FidelityFX Shadow Denoiser

This document provides a **pass-by-pass breakdown** of the denoiser used in the *FidelityFX Shadow Denoiser* library.

ffx_denoiser_shadows_prepare

First, the output from the raytracer is packed into a buffer laid out in a 32bit uint bitmask to represent 8x4 pixel regions. This assists with bandwidth reduction in later passes. An optimization can be made for a raytracing pass to work as a group and write these bitmasks directly. In that case this preparation pass can be skipped. While it is possible to extend that idea beyond one ray per pixel in theory, the current implementation is designed with one ray per pixel in mind.

ffx_denoiser_shadows_tileclassification

Tile Classification performs three major steps:

1. Local Neighborhood
2. Disocclusion Mask
3. Reprojection

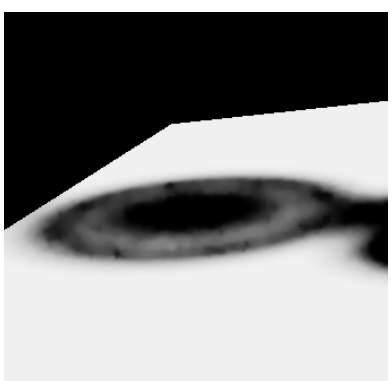
Local Neighborhood encodes the first two moments of the shading values (in this case, the noisy shadow values) surrounding a pixel.

Those moments are called respectively:

- the **mean**, which is the average of the neighboring samples,
- and the **variance**, which represents an estimation of the amount of noise in the image.

These values will be used in the reprojection step so we will see later how they are used; for now, we will focus on how to calculate them.

The FidelityFX Shadow Denoiser sets the kernel radius value to 8, which corresponds to an 17x17 kernel. Here is a series of renders with various kernel sizes under heavy shadow motion:



5x5 kernel

17x17 kernel (default)

29x29 kernel

We can see how the shadow quality increases with the size of the kernel; the 17x17 kernel is selected as a balance between quality and performance.

However, a 17x17 kernel would require 289 taps per pixel, which is prohibitively expensive. The solution here is to realize that the variance calculation kernel is separable, meaning we can perform a horizontal pass, store the intermediate results and finish with a vertical pass; this drops the number of per-pixel taps down to 34 across the two passes. Utilizing the compressed bitmask for ray hits we can further bring the 289 taps down to 18 scalar loads.

Both the horizontal and the vertical pass are integrated into the temporal reprojection pass itself to avoid the memory bandwidth requirements of having to write to and read from an additional intermediate target. That comes with the cost of having to recalculate some of the horizontal values, but that is comparably cheap due to using the compressed shadow mask.

Disocclusion Mask determines new areas on the screen. These are regions that were previously outside of screen-space but are now visible due to camera motion, or now visible due to occluders moving.

This information is typically referred to as disocclusion and in this pass we determine a binary mask flagging which pixels were disoccluded and which were not. In order to determine which areas are new, we calculate for each pixel the depth value that it should have had in the previous frame were it present and compare it with the actual value using the depth buffer from the last frame; if the depth values do not match, this is a disocclusion. To calculate the previous depth value, we use a reprojection matrix that takes a clip-space position in the current frame and returns the clip-space position in the previous frame, from which we can retrieve the desired depth value. The reprojection value is sensitive to numerical errors. Thus, we recommend calculating the intermediate steps in higher precision:

```
reprojection_matrix = view_projection_inverse_matrix * previous_view_projection_matrix;
```

The disocclusion mask flags the new pixels on screen.

In the above image, a larger than 1% depth error is enough to trigger a disocclusion and while this works well in the general case, it breaks down for areas of the screen that exhibit large depth variations, which typically happens at grazing angles. We fix this is by dynamically changing the threshold value per pixel based on the surface grazing angle (estimated using the dot product of the camera forward direction and the surface normal vector):

Constant depth threshold

Adaptive depth threshold

Notice the invalid horizontal lines on the floor caused by the large depth variations, which are removed in the adaptive version.

Reprojection uses the Local Neighborhood data, Disocclusion data, and temporal history buffers provided to perform velocity based reprojection.

Fist we calculate temporal variance, which is an estimate of the amount of noise in the image. This value will be used by the spatial passes to drive the amount of blur needed for denoising:

Temporal variance

When few temporal samples are available, due to masked disoccluded regions resetting the per-pixel sample count, the temporal variance is combined with the spatial one that was described in the Local Neighborhood section of this pass:

```
if (moments_current.z < 16.0f)

{

    const float variance_boost = max(16.0f - moments_current.z, 1.0f);
    variance = max(variance, spatial_variance);
    variance *= variance_boost; // boost variance on first frames

}
```

We boost the value of the variance when few samples are available to get rid of the noise in the regions where temporal reprojection does not work:

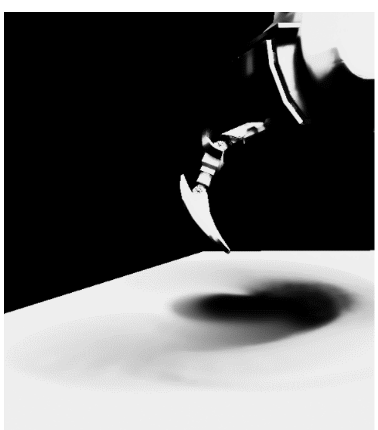
Without variance boost

With variance boost

Notice how the bottom and far-left parts of the image are much noisier without applying the variance boost. Increasing the variance value will mean a more aggressive spatial blur for those pixels that have little to no temporal history; this is cooled off and disabled as the history grows longer.

