the real world and synchronize the user's view in real-time.

To use the Oculus sensor, first initialize the tracking and sensor fusion by calling `ovrHmd_ConfigureTracking`. This function has the following signature:

```
ovrResult  ovrHmd_ConfigureTracking(ovrHmd hmd, unsigned int supportedTrackingCaps,
                                                unsigned int requiredTrackingCaps);
```

`ovrHmd_ConfigureTracking` takes two sets of capability flags as input. These both use flags declared in `ovrTrackingCaps`. `supportedTrackingCaps` describes the HMD tracking capabilities that the should use when available. `requiredTrackingCaps` specifies capabilities that must be supported by the HMD at the time of the call for the application to operate correctly. If the required capabilities are not present, `ovrHmd_ConfigureTracking` will fail.

After tracking is initialized, you can poll sensor fusion for head position and orientation by calling `ovrHmd_GetTrackingState`. These calls are demonstrated by the following code:

```
 // Start the sensor which provides the Rift's pose and motion.
ovrHmd_ConfigureTracking(hmd, ovrTrackingCap_Orientation |
                              ovrTrackingCap_MagYawCorrection |
                              ovrTrackingCap_Position, 0);

// Query the HMD for the current tracking state.
ovrTrackingState ts  = ovrHmd_GetTrackingState(hmd, ovr_GetTimeInSeconds());

if (ts.StatusFlags & (ovrStatus_OrientationTracked | ovrStatus_PositionTracked))
{
    Posef pose = ts.HeadPose;
    ...
}
```

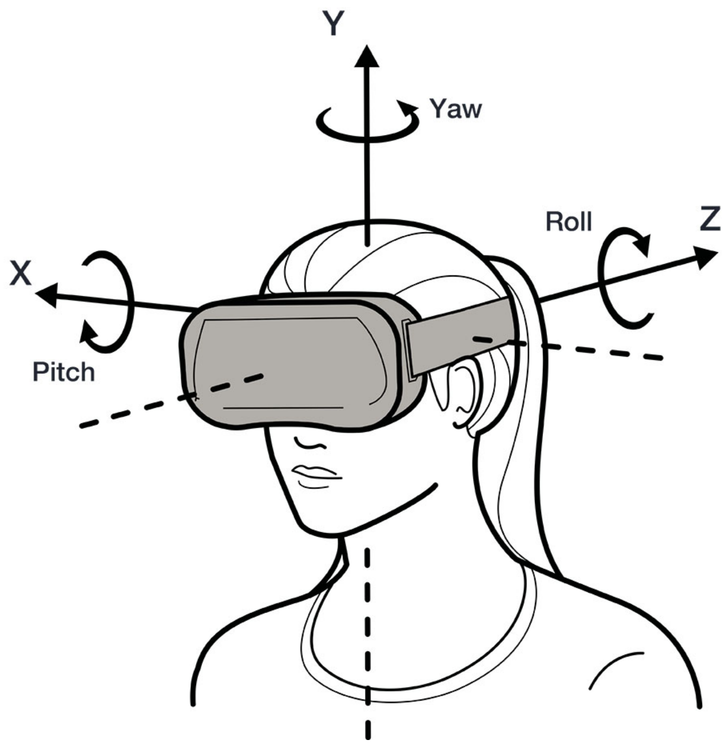
This example initializes the sensors with orientation, yaw correction, and position tracking capabilities if available, while only requiring basic orientation tracking. This means that the code will work for DK1, but will automatically use DK2 tracker-based position tracking. If you are using a DK2 headset and the DK2 tracker is not available during the time of the call, but is plugged in later, the tracker is automatically enabled by the SDK.

After the sensors are initialized, the sensor state is obtained by calling `ovrHmd_GetTrackingState`. This state includes the predicted head pose and the current tracking state of the HMD as described by `StatusFlags`. This state can change at runtime based on the available devices and user behavior. For example with DK2, the `ovrStatus_PositionTracked` flag is only reported when `HeadPose` includes the absolute positional tracking data from the tracker.

The reported `ovrPoseStatef` includes full six degrees of freedom (6DoF) head tracking data including orientation, position, and their first and second derivatives. The pose value is reported for a specified absolute point in time using prediction, typically corresponding to the time in the future that this frame's image will be displayed on screen. To facilitate prediction, `ovrHmd_GetTrackingState` takes absolute time, in seconds, as a second argument. The current value of absolute time can be obtained by calling `ovr_GetTimeInSeconds`. If the time passed into `ovrHmd_GetTrackingState` is the current time or earlier, the tracking state returned will be based on the latest sensor readings with no prediction. In a production application, however, you should use the real-time computed value returned by `ovrHmd_GetFrameTiming`. Prediction is covered in more detail in the section on Frame Timing.

As already discussed, the reported pose includes a 3D position vector and an orientation quaternion. The orientation is reported as a rotation in a right-handed coordinate system, as illustrated in the following figure.

Figure 1: Rift Coordinate System



The x-z plane is aligned with the ground regardless of camera orientation.

As seen from the diagram, the coordinate system uses the following axis definitions:

- Y is positive in the up direction.
- X is positive to the right.
- Z is positive heading backwards.

Rotation is maintained as a unit quaternion, but can also be reported in yaw-pitch-roll form. Positive rotation is counter-clockwise (CCW, direction of the rotation arrows in the diagram) when looking in the negative direction of each axis, and the component rotations are:

- Pitch is rotation around X, positive when pitching up.
- Yaw is rotation around Y , positive when turning left.
- Roll is rotation around Z, positive when tilting to the left in the XY plane.

The simplest way to extract yaw-pitch-roll from `ovrPose` is to use the C++ OVR Math helper classes that are included with the library. The following example uses direct conversion to assign ovrPosef to the equivalent C ++ Posef class. You can then use the `Quatf::GetEulerAngles<>` to extract the Euler angles in the desired axis rotation order.

All simple C math types provided by OVR such as `ovrVector3f` and `ovrQuatf` have corresponding C++ types that provide constructors and operators for convenience. These types can be used interchangeably.

Position Tracking

The frustum is defined by the horizontal and vertical FOV, and the distance to the front and back frustum planes.

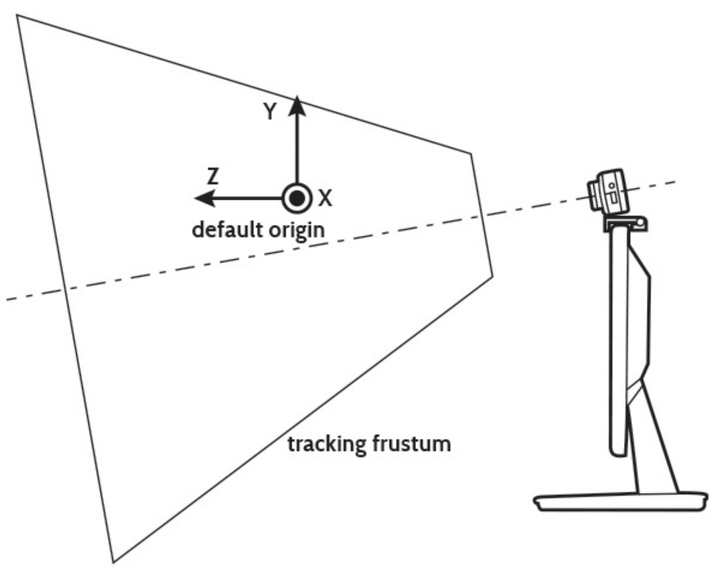
Approximate values for these parameters can be accessed through the `ovrHmdDesc` struct as follows:

```
ovrHmd hmd;
ovrHmd_Create(0, &hmd);

if (hmd)
{
    // Extract tracking frustum parameters.
    float frustomHorizontalFOV = hmd->CameraFrustumHFovInRadians;
    ...
```

The following figure shows the DK2 position tracker mounted on a PC monitor and a representation of the resulting tracking frustum.

Figure 2: Position Tracking Camera and Tracking Frustum



The relevant parameters and typical values are list below:

Field	Type	Typical Value
`CameraFrustumHFovInRadians`	float	1.292 radians (74 degrees)
`CameraFrustumVFovInRadians`	float	0.942 radians (54 degrees)
`CameraFrustumNearZInMeters`	float	0.4m
`CameraFrustumFarZInMeters`	float	2.5m

These parameters are provided to enable application developers to provide a visual representation of the tracking frustum. The previous figure also shows the default tracking origin and associated coordinate system.

Note: Although the tracker axis (and hence the tracking frustum) are shown tilted downwards slightly, the tracking coordinate system is always oriented horizontally such that the and axes are parallel to the ground.

By default, the tracking origin is located one meter away from the tracker in the direction of the optical axis but with the same height as the tracker. The default origin orientation is level with the ground with the negative axis pointing towards the tracker. In other words, a headset yaw angle of zero corresponds to the user looking towards the tracker.

Note: This can be modified using the API call `ovrHmd_RecenterPose` which resets the tracking origin to the headset's current location, and sets the yaw origin to the current headset yaw value.

Note: The tracking origin is set on a per application basis; switching focus between different VR apps also switches the tracking origin.

The head pose is returned by calling `ovrHmd_GetTrackingState`. The returned `ovrTrackingState` struct contains several items relevant to position tracking:

- `HeadPose`—includes both head position and orientation.
- `CameraPose`—the pose of the tracker relative to the tracking origin.
- `LeveledCameraPose`— the pose of the tracker relative to the tracking origin but with roll and pitch zeroed out. You can use this as a reference point to render real-world objects in the correct place.

The `StatusFlags` variable contains three status bits relating to position tracking:

- `ovrStatus_PositionConnected`—set when the position tracker is connected and functioning properly.
- `ovrStatus_PositionTracked`—flag that is set only when the headset is being actively tracked.
- `ovrStatus_CameraPoseTracked`—set after the initial tracker calibration has taken place. Typically this requires the headset to be reasonably stationary within the view frustum for a second or so at the start of tracking. It may be necessary to communicate this to the user if the `ovrStatus_CameraPoseTracked` flag doesn't become set quickly after entering VR.

There are several conditions that may cause position tracking to be interrupted and for the flag to become zero:

- The headset moved wholly or partially outside the tracking frustum.
- The headset adopts an orientation that is not easily trackable with the current hardware (for example facing directly away from the tracker).
- The exterior of the headset is partially or fully occluded from the tracker's point of view (for example by hair or hands).
- The velocity of the headset exceeds the expected range.

Following an interruption, assuming the conditions above are no longer present, tracking normally resumes quickly and the `ovrStatus_PositionTracked` flag is set.

User Input Integration

To provide the most comfortable, intuitive, and usable interface for the player, head tracking should be integrated with an existing control scheme for most applications.

For example, in a first person shooter (FPS) game, the player generally moves forward, backward, left, and right using the left joystick, and looks left, right, up, and down using the right joystick. When using the Rift, the player can now look left, right, up, and down, using their head. However, players should not be required to frequently turn their heads 180 degrees since this creates a bad user experience. Generally, they need a way to reorient themselves so that they are always comfortable (the same way in which we turn our bodies if we want to look behind ourselves for more than a brief glance).

To summarize, developers should carefully consider their control schemes and how to integrate head-tracking when designing applications for VR. The OculusRoomTiny application provides a source code sample that shows how to integrate Oculus head tracking with the aforementioned standard FPS control scheme.

For more information about good and bad practices, refer to the *Oculus Best Practices Guide*.

Health and Safety Warning

All applications that use the Oculus Rift display a health and safety warning when the device is used.

This warning appears for a short amount of time when the Rift first displays a VR scene; it can be dismissed by pressing a key or tapping on the headset. Currently, the warning displays for at least 15 seconds the first time a new profile user puts on the headset and 3 seconds afterwards.

The warning displays automatically as a layer.

The Health and Safety Warning can be disabled through the Oculus Configuration Utility. Before suppressing the Health and Safety Warning, please note that by disabling the Health and Safety warning screen, you agree that you have read the warning, and that no other person will use the headset without reading this warning screen.

To use the Oculus Configuration Utility to suppress the Health and Safety Warning, a registry key setting must be added for Windows builds, while an environment variable must be added for non-Windows builds.

For Windows, the following key must be added if the Windows OS is 32-bit:

```
HKEY LOCAL MACHINE\Software\Oculus VR, LLC\LibOVR\HSWToggleEnabled
```

If the Windows OS is 64-bit, the path will be slightly different:

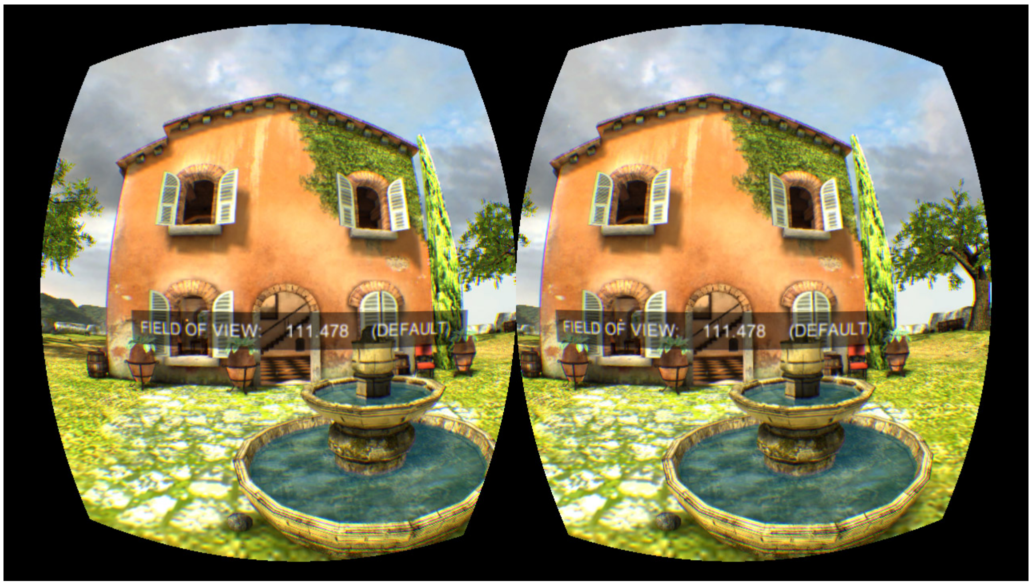
```
HKEY LOCAL MACHINE\Software\Wow6432Node\Oculus VR, LLC\LibOVR\HSWToggleEnabled
```

Setting the value of `HSWToggleEnabled` to 1 enables the Disable Health and Safety Warning check box in the Advanced Configuration panel of the Oculus Configuration Utility. For non-Windows builds, you must create an environment variable named `Oculus LibOVR HSWToggleEnabled` with the value of ”1”.

Rendering to the Oculus Rift

The Oculus Rift requires split-screen stereo with distortion correction for each eye to cancel lens-related distortion.

Figure 3: OculusWorldDemo Stereo Rendering



Correcting for distortion can be challenging, with distortion parameters varying for different lens types and individual eye relief. To make development easier, Oculus SDK handles distortion correction automatically within the Oculus Compositor process; it also takes care of latency-reducing timewarp and presents frames to the headset.

With Oculus SDK doing a lot of the work, the main job of the application is to perform simulation and render stereo world based on the tracking pose. Stereo views can be rendered into either one or two individual textures and are submitted to the compositor by calling `ovrHmd_SubmitFrame`. We cover this process in detail in this section.

Rendering to the Oculus Rift

The Oculus Rift requires the scene to be rendered in split-screen stereo with half of the screen used for each eye.

When using the Rift, the left eye sees the left half of the screen, and the right eye sees the right half. Although varying from person-to-person, human eye pupils are approximately 65 mm apart. This is known as interpupillary distance (IPD). The in-application cameras should be configured with the same separation.

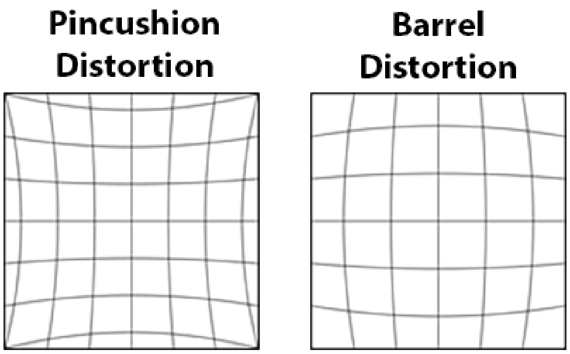
Note:

This is a translation of the camera, not a rotation, and it is this translation (and the parallax effect that goes with it) that causes the stereoscopic effect. This means that your application will need to render the entire scene twice, once with the left virtual camera, and once with the right.

The reprojection stereo rendering technique, which relies on left and right views being generated from a single fully rendered view, is usually not viable with an HMD because of significant artifacts at object edges.

The lenses in the Rift magnify the image to provide a very wide field of view (FOV) that enhances immersion. However, this process distorts the image significantly. If the engine were to display the original images on the Rift, then the user would observe them with pincushion distortion.

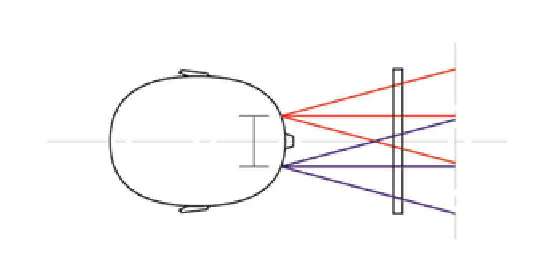
Figure 4: Pincushion and Barrel Distortion



To counteract this distortion, the SDK applies post-processing to the rendered views with an equal and opposite barrel distortion so that the two cancel each other out, resulting in an undistorted view for each eye. Furthermore, the SDK also corrects chromatic aberration, which is a color separation effect at the edges caused by the lens. Although the exact distortion parameters depend on the lens characteristics and eye position relative to the lens, the Oculus SDK takes care of all necessary calculations when generating the distortion mesh.

When rendering for the Rift, projection axes should be parallel to each other as illustrated in the following figure, and the left and right views are completely independent of one another. This means that camera setup is very similar to that used for normal non-stereo rendering, except that the cameras are shifted sideways to adjust for each eye location.

Figure 5: HMD Eye View Cones



In practice, the projections in the Rift are often slightly off-center because our noses get in the way! But the point remains, the left and right eye views in the Rift are entirely separate from each other, unlike stereo views generated by a television or a cinema screen. This means you should be very careful if trying to use methods developed for those media because they do not usually apply in VR.

The two virtual cameras in the scene should be positioned so that they are pointing in the same direction (determined by the orientation of the HMD in the real world), and such that the distance between them is the same as the distance between the eyes, or interpupillary distance (IPD). This is typically done by adding the `ovrEyeRenderDesc::HmdToEyeViewOffset` translation vector to the translation component of the view matrix.

Although the Rift's lenses are approximately the right distance apart for most users, they may not exactly match the user's IPD. However, because of the way the optics are designed, each eye will still see the correct view. It is important that the software makes the distance between the virtual cameras match the user's IPD as found in their profile (set in the configuration utility), and not the distance between the Rift's lenses.

Rendering Setup Outline

The Oculus SDK makes use of a compositor process to present frames and handle distortion.

To target the Rift, you render the scene into one or two render textures, passing these textures into the API. The Oculus runtime handles distortion rendering, GPU synchronization, frame timing, and frame presentation to the HMD.

The following are the steps for SDK rendering:

1. Initialize:
   a. Initialize Oculus SDK and create an `ovrHMD` object for the headset as was described earlier.
   b. Compute the desired FOV and texture sizes based on `ovrHMDDesc` data.
   c. Allocate `ovrSwapTextureSet` objects, used to represent eye buffers, in an API-specific way: call `ovrHmd_CreateSwapTextureSetD3D11` for Direct3D or `ovrHmd_CreateSwapTextureSetGL` for OpenGL.
2. Set up frame handling:
   a. Use `ovrHmd_GetTrackingState` and `ovr_CalcEyePoses` to compute eye poses needed for view rendering based on frame timing information.
   b. Perform rendering for each eye in an engine-specific way, rendering into the current texture within the texture set. Current texture is identified by the `ovrSwapTextureSet::CurrentIndex` variable.
   c. Call `ovrHmd_SubmitFrame`, passing swap texture set(s) from the previous step within a `ovrLayerEyeFov` structure. Although a single layer is required to submit a frame, you can use multiple layers and layer types for advanced rendering. `ovrHmd_SubmitFrame` passes layer textures to the compositor which handles distortion, timewarp, and GPU synchronization before presenting it to the headset.
   d. Advance `CurrentIndex` within each used texture set to target the next consecutive texture buffer for the following frame.
3. Shutdown:
   a. You can use `ovrHmd_DestroySwapTextureSet` to destroy swap texture buffers. This effectively removes your application output from the compositor. Alternatively, you can just destroy the `ovrHmd` object by calling `ovrHmd_Destroy`.

Swap Texture Set Initialization

This section describes rendering initialization, including creation of swap texture sets.