Once moments and variance are calculated, the shader reprojects the shadow values from the previous frames, from the history buffer, and re-use the samples for denoising.

One important issue here is that shadows can move, and this motion is not reflected into the velocity map. So, we need a way to accept or reject history samples for these cases. This is done by clamping the reprojected history value to the local neighborhood that was calculated earlier:



Naïve blending

Neighborhood clamping

Notice how the shadow pretty much disappears as many temporal samples get incorrectly blended. On the other hand, neighborhood clamping helps with obtaining a much more responsive filter and preserves the shadow details under motion.

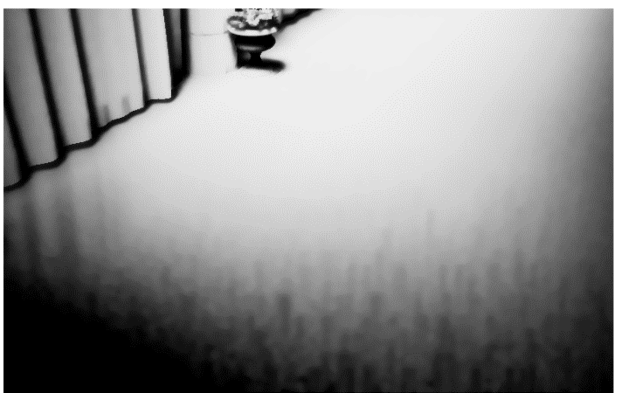
```
// Compute the clamping bounding box
const float std_deviation = sqrt(local_variance);
const float nmax = local_mean + 0.5f * std_deviation;
const float nmin = local_mean - 0.5f * std_deviation;

// Clamp reprojected sample to local neighborhood
const float shadow_previous = SampleHistory(uv - velocity);
const float shadow_clamped = clamp(shadow_previous, nmin, nmax);
```

The neighborhood clamping implementation resembles the above code and can be seen towards the end of the `FFX_DNSR_Shadows_TileClassification` function.

The clamped history information is finally merged with the current frame using a simple exponential moving average blend. However, we need to choose the blend factor where:

- a low blend factor will mostly keep the current frame value resulting in a responsive but unstable filter,
- a high blend factor will mostly keep the clamped history value resulting in a stable but unresponsive filter.

One solution is to choose the blend factor per pixel based on the amount of history available - where we have little to no history, we will go for a low blend factor, whereas where we are confident about our reprojection we will go for a high blend factor:



Constant blend factor

Adaptive blend factor

Notice how the adaptive version produces a more responsive filter, eliminating most of the temporal bleeding from the initial render.

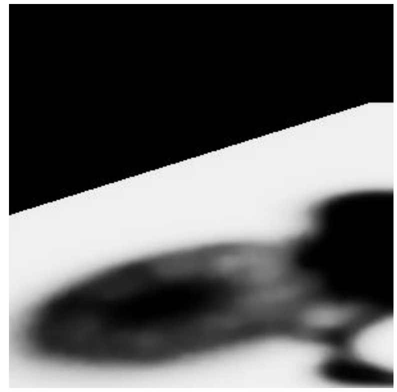
ffx_denoiser_shadows_filter

The final pass of the FidelityFX Shadow Denoiser is responsible for performing the spatial filtering and is run three times. The three passes have a relatively small region where they sample from so these run optimized kernels that utilize groupshared memory to cache samples.

It implements the Edge-Avoiding À-Trous Wavelet (EAW) filtering technique, where blurs are performed repeatedly with increasing radius values over multiple passes:

No EAW pass

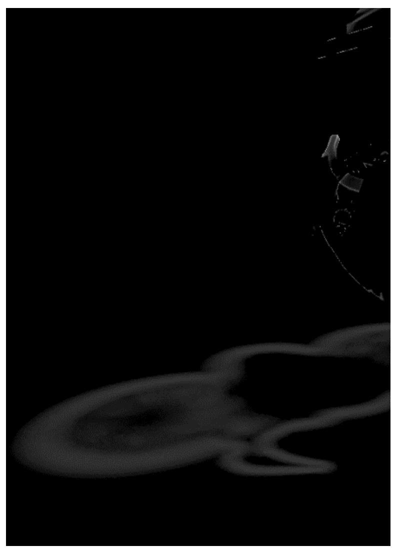
Single EAW pass



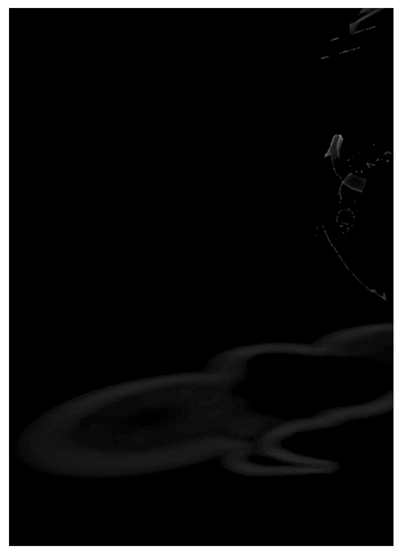
3 EAW passes

Additionally, the variance estimated in the temporal pass is updated with its filtered value after each subsequent blur pass; this allows to cool off the amount of blurring where it is not needed anymore:

Variance after 1 blur pass



Variance after 2 blur passes



Variance after 3 blur passes

Notice how the variance reduces with each subsequent blur pass.

Integration

There are 4 HLSL shaders included in the ffx-shadow-denoiser directory:

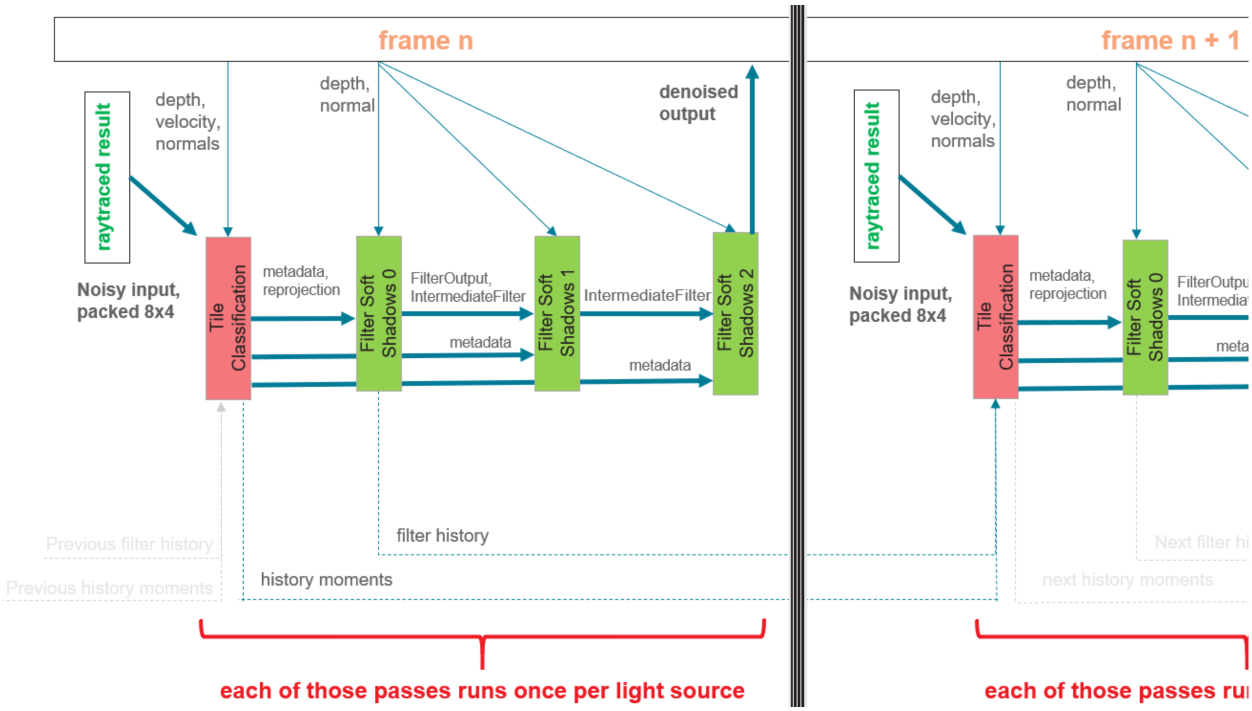
- ffx_denoiser_shadows_filter.h
- ffx_denoiser_shadows_prepare.h
- ffx_denoiser_shadows_tileclassification.h
- ffx_denoiser_shadows_util.h

All required data is provided via Get/Read/Write style API functions, which are to be created by the application.

We have found the filter passes work better in Wave32 mode while the Tile Classification pass is faster in Wave64 mode. Please kindly talk to your AMD representative if you would find that any of those passes does not run the desired wave mode in your integration.

Dataflow

Below is a map of resource use for the various passes.



TAA

Temporal anti-aliasing or TAA aims at anti-aliasing a rendered image by performing temporal reprojection. TAA can further stabilize and clean up the image after the denoiser has run.

Without TAA

With TAA

Notice how the render without TAA exhibits artifacts at the edges where the spatial blur fails to find matching samples. If TAA is used in your title you should experiment with including denoiser output to make sure it makes sense in your scenes.

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