Initially, you determine the rendering FOV and allocate the required ovrSwapTextureSet. The following code shows how the required texture size can be computed:

```
// Configure Stereo settings.
Sizei recommenedTex0Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Left,
                                                     hmd->DefaultEyeFov[0], 1.0f);
Sizei recommenedTex1Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Right,
                                                     hmd->DefaultEyeFov[1], 1.0f);
Sizei bufferSize;
bufferSize.w  = recommenedTex0Size.w + recommenedTex1Size.w;
bufferSize.h = max ( recommenedTex0Size.h, recommenedTex1Size.h );
```

Render texture size is determined based on the FOV and the desired pixel density at the center of the eye. Although both the FOV and pixel density values can be modified to improve performance, this example uses the recommended FOV (obtained from `hmd->DefaultEyeFov`). The function `ovrHmd_GetFovTextureSize` computes the desired texture size for each eye based on these parameters.

The Oculus API allows the application to use either one shared texture or two separate textures for eye rendering. This example uses a single shared texture for simplicity, making it large enough to fit both eye renderings. Once texture size is known, the application can call `ovrHmd_CreateSwapTextureSetGL` or `ovrHmd_CreateSwapTextureSetD3D11` to allocate the texture sets in an API-specific way. Here's how a texture set can be created and accessed under OpenGL:

```
ovrSwapTextureSet * pTextureSet = 0;

if (ovrHmd_CreateSwapTextureSetGL(hmd, GL_RGBA, bufferSize.w, bufferSize.h,
                                      &pTextureSet) == ovrSuccess)
{
    // Sample texture access:
    ovrGLTexture* tex = (ovrGLTexture*)&pTextureSet->Textures[i];
    glBindTexture(GL_TEXTURE_2D, tex->OGL.TexId);
    ...
}
```

As can be seen from this example, `ovrSwapTextureSet` contains an array of `ovrTexture` objects, each wrapping either a D3D texture handle or OpenGL texture ID that can be used for rendering. Here's a similar example of texture set creation and access using Direct3D:

```
ovrSwapTextureSet *      pTextureSet = 0;
ID3D11RenderTargetView * pTexRtv[3];

D3D11_TEXTURE2D_DESC dsDesc;
dsDesc.Width            = bufferSize.w;
dsDesc.Height           = bufferSize.h;
dsDesc.MipLevels        = 1;
dsDesc.ArraySize        = 1;
dsDesc.Format           = DXGI_FORMAT_B8G8R8A8_UNORM;
dsDesc.SampleDesc.Count   = 1;
dsDesc.SampleDesc.Quality = 0;
dsDesc.Usage            = D3D11_USAGE_DEFAULT;
dsDesc.CPUAccessFlags   = 0;
dsDesc.MiscFlags        = 0;
dsDesc.BindFlags        = D3D11_BIND_SHADER_RESOURCE | D3D11_BIND_RENDER_TARGET;

if (ovrHmd_CreateSwapTextureSetD3D11(hmd, DIRECTX.Device, &dsDesc, &pTextureSet) == ovrSuccess)
{
    for (int i = 0; i < pTextureSet->TextureCount; ++i)
    {
        ovrD3D11Texture* tex = (ovrD3D11Texture*)&pTextureSet->Textures[i];
        DIRECTX.Device->CreateRenderTargetView(tex->D3D11.pTexture, NULL, &pTexRtv[i]);
    }
}
```

In this case, newly created render target views can be used to perform eye texture rendering. The Frame Rendering section of this guide describes viewport setup in more detail.

Frame Rendering

Frame rendering typically involves several steps: obtaining predicted eye poses based on the headset tracking pose, rendering the view for each eye and, finally, submitting eye textures to the compositor through `ovrHmd_SubmitFrame`. After the frame is submitted, the Oculus compositor handles distortion and presents it on the Rift.

Before rendering frames it is helpful to initialize some data structures that can be shared across frames. As an example, we query eye descriptors and initialize the layer structure outside of the rendering loop:

```
 // Initialize VR structures, filling out description.
ovrEyeRenderDesc eyeRenderDesc[2];
```

```
ovrVector3f      hmdToEyeViewOffset[2];
eyeRenderDesc[0]      = ovrHmd_GetRenderDesc(hmd, ovrEye_Left, hmd->DefaultEyeFov[0]);
eyeRenderDesc[1]      = ovrHmd_GetRenderDesc(hmd, ovrEye_Right, hmd->DefaultEyeFov[1]);
hmdToEyeViewOffset[0] = eyeRenderDesc[0].HmdToEyeViewOffset;
hmdToEyeViewOffset[1] = eyeRenderDesc[1].HmdToEyeViewOffset;

// Initialize our single full screen Fov layer.
ovrLayerEyeFov layer;
layer.Header.Type      = ovrLayerType_EyeFov;
layer.Header.Flags     = 0;
layer.ColorTexture[0]  = pTextureSet;
layer.ColorTexture[1]  = pTextureSet;
layer.Fov[0]           = eyeRenderDesc[0].Fov;
layer.Fov[1]           = eyeRenderDesc[1].Fov;
layer.Viewport[0]      = Recti(0, 0,                bufferSize.w / 2, bufferSize.h);
layer.Viewport[1]      = Recti(bufferSize.w / 2, 0, bufferSize.w / 2, bufferSize.h);
// ld.RenderPose is updated later per frame.
```

This code example first gets rendering descriptors for each eye, given the chosen FOV. The returned `ovrEyeRenderDesc`structure contains useful values for rendering, including the `HmdToEyeViewOffset` for each eye. Eye view offsets are used later to adjust for eye separation.

The code also initializes the `ovrLayerEyeFov` structure for a full screen layer. Starting with Oculus SDK 0.6, frame submission uses layers to composite multiple view images or texture quads on top of each other. This example uses a single layer to present a VR scene. For this purpose, we use `ovrLayerEyeFov`, which describes a dual-eye layer that covers the entire eye field of view. Since we are using the same texture set for both eyes, we initialize both eye color textures to `pTextureSet` and configure viewports to draw to the left and right sides of this shared texture, respectively.

Note: Although it is often enough to initialize viewports once in the beginning, specifying them as a part of the layer structure that is submitted every frame allows applications to change render target size dynamically, if desired. This is useful for optimizing rendering performance.

After setup completes, the application can begin generating the rendering loop. First, we need to get the eye poses to render the left and right views.

```
// Get both eye poses simultaneously, with IPD offset already included.
ovrFrameTiming   ftiming  = ovrHmd_GetFrameTiming(hmd, 0);
ovrTrackingState hmdState = ovrHmd_GetTrackingState(hmd, ftiming.DisplayMidpointSeconds);
ovr_CalcEyePoses(hmdState.HeadPose.ThePose, hmdToEyeViewOffset, layer.RenderPose);
```

In VR, rendered eye views depend on the headset position and orientation in the physical space, tracked with the help of internal IMU and external trackers. Prediction is used to compensate for the latency in the system, giving the best estimate for where the headset will be when the frame is displayed on the headset. In the Oculus SDK, this tracked, predicted pose is reported by `ovrHmd_GetTrackingState`.

To do accurate prediction, `ovrHmd_GetTrackingState` needs to know when the current frame will actually be displayed. The code above calls `ovrHmd_GetFrameTiming` to obtain `DisplayMidpointSeconds` for the current frame, using it to compute the best predicted tracking state. The head pose from the tracking state is then passed to `ovr_CalcEyePoses` to calculate correct view poses for each eye. These poses are stored directly into the `layer.RenderPose[2]` array. With eye poses ready, we can proceed onto the actual frame rendering.

```
if (isVisible)
{
    // Increment to use next texture, just before writing
    pTextureSet->CurrentIndex = (pTextureSet->CurrentIndex + 1) % pTextureSet->TextureCount;

    // Clear and set up render-target.
    DIRECTX.SetAndClearRenderTarget(pTexRtv[pTextureSet->CurrentIndex], pEyeDepthBuffer);

    // Render Scene to Eye Buffers
    for (int eye = 0; eye < 2; eye++)
    {
        // Get view and projection matrices for the Rift camera
        Vector3f pos = originPos + originRot.Transform(layer.RenderPose[eye].Position);
```

```
        Matrix4f rot = originRot * Matrix4f(layer.RenderPose[eye].Orientation);

        Vector3f finalUp      = rot.Transform(Vector3f(0, 1, 0));
        Vector3f finalForward = rot.Transform(Vector3f(0, 0, -1));
        Matrix4f view         = Matrix4f::LookAtRH(pos, pos + finalForward, finalUp);

        Matrix4f proj = ovrMatrix4f_Projection(layer.Fov[eye], 0.2f, 1000.0f,
                                               ovrProjection_RightHanded);
        // Render the scene for this eye.
        DIRECTX.SetViewport(layer.Viewport[eye]);
        roomScene.Render(proj * view, 1, 1, 1, 1, true);
    }
}

// Submit frame with one layer we have.
ovrLayerHeader* layers = &layer.Header;
ovrResult       result = ovrHmd_SubmitFrame(hmd, 0, nullptr, &layers, 1);
isVisible = (result == ovrSuccess);
```

This code takes a number of steps to render the scene:

- First it increments the `CurrentIndex` to point to the next texture within the output texture set. `CurrentIndex` must be advanced round-robin fashion every time we draw a new frame.
- It applies the texture as a render target and clears it for rendering. In this case, the same texture is used for both eyes.
- The code then computes view and projection matrices and sets viewport scene rendering for each eye. In this example, view calculation combines the original pose (`originPos` and `originRot` values) with the new pose computed based on the tracking state and stored in the layer. There original values can be modified by input to move the player within the 3D world.
- After texture rendering is complete, we call ovrHmd_SubmitFrame to pass frame data to the compositor. From this point, the compositor takes over by accessing texture data through shared memory, distorting it, and presenting it on the Rift.

`ovrHmd_SubmitFrame` returns once frame present is queued up and the next texture slot in the `ovrSwapTextureSet` is available for the next frame. When successful, its return value is either `ovrSuccess` or `ovrSuccess_NotVisible`.

`ovrSuccess_NotVisible` is returned if the frame wasn't actually displayed, which can happen when VR application loses focus. Our sample code handles this case by updating the `isVisible` flag, checked by the rendering logic. While frames are not visible, rendering is paused to eliminate unnecessary GPU load.

Frame Timing

The Oculus SDK reports frame timing information through the `ovrHmd_GetFrameTiming` function, relying on the application-provided frame index to ensure correct timing is reported across different threads.

Accurate frame and sensor timing are required for accurate head motion prediction, which is essential for a good VR experience. Prediction requires knowing exactly when in the future the current frame will appear on the screen. If we know both sensor and display scanout times, we can predict the future head pose and improve image stability. Computing these values incorrectly can lead to under or over-prediction, degrading perceived latency, and potentially causing overshoot “wobbles”.

To ensure accurate timing, the Oculus SDK uses absolute system time, stored as a double, to represent sensor and frame timing values. The current absolute time is returned by `ovr_GetTimeInSeconds`. Current time should rarely be used, however, since simulation and motion prediction will prodice better results when relying on the timing values returned by `ovrHmd_GetFrameTiming`. This function has the following signature:

```
ovrFrameTiming ovrHmd_GetFrameTiming(ovrHmd hmd, unsigned int frameIndex);
```

The `frameIndex` argument specifies which application frame we are rendering. Applications that make use of multi-threaded rendering must keep an internal frame index and manually increment it, passing it across threads along with frame data to ensure correct timing and prediction. The same `frameIndex` value must be passed to `ovrHmd_SubmitFrame` as was used to obtain timing for the frame. The details of multi-threaded timing are covered in the next section, *Rendering on Different Threads* on page 19.

A special `frameIndex` value of 0 can be used in both functions to request that the SDK keep track of frame indices automatically. This, however, only works when all frame timing requests and render submission is done on the same thread.

`ovrFrameTiming` provides the following set of absolute times values associated with the current frame:

`DisplayMidpointSeconds`	double	A point in time when the middle of the screen will be displayed. This is the most important value that can be passed to `ovrHmd_GetTrackingState` for accurate prediction.
`FrameIntervalSeconds`	double	Display interval between the frames. This will generally be 1 / refresh rate of the headset; however, it may vary slightly during runtime based on video card scan-out timing.
`AppFrameIndex`	unsigned int	Application frame index for which we requested timing.
`DisplayFrameIndex`	unsigned int	HW display frame index that we expect this application frame will hit; this is the frame that will be displayed at DisplayMidpointSeconds.

The most important value is `DisplayMidpointSeconds`, which is the predicted time frame will be displayed. This value can be used for both simulation and rendering prediction. Other values can be used to make estimates about future frames to detect if display frames were actually skipped.

Rendering on Different Threads

In some engines, render processing is distributed across more than one thread.

For example, one thread may perform culling and render setup for each object in the scene (we'll call this the “main” thread), while a second thread makes the actual D3D or OpenGL API calls (we'll call this the “render” thread). Both of these threads may need accurate estimates of frame display time, so as to compute best possible predictions of head pose.

The asynchronous nature of this approach makes this challenging: while the render thread is rendering a frame, the main thread might be processing the next frame. This parallel frame processing may be out of sync by exactly one frame or a fraction of a frame, depending on game engine design. If we used the default global state to access frame timing, the result of `ovrHmd_GetFrameTiming` could either be off by one frame depending which thread the function is called from, or worse, could be randomly incorrect depending on how threads are scheduled. To addess this issue, previous section introduced the concept of `frameIndex` that is tracked by the application and passed across threads along with frame data.

For multi-threaded rendering result to be correct, the following must be true: (a) pose prediction, computed based on frame timing, must be consistent for the same frame regardless of which thread it is accessed from; and (b) eye poses that were actually used for rendering must be passed into `ovrHmd_SubmitFrame`, along with the frame index.

Here is a summary of steps you can take to ensure this is the case:

1. The main thread needs to assign a frame index to the current frame being processed for rendering. It would increment this index each frame and pass it to `ovrHmd_GetFrameTiming` to obtain the correct timing for pose prediction.
2. The main thread should call the thread safe function `ovrHmd_GetTrackingState` with the predicted time value. It can also call `ovr_CalcEyePoses` if necessary for rendering setup.
3. Main thread needs to pass the current frame index and eye poses to the render thread, along with any rendering commands or frame data it needs.
4. When the rendering commands executed on the render thread, developers need to make sure these things hold:

    a. The actual poses used for frame rendering are stored into the `RenderPose` for the layer.
    b. The same value of `frameIndex` as was used on the main thead is passed into `ovrHmd_SubmitFrame`.

The following code illustrates this in more detail:

```
void MainThreadProcessing()
{
    frameIndex++;

    // Ask the API for the times when this frame is expected to be displayed.
    ovrFrameTiming frameTiming = ovrHmd_GetFrameTiming(hmd, frameIndex);

    // Get the corresponding predicted pose state.
    ovrTrackingState state = ovrHmd_GetTrackingState(hmd, frameTiming.DisplayMidpointSeconds);
    ovrPosef         eyePoses[2];
    ovr_CalcEyePoses(state.HeadPose.ThePose, hmdToEyeViewOffset, eyePoses);

    SetFrameHMDData(frameIndex, eyePoses);

    // Do render pre-processing for this frame.
    ...
}

void RenderThreadProcessing()
{
    int      frameIndex;
    ovrPosef eyePoses[2];

    GetFrameHMDData(&frameIndex, eyePoses);
    layer.RenderPose[0] = eyePoses[0];
    layer.RenderPose[1] = eyePoses[1];

    // Execute actual rendering to eye textures.
    ...

   // Submit frame with one layer we have.
   ovrLayerHeader* layers = &layer.Header;
   ovrResult       result = ovrHmd_SubmitFrame(hmd, frameIndex, nullptr, &layers, 1);
}
```

Layers

Similar to the way a monitor view can be composed of multiple windows, the display on the headset can be composed of multiple layers. Typically at least one of these layers will be a view rendered from the user's virtual eyeballs, but other layers may be HUD layers, information panels, text labels attached to items in the world, aiming reticles, and so on.

Each layer can have a different resolution, can use a different texture format, can use a different field of view or size, and might be in mono or stereo. The application can also be configured to not update a layer's texture if the information in it has not changed. For example, it might not update if the text in an information panel has not changed since last frame or if the layer is a picture-in-picture view of a video stream with a low framerate. Applications can supply mipmapped textures to a layer and, together with a high-quality distortion mode, this is very effective at improving the readability of text panels.

Every frame, all active layers are composited from back to front using pre-multiplied alpha blending. Layer 0 is the furthest layer, layer 1 is on top of it, and so on; there is no depth-buffer intersection testing of layers, even if a depth-buffer is supplied.

A powerful feature of layers is that each can be a different resolution. This allows an application to scale to lower performance systems by dropping resolution on the main eye-buffer render that shows the virtual world, but keeping essential information, such as text or a map, in a different layer at a higher resolution.

There are several layer types available:

EyeFov	The standard "eye buffer" familiar from previous SDKs, which is typically a stereo view of a virtual scene rendered from the position of the user's eyes. Although mono eye buffers can be mono, they can cause discomfort. Previous SDKs had an implicit field of view (FOV) and viewport; these are now supplied explicitly and the application can change them every frame, if desired.
EyeFovDepth	An eye buffer render with depth buffer information for use with positional timewarp (PTW). Our current support for depth-based PTW is experimental. It is a rendering enhancement that is still in development and drops below full frame rate; we welcome developer feedback on this layer type. Note: The depth buffer is only used for timewarp correction and is not used for occlusion (Z testing) between layer types. Additionally, in the current version of the SDK, only layer #0 can be of this type and it only reliably supports a D32F format.
QuadInWorld	A monoscopic image that is displayed as a rectangle at a given pose and size in the virtual world. This is useful for heads-up-displays, text information, object labels and so on. The pose is specified relative to the user's real-world space and the quad will remain fixed in space rather than moving with the user's head or body motion.
QuadHeadLocked	Similar to the QuadInWorld type, but the pose is specified relative to the user's face. When the user moves their head, the quad follows. This quad type is useful for reticles used in gaze-based aiming or selection. However, it can be uncomfortable if used for text information and it is usually preferable to use a QuadInWorld layer type for this purpose.
Direct	Displayed directly on the framebuffer, this is intended primarily for debugging. No timewarp, distortion or chromatic aberration is applied to this layer; images from this layer type will usually not look correct or comfortable while wearing the HMD.
Disabled	Ignored by the compositor, disabled layers do not cost performance. We recommend that applications perform basic frustum-culling and disable layers that are out of view. However, there is no need for the application to repack the list of active layers tightly together when turning one layer off; disabling it and leaving it in the list is sufficient. Equivalently, the pointer to the layer in the list can be set to null.

Each layer style has a corresponding member of the `ovrLayerType` enum, and an associated structure holding the data required to display that layer. For example, the EyeFov layer is type number `ovrLayerType_EyeFov` and is described by the data in the structure `ovrLayerEyeFov`. These structures share a similar set of parameters, though not all layer types require all parameters:

Parameter	Type	Description

Parameter	Type	Description
`Header.Type`	One of the `ovrLayerType` enum values listed above.	Must be set by all layers to specify what type they are.
`Header.Flags`	A bitfield of `ovrLayerFlags`.	See below for more information.
`ColorTexture`	`ovrSwapTextureSet`	Provides color and translucency data for the layer. Layers are blended over one another using premultiplied alpha. This allows them to express either lerp-style blending, additive blending, or a combination of the two. Layer textures must be RGBA formats and might have mipmaps, but cannot be arrays, cubes, or have MSAA.
`DepthTexture`	`ovrSwapTextureSet`	Provides depth data for the EyeFovDepth layer type. This data cannot be used for occlusion or intersection with other layers; it is used by positional timewarp to try to apply the correct parallax for a layer.
`ProjectionDesc`		Supplies information about how to interpret the data held in `DepthTexture` for the EyeFovDepth layer type. This is typically extracted from the applications' projection matrix using the `ovrTimewarpProjectionDesc_FromProject` utility function.
`Viewport`		The rectangle of the texture that is actually used, specified in 0-1 texture "UV" coordinate space (not pixels). In theory, texture data outside this region is not visible in the layer. However, the usual caveats about texture sampling apply, especially with mipmapped textures. It is good practice to leave a border of RGBA(0,0,0,0) pixels around the displayed region to avoid "bleeding," especially between two eye buffers packed side by side into the same texture. The size of the border depends on the exact usage case, but around 8 pixels seems to work well in most cases.
`Fov`		The field of view used to render the scene in an Eye layer type. Note this does not control the

Parameter	Type	Description
		HMD's display, it simply tells the compositor what FOV was used to render the texture data in the layer - the compositor will then adjust appropriately to whatever the actual user's FOV is. Applications may change FOV dynamically for special effects. Reducing FOV may also help with performance on slower machines, though typically it is more effective to reduce resolution before reducing FOV.
`RenderPose`		The camera pose used to render the scene in an Eye layer type. This is typically predicted by the SDK and application using the `ovrHmd_GetTrackingState` and `ovr_CalcEyePoses` functions. The difference between this pose and the actual pose of the eye at display time is used by the compositor to apply timewarp to the layer.
`QuadPoseCenter`		Specifies the orientation and position of the center point of a Quad layer type. The supplied direction is the vector perpendicular to the quad. The position is in real-world meters (not the application's virtual world, the actual world the user is in) and is relative to the "zero" position set by `ovrHmd_RecenterPose`.
`QuadSize`		Specifies the width and height of a Quad layer type. As with position, this is in real-world meters.

Layers that take stereo information (all those except Quad layer types) take two sets of most parameters, and these can be used in three different ways:

- Stereo data, separate textures—the app supplies a different `ovrSwapTextureSet` for the left and right eyes, and a viewport for each.
- Stereo data, shared texture—the app supplies the same `ovrSwapTextureSet` for both left and right eyes, but a different viewport for each. This allows the application to render both left and right views to the same texture buffer.
- Mono data—the app supplies the same `ovrSwapTextureSet` for both left and right eyes, and the same viewport for each.

Texture and viewport sizes may be different for the left and right eyes, and each can even have different fields of view. However beware of causing stereo disparity and discomfort in your users.

The flags available for all layers are a logical-or of the following:

- `ovrLayerFlag_HighQuality`—enables a slightly more expensive but higher-quality path in the compositor for this layer. This can provide a significant increase in legibility, especially when used with a texture with mipmaps; this is recommended for high-frequency images such as text or diagrams and when used with the Quad layer types. It has relatively little visual effect on the Eye layer types with typical virtual world images.
- `ovrLayerFlag_TextureOriginAtBottomLeft`—the origin of a layer's texture is assumed to be at the top-left corner. However, some engines (particularly those using OpenGL) prefer to use the bottom-left corner as the origin. In this case, set the flag for that layer type.

At the end of each frame, after rendering to whichever `ovrSwapTextureSets` the application wants to update, the data for each layer is put into the relevant `ovrLayerEyeFov`/`ovrLayerEyeFovDepth`/`ovrLayerQuad`/`ovrLayerDirect` structure. The application then creates a list of pointers to those layer structures, specifically to the `Header` field which is guaranteed to be the first member of each structure. Then the application builds a `ovrViewScaleDesc` struct with the required data, and calls the `ovrHmd_SubmitFrame` function.

```
// Create eye layer.
ovrLayerEyeFov eyeLayer;
eyeLayer.Header.Type    = ovrLayerType_EyeFov;
eyeLayer.Header.Flags   = 0;
for ( int eye = 0; eye < 2; eye++ )
{
 eyeLayer.ColorTexture[eye] = EyeBufferSet[eye];
 eyeLayer.Viewport[eye]     = EyeViewport[eye];
 eyeLayer.Fov[eye]          = EyeFov[eye];
 eyeLayer.RenderPose[eye]   = EyePose[eye];
}

// Create HUD layer, fixed to the player's torso
ovrLayerQuad hudLayer;
hudLayer.Header.Type    = ovrLayerType_QuadInWorld;
hudLayer.Header.Flags   = ovrLayerFlag_HighQuality;
hudLayer.ColorTexture   = TheHudTextureSet;
// 50cm in front and 20cm down from the player's nose,
// but it's a QuadInWorld, so fixed relative to their torso.
hudLayer.QuadPoseCenter.Position.x =  0.00f;
hudLayer.QuadPoseCenter.Position.y = -0.20f;
hudLayer.QuadPoseCenter.Position.z = -0.50f;
hudLayer.QuadPoseCenter.Orientation = ovrQuatf();
// HUD is 50cm wide, 30cm tall.
hudLayer.QuadSize.x = 0.50f;
hudLayer.QuadSize.y = 0.30f;
// Display all of the HUD texture.
hudLayer.Viewport.Pos.x = 0.0f;
hudLayer.Viewport.Pos.y = 0.0f;
hudLayer.Viewport.Size.w = 1.0f;
hudLayer.Viewport.Size.h = 1.0f;

// The list of layers.
ovrLayerHeader *layerList[2];
layerList[0] = &eyeLayer.Header;
layerList[1] = &hudLayer.Header;

// Set up positional data.
ovrViewScaleDesc viewScaleDesc;
viewScaleDesc.HmdSpaceToWorldScaleInMeters = 1.0f;
viewScaleDesc.HmdToEyeViewOffset[0] = hmdToEyeViewOffset[0];
viewScaleDesc.HmdToEyeViewOffset[1] = hmdToEyeViewOffset[1];

ovrResult result = ovrHmd_SubmitFrame(Hmd, 0, &viewScaleDesc, layerList, 2);
```

The compositor performs timewarp, distortion, and chromatic aberration correction on each layer separately before blending them together; there is no intermediate filtering step between sampling the layer image and the final framebuffer. This can provide a substantial improvement in text quality over the traditional method of rendering the layer as a quad to the eye buffer, which involves a double-filter step (once to the eye buffer, then once during distortion), especially when combined with the high-quality distortion flag.

One current disadvantage of layers is that no post-processing can be performed on the final composited image, such as soft-focus effects, light-bloom effects, or the Z intersection of layer data.

Calling ovrHmd_SubmitFrame queues the layers for display, and transfers control of the CurrentIndex texture inside the ovrSwapTextureSet to the compositor. It is important to understand that these textures are being shared (rather than copied) between the application and the compositor threads, and that composition does not necessarily happen at the time ovrHmd_SubmitFrame is called, so care must be taken. Oculus strongly recommends that the application should not try to use or render to any of the textures and indices that were submitted in the most recent ovrHmd_SubmitFrame call. For example:

```
// Create two SwapTextureSets to illustrate. Each will have two textures, [0] and [1].
ovrSwapTextureSet *eyeSwapTextureSet;
ovrHmd_CreateSwapTextureSetD3D11 ( ... &eyeSwapTextureSet );
ovrSwapTextureSet *hudSwapTextureSet;
ovrHmd_CreateSwapTextureSetD3D11 ( ... &hudSwapTextureSet );

// Set up two layers.
ovrLayerEyeFov eyeLayer;
ovrLayerEyeFov hudLayer;
eyeLayer.Header.Type = ovrLayerType_EyeFov;
eyeLayer...etc... // set up the rest of the data.
hudLayer.Header.Type = ovrLayerType_QuadInWorld;
hudLayer...etc... // set up the rest of the data.

// the list of layers
ovrLayerHeader *layerList[2];
layerList[0] = &eyeLayer.Header;
layerList[1] = &hudLayer.Header;

// Right now (no calls to ovrHmd_SubmitFrame done yet)
// eyeSwapTextureSet->Textures[0]: available
// eyeSwapTextureSet->Textures[1]: available
// hudSwapTextureSet->Textures[0]: available
// hudSwapTextureSet->Textures[1]: available

// Frame 1.
eyeSwapTextureSet->CurrentIndex = 0;
hudSwapTextureSet->CurrentIndex = 0;
eyeLayer.ColorTexture[0] = eyeSwapTextureSet;
eyeLayer.ColorTexture[1] = eyeSwapTextureSet;
hudLayer.ColorTexture = hudSwapTextureSet;
ovrHmd_SubmitFrame(Hmd, 0, nullptr, layerList, 2);

// Now,
// eyeSwapTextureSet->Textures[0]: in use by compositor
// eyeSwapTextureSet->Textures[1]: available
// hudSwapTextureSet->Textures[0]: in use by compositor
// hudSwapTextureSet->Textures[1]: available

// Frame 2.
eyeSwapTextureSet->CurrentIndex = 1;
AppRenderScene ( eyeSwapTextureSet->Textures[1] );
// App does not render to the HUD, does not change the layer setup.
ovrHmd_SubmitFrame(Hmd, 0, nullptr, layerList, 2);

// Now,
// eyeSwapTextureSet->Textures[0]: available
// eyeSwapTextureSet->Textures[1]: in use by compositor
// hudSwapTextureSet->Textures[0]: in use by compositor
// hudSwapTextureSet->Textures[1]: available

// Frame 3.
eyeSwapTextureSet->CurrentIndex = 0;
AppRenderScene ( eyeSwapTextureSet->Textures[0] );
// App hides the HUD
hudLayer.Header.Type = ovrLayerType_Disabled;
ovrHmd_SubmitFrame(Hmd, 0, nullptr, layerList, 2);

// Now,
// eyeSwapTextureSet->Textures[0]: in use by compositor
// eyeSwapTextureSet->Textures[1]: available
// hudSwapTextureSet->Textures[0]: available
// hudSwapTextureSet->Textures[1]: available
```

In other words, if the texture was used by the last ovrHmd_SubmitFrame call, don't try to render to it. If it wasn't, you can.

Advanced Rendering Configuration

By default, the SDK generates configuration values that optimize for rendering quality.

It also provides a degree of flexibility. For example, you can make changes when creating render target textures.

This section discusses changes you can make when choosing between rendering quality and performance, or if the engine you are using imposes constraints.

Coping with Graphics API or Hardware Rendertarget Granularity

The SDK is designed with the assumption that you want to use your video memory as carefully as possible and that you can create exactly the right render target size for your needs.

However, real video cards and real graphics APIs have size limitations (all have a maximum size; some also have a minimum size). They might also have granularity restrictions, for example, only being able to create render targets that are a multiple of 32 pixels in size or having a limit on possible aspect ratios. As an application developer, you can also impose extra restrictions to avoid using too much graphics memory.

In addition to the above, the size of the actual render target surface in memory might not necessarily be the same size as the portion that is rendered to. The latter may be slightly smaller. However, since it is specified as a viewport, it typically does not have any granularity restrictions. When you bind the render target as a texture, however, it is the full surface that is used, and so the UV coordinates must be corrected for the difference between the size of the rendering and the size of the surface it is on. The API will do this for you, but you need to tell it the relevant information.

The following code shows a two-stage approach for settings render target resolution. The code first calls `ovrHmd_GetFovTextureSize` to compute the ideal size of the render target. Next, the graphics library is called to create a render target of the desired resolution. In general, due to idiosyncrasies of the platform and hardware, the resulting texture size might be different from that requested.

```
// Get recommended left and right eye render target sizes.
Sizei recommenedTex0Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Left,
                              hmd->DefaultEyeFov[0], pixelsPerDisplayPixel);
Sizei recommenedTex1Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Right,
                              hmd->DefaultEyeFov[1], pixelsPerDisplayPixel);

// Determine dimensions to fit into a single render target.
Sizei renderTargetSize;
renderTargetSize.w = recommenedTex0Size.w + recommenedTex1Size.w;
renderTargetSize.h = max ( recommenedTex0Size.h, recommenedTex1Size.h );

// Create texture.
pRendertargetTexture = pRender->CreateTexture(renderTargetSize.w, renderTargetSize.h);

// The actual RT size may be different due to HW limits.
renderTargetSize.w = pRendertargetTexture->GetWidth();
renderTargetSize.h = pRendertargetTexture->GetHeight();

// Initialize eye rendering information.
// The viewport sizes are re-computed in case RenderTargetSize changed due to HW limitations.
ovrFovPort eyeFov[2] = { hmd->DefaultEyeFov[0], hmd->DefaultEyeFov[1] };

EyeRenderViewport[0].Pos  = Vector2i(0,0);
EyeRenderViewport[0].Size = Sizei(renderTargetSize.w / 2, renderTargetSize.h);
EyeRenderViewport[1].Pos  = Vector2i((renderTargetSize.w + 1) / 2, 0);
EyeRenderViewport[1].Size = EyeRenderViewport[0].Size;
```

For SDK distortion rendering, this data is passed into `ovrHmd_ConfigureRendering` as follows (code shown is for the D3D11 API):

```
ovrEyeRenderDesc eyeRenderDesc[2];

ovrBool result = ovrHmd_ConfigureRendering(hmd, &d3d11cfg.Config,
                                           ovrDistortion_Chromatic | ovrDistortion_TimeWarp,
                                           eyeFov, eyeRenderDesc);
```

You are free to choose the render target texture size and left and right eye viewports as you like, provided that you specify these values when calling `ovrHmd_EndFrame` using the `ovrTexture`. However, using `ovrHmd_GetFovTextureSize` will ensure that you allocate the optimum size for the particular HMD in use. The following sections describe how to modify the default configurations to make quality and performance trade-offs. You should also note that the API supports using different render targets for each eye if that is required by your engine (although using a single render target is likely to perform better since it will reduce context switches). OculusWorldDemo allows you to toggle between using a single combined render target versus separate ones for each eye, by navigating to the settings menu (press the Tab key) and selecting the Share RenderTarget option.

Forcing a Symmetrical Field of View

Typically the API will return an FOV for each eye that is not symmetrical, meaning the left edge is not the same distance from the center as the right edge.

This is because humans, as well as the Rift, have a wider FOV when looking outwards. When you look inwards, your nose is in the way. We are also better at looking down than we are at looking up. For similar reasons, the Rift's view is not symmetrical. It is controlled by the shape of the lens, various bits of plastic, and the edges of the screen. The exact details depend on the shape of your face, your IPD, and where precisely you place the Rift on your face; all of this is set up in the configuration tool and stored in the user profile. All of this means that almost nobody has all four edges of their FOV set to the same angle, so the frustum produced will be off-center. In addition, most people will not have the same fields of view for both their eyes. They will be close, but rarely identical.

As an example, on the DK1, the author's left eye has the following FOV:

- 53.6 degrees up
- 58.9 degrees down
- 50.3 degrees inwards (towards the nose)
- 58.7 degrees outwards (away from the nose)

In the code and documentation, these are referred to as 'half angles' because traditionally a FOV is expressed as the total edge-to-edge angle. In this example, the total horizontal FOV is 50.3+58.7 = 109.0 degrees, and the total vertical FOV is 53.6+58.9 = 112.5 degrees.

The recommended and maximum fields of view can be accessed from the HMD as shown below:

```
ovrFovPort defaultLeftFOV = hmd->DefaultEyeFov[ovrEye_Left];

ovrFovPort maxLeftFOV = hmd->MaxEyeFov[ovrEye_Left];
```

`DefaultEyeFov` refers to the recommended FOV values based on the current user's profile settings (IPD, eye relief etc). `MaxEyeFov` refers to the maximum FOV that the headset can possibly display, regardless of profile settings.

The default values provide a good user experience with no unnecessary additional GPU load. If your application does not consume significant GPU resources, you might want to use the maximum FOV settings to reduce reliance on the accuracy of the profile settings. You might provide a slider in the application control panel that enables users to choose interpolated FOV settings between the default and the maximum. But, if your application is heavy on GPU usage, you might want to reduce the FOV below the default values as described in *Improving Performance by Decreasing Field of View* on page 30.

The chosen FOV values should be passed into `ovrHmd_ConfigureRendering`.

The FOV angles for up, down, left, and right (expressed as the tangents of the half-angles), is the most convenient form to set up culling or portal boundaries in your graphics engine. The FOV values are also used to determine the projection matrix used during left and right eye scene rendering. We provide an API utility function ovrMatrix4f_Projection for this purpose:

```
ovrFovPort fov;

// Determine fov.
...

ovrMatrix4f projMatrix = ovrMatrix4f_Projection(fov, znear, zfar, isRightHanded);
```

It is common for the top and bottom edges of the FOV to not be the same as the left and right edges when viewing a PC monitor. This is commonly called the 'aspect ratio' of the display, and very few displays are square. However, some graphics engines do not support off-center frustums. To be compatible with these engines, you will need to modify the FOV values reported by the `ovrHmdDesc` struct. In general, it is better to grow the edges than to shrink them. This will put a little more strain on the graphics engine, but will give the user the full immersive experience, even if they won't be able to see some of the pixels being rendered.

Some graphics engines require that you express symmetrical horizontal and vertical fields of view, and some need an even less direct method such as a horizontal FOV and an aspect ratio. Some also object to having frequent changes of FOV, and may insist that both eyes be set to the same. The following is a an example of code for handling this restrictive case:

```
ovrFovPort fovLeft = hmd->DefaultEyeFov[ovrEye_Left];
ovrFovPort fovRight = hmd->DefaultEyeFov[ovrEye_Right];

ovrFovPort fovMax = FovPort::Max(fovLeft, fovRight);
float combinedTanHalfFovHorizontal = max ( fovMax.LeftTan, fovMax.RightTan );
float combinedTanHalfFovVertical = max ( fovMax.UpTan, fovMax.DownTan );

ovrFovPort fovBoth;
fovBoth.LeftTan = fovBoth.RightTan = combinedTanHalfFovHorizontal;
fovBoth.UpTan = fovBoth.DownTan = combinedTanHalfFovVertical;


// Create render target.
Sizei recommenedTex0Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Left,
                                                     fovBoth, pixelsPerDisplayPixel);
Sizei recommenedTex1Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Right,
                                                     fovBoth, pixelsPerDisplayPixel);

...


// Initialize rendering info.
ovrFovPort eyeFov[2];
eyeFov[0]                       = fovBoth;
eyeFov[1]                       = fovBoth;
```

```
...

// Compute the parameters to feed to the rendering engine.
// In this case we are assuming it wants a horizontal FOV and an aspect ratio.
float horizontalFullFovInRadians = 2.0f * atanf ( combinedTanHalfFovHorizontal );
float aspectRatio = combinedTanHalfFovHorizontal / combinedTanHalfFovVertical;

GraphicsEngineSetFovAndAspect ( horizontalFullFovInRadians, aspectRatio );
...
```

Note: You will need to determine FOV before creating the render targets, since FOV affects the size of the recommended render target required for a given quality.

Improving Performance by Decreasing Pixel Density

The DK1 has a resolution of 1280x800 pixels, split between the two eyes. However, because of the wide FOV of the Rift and the way perspective projection works, the size of the intermediate render target required to match the native resolution in the center of the display is significantly higher.

For example, to achieve a 1:1 pixel mapping in the center of the screen for the author's field-of-view settings on a DK1 requires a much larger render target that is 2000x1056 pixels in size.

Even if modern graphics cards can render this resolution at the required 60Hz, future HMDs might have significantly higher resolutions. For virtual reality, dropping below 60Hz provides a terrible user experience; it is always better to decrease the resolution to maintain framerate. This is similar to a user having a high resolution 2560x1600 monitor. Very few 3D games can run at this native resolution at full speed, so most allow the user to select a lower resolution to which the monitor upscales to the fill the screen.

You can use the same strategy on the HMD. That is, run it at a lower video resolution and let the hardware upscale for you. However, this introduces two steps of filtering: one by the distortion processing and one by the video upscaler. Unfortunately, this double filtering introduces significant artifacts. It is usually more effective to leave the video mode at the native resolution, but limit the size of the intermediate render target. This gives a similar increase in performance, but preserves more detail.

One way to resolve this is to allow the user to adjust the resolution through a resolution selector. However, the actual resolution of the render target depends on the user's configuration, rather than a standard hardware setting This means that the 'native' resolution is different for different people. Additionally, presenting resolutions higher than the physical hardware resolution might confuse some users. They might not understand that selecting 1280x800 is a significant drop in quality, even though this is the resolution reported by the hardware.

A better option is to modify the `pixelsPerDisplayPixel` value that is passed to the `ovrHmd_GetFovTextureSize` function. This could also be based on a slider presented in the applications render settings. This determines the relative size of render target pixels as they map to pixels at the center of the display surface. For example, a value of 0.5 would reduce the render target size from 2000x1056 to 1000x528 pixels, which might allow mid-range PC graphics cards to maintain 60Hz.

```
float pixelsPerDisplayPixel = GetPixelsPerDisplayFromApplicationSettings();

Sizei recommenedTexSize = ovrHmd_GetFovTextureSize(hmd, ovrEye_Left,  fovLeft,
                                                   pixelsPerDisplayPixel);
```

Although you can set the parameter to a value larger than 1.0 to produce a higher-resolution intermediate render target, Oculus hasn't observed any useful increase in quality and it has a high performance cost.

OculusWorldDemo allows you to experiment with changing the render target pixel density. Navigate to the settings menu (press the Tab key) and select Pixel Density. Press the up and down arrow keys to adjust the pixel density at the center of the eye projection. A value of 1.0 sets the render target pixel density to the display surface 1:1 at this point on the display. A value of 0.5 means sets the density of the render target pixels to half of the display surface. Additionally, you can select Dynamic Res Scaling which will cause the pixel density to automatically adjust between 0 to 1.

Improving Performance by Decreasing Field of View

In addition to reducing the number of pixels in the intermediate render target, you can increase performance by decreasing the FOV that the pixels are stretched across.

Depending on the reduction, this can result in tunnel vision which decreases the sense of immersion. Nevertheless, reducing the FOV increases performance in two ways. The most obvious is fillrate. For a fixed pixel density on the retina, a lower FOV has fewer pixels. Because of the properties of projective math, the outermost edges of the FOV are the most expensive in terms of numbers of pixels. The second reason is that there are fewer objects visible in each frame which implies less animation, fewer state changes, and fewer draw calls.

Reducing the FOV set by the player is a very painful choice to make. One of the key experiences of virtual reality is being immersed in the simulated world, and a large part of that is the wide FOV. Losing that aspect is not a thing we would ever recommend happily. However, if you have already sacrificed as much resolution as you can, and the application is still not running at 60Hz on the user's machine, this is an option of last resort.

We recommend giving players a Maximum FOV slider that defines the four edges of each eye's FOV.

```
ovrFovPort defaultFovLeft = hmd->DefaultEyeFov[ovrEye_Left];
ovrFovPort defaultFovRight = hmd->DefaultEyeFov[ovrEye_Right];

float maxFovAngle = ...get value from game settings panel...;
float maxTanHalfFovAngle = tanf ( DegreeToRad ( 0.5f * maxFovAngle ) );

ovrFovPort newFovLeft  = FovPort::Min(defaultFovLeft, FovPort(maxTanHalfFovAngle));
ovrFovPort newFovRight = FovPort::Min(defaultFovRight, FovPort(maxTanHalfFovAngle));


// Create render target.
Sizei recommenedTex0Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Left  newFovLeft,
                                                    pixelsPerDisplayPixel);
Sizei recommenedTex1Size = ovrHmd_GetFovTextureSize(hmd, ovrEye_Right, newFovRight,
                                                    pixelsPerDisplayPixel);

...


// Initialize rendering info.
ovrFovPort eyeFov[2];
eyeFov[0]                       = newFovLeft;
eyeFov[1]                       = newFovRight;

...


// Determine projection matrices.
ovrMatrix4f projMatrixLeft = ovrMatrix4f_Projection(newFovLeft, znear, zfar, isRightHanded);
ovrMatrix4f projMatrixRight = ovrMatrix4f_Projection(newFovRight, znear, zfar, isRightHanded);
```

It might be interesting to experiment with non-square fields of view. For example, clamping the up and down ranges significantly (e.g. 70 degrees FOV) while retaining the full horizontal FOV for a 'Cinemascope' feel.

OculusWorldDemo allows you to experiment with reducing the FOV below the defaults. Navigate to the settings menu (press the Tab key) and select the "Max FOV" value. Pressing the up and down arrows to change the maximum angle in degrees.

Improving Performance by Rendering in Mono

A significant cost of stereo rendering is rendering two views, one for each eye.

For some applications, the stereoscopic aspect may not be particularly important and a monocular view might be acceptable in return for some performance. In other cases, some users may get eye strain from a stereo view and wish to switch to a monocular one. However, they still wish to wear the HMD as it gives them a high FOV and head-tracking.

OculusWorldDemo allows the user to toggle mono render mode by pressing the F7 key.

To render in mono, your code should have the following changes:

- Set the FOV to the maximum symmetrical FOV based on both eyes.
- Call `ovhHmd_GetFovTextureSize` with this FOV to determine the recommended render target size.
- Configure both eyes to use the same render target and the same viewport when calling `ovrHmd_EndFrame` or `ovrHmd_GetRenderScaleAndOffset`.
- Render the scene once to the shared render target.

This merges the FOV of the left and right eyes into a single intermediate render. This render is still distorted twice, once per eye, because the lenses are not exactly in front of the user's eyes. However, this is still a significant performance increase.

Setting a virtual IPD to zero means that everything will seem gigantic and infinitely far away, and of course the user will lose much of the sense of depth in the scene.

Note: It is important to scale virtual IPD and virtual head motion together so, if the virtual IPD is set to zero, all virtual head motion due to neck movement is also be eliminated. Sadly, this loses much of the depth cues due to parallax. But, if the head motion and IPD do not agree, it can cause significant disorientation and discomfort. Experiment with caution!

Chromatic Aberration

Chromatic aberration is a visual artifact seen when viewing images through lenses.

The phenomenon causes colored fringes to be visible around objects, and is increasingly more apparent as our view shifts away from the center of the lens. The effect is due to the refractive index of the lens varying for different wavelengths of light (shorter wavelengths towards the blue end of the spectrum are refracted less than longer wavelengths towards the red end). Since the image displayed on the Rift is composed of individual red, green, and blue pixels,2 it is susceptible to the unwanted effects of chromatic aberration. The manifestation, when looking through the Rift, is that the red, green, and blue components of the image appear to be scaled out radially, and by differing amounts. Exactly how apparent the effect is depends on the image content and to what degree users are concentrating on the periphery of the image versus the center.

Chromatic Aberration

Fortunately, programmable GPUs enable you to significantly reduce the degree of visible chromatic aberration, albeit at some additional GPU expense.

To do this, pre-transform the image so that the chromatic aberration of the lens will result in a more normal looking image. This is analogous to the way in which we pre-distort the image to cancel out the distortion effects generated by the lens.

Sub-Channel Aberration

Although we can reduce the artifacts through the use of distortion correction, we cannot completely remove them for an LCD display panel.

This is due to the fact that each color channel is actually comprised of a range of visible wavelengths, each of which is refracted by a different amount when viewed through the lens. As a result, although we are able to distort the image for each channel to bring the peak frequencies back into spatial alignment, it is not possible to compensate for the aberration that occurs within a color channel. Typically, when designing optical systems, chromatic aberration across a wide range of wavelengths is managed by carefully combining specific optical elements (in other texts, for example, look for "achromatic doublets").

SDK Samples and Gamepad Usage

Some of the Oculus SDK samples use gamepad controllers to enable movement around the virtual world.

This section describes the devices that are currently supported and setup instructions.

Xbox 360 Wired Controller for Windows

To set up the controller:

- Plug the device into a USB port. Windows should recognize the controller and install any necessary drivers automatically.

Logitech F710 Wireless Gamepad

To set up the gamepad for Windows:

1. Put the controller into 'XInput' mode by moving the switch on the front of the controller to the 'X' position.
2. Press a button on the controller so that the green LED next to the 'Mode' button begins to flash.
3. Plug the USB receiver into the PC while the LED is flashing.
4. Windows should recognize the controller and install any necessary drivers automatically.

To set up the gamepad for Mac:

1. Put the controller into 'DirectInput' mode by moving the switch on the front of the controller to the 'D' position.
2. Press a button on the controller so that the green LED next to the 'Mode' button begins to flash.
3. Plug the USB receiver into the PC while the LED is flashing.
4. OSX should recognize the controller and install any necessary drivers automatically.

Sony PlayStation DUALSHOCK3 Controller

To set up the controller for Mac:

1. Turn off any nearby PS3 consoles.
2. Go to System Preferences -> Bluetooth.
3. Make sure the 'On' and 'Discoverable' check boxes are checked.
4. Plug the controller into the Mac using the USB cable.
5. Press the 'PS' Button in the middle of the controller for 3 seconds and then remove the USB cable.
6. After removing the cable, the controller should immediately appear in the device list. If a dialog appears requesting a passcode enter 'xxxx' and then press Pair.
7. Click on the gear symbol beneath the list of Bluetooth devices and select Add to Favorites.
8. Click on the gear symbol once more and select Update Services.
9. Quickly turn Bluetooth off and then immediately back on again.
10. Press the 'PS' Button on the controller. The controller status should now appear as 'Connected'.

Low-Level Sensor Details

In normal use, applications use the API functions which handle sensor fusion, correction, and prediction for them.

Note: This section is left for reference; parts of it may be out of date after the introduction of the external position tracker with DK2.

In normal use, applications will use the API functions which handle sensor fusion, correction, and prediction for them. This section is provided purely for interest.

Developers can read the raw sensor data directly from ovrTrackingState::RawSensorData. This contains the following data:

```
ovrVector3f Accelerometer;  // Acceleration reading in m/s^2.
ovrVector3f Gyro;           // Rotation rate in rad/s.
ovrVector3f Magnetometer;   // Magnetic field in Gauss.
float       Temperature;    // Temperature of the sensor in degrees Celsius.
float       TimeInSeconds;  // Time when the reported IMU reading took place, in seconds.
```

Over long periods of time, a discrepancy will develop between Q (the current head pose estimate) and the true orientation of the Rift. This problem is called drift error, which described more in the following section. Errors in pitch and roll are automatically reduced by using accelerometer data to estimate the gravity vector.

Errors in yaw are reduced by magnetometer data. For many games, such as a standard First Person Shooter (FPS), the yaw direction is frequently modified by the game controller and there is no problem. However, in many other games or applications, the yaw error will need to be corrected. For example, if you want to maintain a cockpit directly in front of the player. It should not unintentionally drift to the side over time. Yaw error correction is enabled by default.

Sensor Fusion Details

The most important part of sensor fusion is the integration of angular velocity data from the gyroscope.

In each tiny interval of time, a measurement of the angular velocity arrives:

In each tiny interval of time, a measurement of the angular velocity arrives:

$$\ell = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

Oculus API Changes

This section describes API changes for each version release.

Changes Since Release 0.2

The Oculus API has been significantly redesigned since the 0.2.5 release, with the goals of improving ease of use, correctness and supporting a new driver model.

The following is the summary of changes in the API:

- All of the HMD and sensor interfaces have been organized into a C API. This makes it easy to bind from other languages.
- The new Oculus API introduces two distinct approaches to rendering distortion: SDK Rendered and Client Rendered. As before, the application is expected to render stereo scenes onto one or more render targets. With the SDK rendered approach, the Oculus SDK then takes care of distortion rendering, frame present, and timing within the SDK. This means that developers don't need to setup pixel and vertex shaders or worry about the details of distortion rendering, they simply provide the device and texture pointers to the SDK. In client rendered mode, distortion rendering is handled by the application as with previous versions of the SDK. SDK Rendering is the preferred approach for future versions of the SDK.
- The method of rendering distortion in client rendered mode is now mesh based. The SDK returns a mesh which includes vertices and UV coordinates which are then used to warp the source render target image to the final buffer. Mesh based distortion is more efficient and flexible than pixel shader approaches.
- The Oculus SDK now keeps track of game frame timing and uses this information to accurately predict orientation and motion.
- A new technique called Timewarp is introduced to reduce motion-to-photon latency. This technique re-projects the scene to a more recently measured orientation during the distortion rendering phase.

The table on the next page briefly summarizes differences between the 0.2.5 and 0.4 API versions.

Functionality	0.2 SDK APIs	0.4 SDK C APIs
`Initialization`	`OVR::System::Init`, `DeviceManager`, `HMDDevice`, `HMDInfo`.	`ovr_Initialize`, `ovrHmd_Create`, `ovrHmd` handle and `ovrHmdDesc`.
`Sensor Interaction`	`OVR::SensorFusion` class, with `GetOrientation` returning `Quatf`. Prediction amounts are specified manually relative to the current time.	`ovrHmd_ConfigureTracking`, `ovrHmd_GetTrackingState` returning `ovrTrackingState`. `ovrHmd_GetEyePoses` returns head pose based on correct timing.
`Rendering Setup`	`Util::Render::StereoConfig` helper class creating `StereoEyeParams`, or manual setup based on members of `HMDInfo`.	`ovrHmd_ConfigureRendering` populates `ovrEyeRenderDesc` based on the field of view. Alternatively, `ovrHmd_GetRenderDesc` supports rendering setup for client distortion rendering.
`Distortion Rendering`	App-provided pixel shader based on distortion coefficients.	Client rendered: based on the distortion mesh returned by `ovrHmd_CreateDistortionMesh`. (or) SDK rendered:

Functionality	0.2 SDK APIs	0.4 SDK C APIs
		done automatically in `ovrHmd_EndFrame`.
`Frame Timing`	Manual timing with current-time relative prediction.	Frame timing is tied to vsync with absolute values reported by `ovrHmd_BeginFrame` or `ovr_BeginFrameTiming`.

Changes Since Release 0.3

A number of changes were made to the API since the 0.3.2 Preview release.

These are summarized as follows:

- Removed the method `ovrHmd_GetDesc`. The `ovrHmd` handle is now a pointer to a `ovrHmdDesc` struct.
- The sensor interface has been simplified. Your application should now call `ovrHmd_ConfigureTracking` at initialization and `ovrHmd_GetTrackingState` or `ovrHmd_GetEyePoses` to get the head pose.
- `ovrHmd_BeginEyeRender` and `ovrHmd_EndEyeRender` have been removed. You should now use `ovrHmd_GetEyePoses` to determine predicted head pose when rendering each eye. Render poses and `ovrTexture` info is now passed into `ovrHmd_EndFrame` rather than `ovrHmd_EndEyeRender`.
- `ovrSensorState` struct is now `ovrTrackingState`. The predicted pose Predicted is now named `HeadPose`. `CameraPose` and `LeveledCameraPose` have been added. Raw sensor data can be obtained through `RawSensorData`.
- `ovrSensorDesc` struct has been merged into ovrHmdDesc.
- Addition of `ovrHmd_AttachToWindow`. This is a platform specific function to specify the application window whose output will be displayed on the HMD. Only used if the `ovrHmdCap_ExtendDesktop` flag is false.
- Addition of `ovr_GetVersionString`. Returns a string representing the libOVR version.

There have also been a number of minor changes:

- Renamed `ovrSensorCaps` struct to `ovrTrackingCaps`.
- Addition of `ovrHmdCaps::ovrHmdCap_Captured` flag. Set to `true` if the application captured ownership of the HMD.
- Addition of `ovrHmdCaps::ovrHmdCap_ExtendDesktop` flag. The display driver is in compatibility mode (read only).
- Addition of `ovrHmdCaps::ovrHmdCap_NoMirrorToWindow` flag. Disables mirroring of HMD output to the window. This may improve rendering performance slightly (only if 'Extend-Desktop' is off).
- Addition of `ovrHmdCaps::ovrHmdCap_DisplayOff` flag. Turns off HMD screen and output (only if 'ExtendDesktop' is off).
- Removed `ovrHmdCaps::ovrHmdCap_LatencyTest` flag. Was used to indicate support of pixel reading for continuous latency testing.
- `AdditionofovrDistortionCaps::ovrDistortionCap_Overdriveflag. Overdrivebrightness` transitions to reduce artifacts on DK2 displays.
- Addition of `ovrStatusBits::ovrStatus_CameraPoseTracked` flag. Indicates that the camera pose is successfully calibrated.

Changes Since Release 0.4

A number of changes were made to the API since the 0.4 release.

The Oculus SDK 0.5 moves from static linking to a dynamic link library (DLL) model. Using a DLL offers several advantages:

- As long as the arguments and return values are the same, experiences do not need to be recompiled to take advantage of the updated library.
- Localization into new languages is easier because the functions remain consistent across languages.
- The DLL can be updated to take advantage of new features and headsets without affecting current games and experiences.

In addition to moving to a DLL model, the following changes were made:

- SDK versions now use a *product.major.minor.patch* format. The product value is currently set to 0 as this is a pre-release product. For example, 0.5.0.1 means Product 0, Major 5, Minor 0, Patch 1.
- Significant improvements were made to tracking behavior and performance.
- Improvements were made to the samples.
- The SDK now provides better reporting of display driver incompatibility.
- Support for DX10 was removed.
- DX9 support is deprecated and will be removed in a future version of the SDK.
- A bug was fixed where full persistence was inadvertently enabled due to device initialization races.
- Improvements were made to headset USB sleep management.
- Uncommon deadlocks were fixed in the runtime service.
- Diagnostics and configuration capture were improved.
- Monitor rotation is now supported in the legacy Extended mode.
- Default time warp scheduling is improved, which should reduce frame drops.

The following SDK changes were made:

- Moved and renamed LibOVR/Src/OVR_CAPI.h to LibOVR/Include/OVR_CAPI_0_5_0.h. Some additional public headers such as OVR_Version.h have been moved to LibOVR/Include/. Any other previously public headers are now private to LibOVR.
- Added enum ovrHmdCaps::ovrHmdCap_DebugDevice.
- Renamed enum ovrDistortionCaps::ovrDistortionCap_ProfileNoTimewarpSpinWaits to ovrDistortionCap_ProfileNoSpinWaits.
- Removed enum ovrDistortionCaps::ovrDistortionCap_NoTimewarpJit.
- Added enum ovrDistortionCaps::ovrDistortionCap_TimewarpJitDelay.
- Removed ovrTrackingState::LastVisionProcessingTime.
- Removed ovrTrackingState::LastVisionFrameLatency.
- ovr_Initialize now takes a params argument. See the in-code documentation for details.
- ovr_Initialize now returns false for additional reasons.
- No API functions can be called after ovr_Shutdown except ovr_Initialize.
- The hmdToEyeViewOffset argument for ovrHmd_GetEyePosess is now const.
- Added the ovrQuatf playerTorsoMotion argument to ovrHmd_GetEyeTimewarpMatricesDebug.
- Added ovr_TraceMessage.

Changes Since Release 0.5

A number of changes were made to the API since the 0.5 release.

New Features

The following are major new features for the Oculus SDK and runtime:

- Added the compositor service, which improves compatibility and support for simultaneous applications.
- Added layer support, which increases flexibility and enables developers to tune settings based on the characteristics and requirements of each layer.
- Significantly improved error handling and reporting.
- Added a suite of new sample projects which demonstrate techniques and the new SDK features.
- Removed application-side DirectX and OpenGL API shims, which results in improved runtime compatibility and reliability.
- Simplified the API, as described below.
- Changed Extended mode to use the compositor process. Rendering setup is now identical for extended and direct modes. The application no longer needs to know which mode is being used.
- Extended mode can now support mirroring, which was previously only supported by Direct mode.
- Simplified the timing interface and made it more robust by moving to a single function: ovrHmd_GetFrameTiming.
- Fixed a number of bugs and reliability problems.

The following are major new features for Unity:

- Disabled eye texture anti-aliasing when using deferred rendering. This fixes the blackscreen issue.
- Eliminated the need for the DirectToRift.exe in Unity 4.6.3p2 and later.
- Removed the hard dependency from the Oculus runtime. Apps now render in mono without tracking when VR isn't present.

API Changes

This release represents a major revision of the API. These changes significantly simplify the API while retaining essential functionality. Changes to the API include:

- Removed support for application-based distortion rendering. Removed functions include ovrHmd_CreateDistortionMesh, ovrHmd_GetRenderScaleAndOffset, and so on. If you feel that you require application-based distortion rendering, please contact Oculus Developer Relations.
- Introduced ovrSwapTextureSets, which are textures shared between the OVRServer process and the application process. Instead of using your own back buffers, applications must render VR scenes and layers to ovrSwapTextureSet textures. Texture sets are created with ovrHmd_CreateSwapTextureSetD3D11/OpenGL and destroyed with ovrHmd_DestroySwapTextureSet.
- ovrHmd_BeginFrame was removed and ovrHmd_EndFrame was replaced with ovrHmd_SubmitFrame.
- Added a new layer API. A list of layer pointers is passed into ovrHmd_SubmitFrame.
- Improved error reporting, including adding the ovrResult type. Some API functions were changed to return ovrResult. ovrHmd_GetLastError was replaced with ovr_GetLastErrorInfo.
- Removed ovr_InitializeRenderingShim, as it is no longer necessary with the service-based compositor.
- Removed some ovrHmdCaps flags, including ovrHmdCap_Present, ovrHmdCap_Available, ovrHmdCap_Captured, ovrHmdCap_ExtendDesktop, ovrHmdCap_NoMirrorToWindow, and ovrHmdCap_DisplayOff.
- Removed ovrDistortionCaps. Some of this functionality is present in ovrLayerFlags.

- ovrHmdDesc no longer contains display device information, as the service-based compositor now handles the display device.
- Simplified ovrFrameTiming to only return the DisplayMidpointSeconds prediction timing value. All other timing information is now available though the thread-safe ovrHmd_GetFrameTiming. The ovrHmd_BeginFrameTiming and EndFrameTiming functions were removed.
- Removed the LatencyTest functions (e.g. ovrHmd_GetLatencyTestResult).
- Removed the PerfLog functions (e.g. ovrHmd_StartPerfLog), as these are effectively replaced by ovrLogCallback (introduced in SDK 0.5).
- Removed the health-and-safety-warning related functions (e.g. ovrHmd_GetHSWDisplayState). The HSW functionality is now handled automatically.
- Removed support for automatic HMD mirroring. Applications can now create a mirror texture (e.g. with ovrHmd_CreateMirrorTextureD3D11 / ovrHmd_DestroyMirrorTexture) and manually display it in a desktop window instead. This gives developers flexibility to use the application window in a manner that best suits their needs, and removes the OpenGL problem with previous SDKs in which the application back-buffer limited the HMD render size.
- Added ovrInitParams::ConnectionTimeoutMS, which allows the specification of a timeout for ovr_Initialize to successfully complete.
- Removed ovrHmd_GetHmdPosePerEye and added ovr_CalcEyePoses.

Bugs Fixed Since the Last Release

The following are bugs fixed since 0.5:

- HmdToEyeViewOffset provided the opposite of the expected result; it now properly returns a vector to each eye's position from the center.
- If both the left and right views are rendered to the same texture, there is less "bleeding" between the two. Apps still need to keep a buffer zone between the two regions to prevent texture filtering from picking up data from the adjacent eye, but the buffer zone is much smaller than before. We recommend about 8 pixels, rather than the previously recommended 100 pixels. Because systems vary, feedback on this matter is appreciated.
- Fixed a crash when switching between Direct and Extended Modes
- Fixed performance and judder issues in Extended Mode
- Switching from Extended Mode to Direct Mode while running Oculus World Demo causes sideways rendering.
- Judder with Oculus Room Tiny Open GL examples in Windows 7