Non-Opaque Surfaces

Final opacity

Bxdfs not only compute the scattering of light, but are also allowed to provide:

- *presence* (a scalar)
- *opacity* (a color)

of non-opaque materials. This is done using the `RixOpacity` interface, that the renderer will query by invoking `RixBxdfFactory::BeginOpacity()`.

Historically (RenderMan RIS 21 and before) *presence* has been used for masking out parts of an object, while *opacity* has been used for coloring shadows cast by an object. Depending some ray types (e.g. camera rays), *opacity* was being ignored, and probabilistic hit-testing was mandatory for *presence*.

In RenderMan RIS 22, this has been unified, and *presence* and *opacity* are now combined into a single property, the ***final opacity***. This *final opacity* can be used for both probabilistic hit-testing and traditional 'blending' opacity.

However, despite the fact that we are now dealing with a combined *final opacity*, it can still be helpful to describe the main two usages of this quantity as:

- a 'presence' (actually: scalar *final opacity*)
- an 'opacity' (actually: colored *final opacity)*

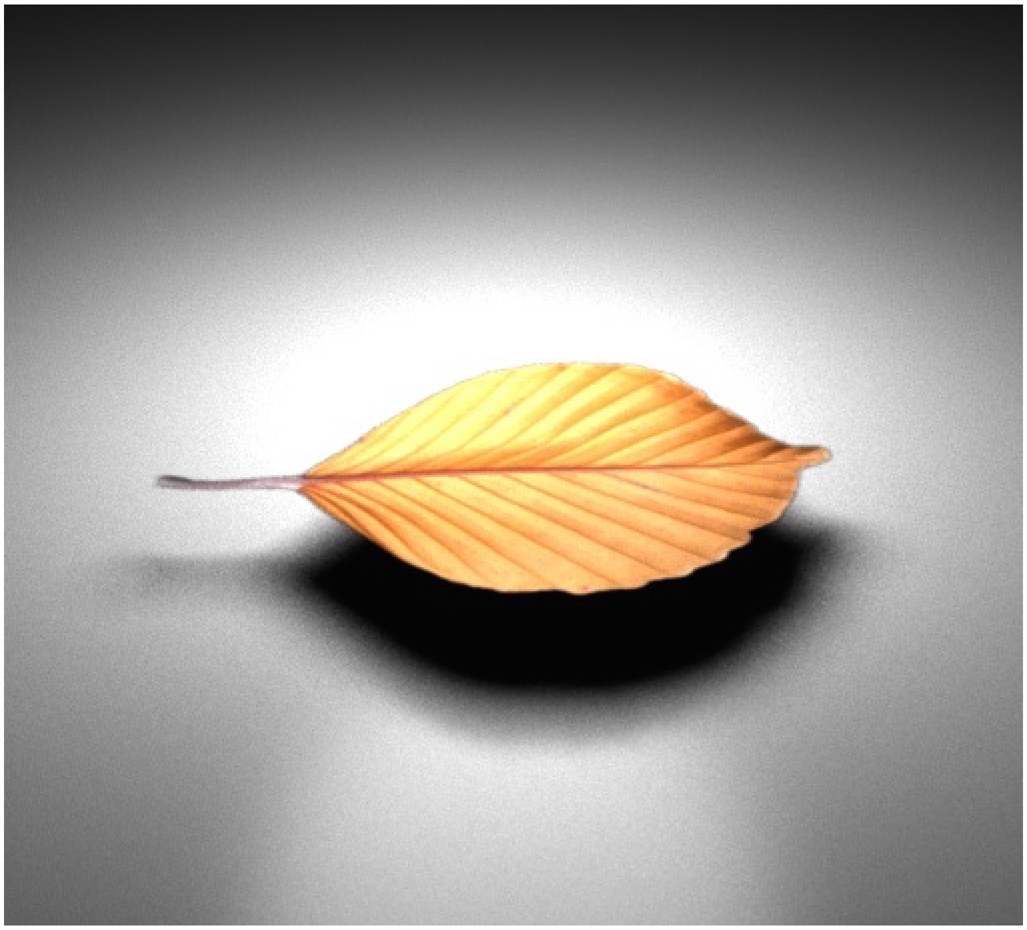
Note:

- the `RixOpacity` API still exposes two hooks (for each of the *presence/scalar* and *opacity/colored* component of the *final opacity*), and depending on the instance hint returned by the `RixBxdfFactory`, and on the ray type, only one of this hook may be called.
- the shading mode (`RixSCShadingMode`) passed to `RixBxdfFactory::BeginOpacity()` is a hint as to the renderer's intentions for the `RixOpacity` object:
    - if the shading mode is `k_RixSCPresenceQuery`, only the `RixOpacity::GetPresence()` method will be called. `RixBxdfFactory::BeginOpacity()` need only evaluate the pattern inputs relevant to computing the *presence* component.
    - if the shading mode is `k_RixSCOpacityQuery`, either `RixOpacity::GetPresence()`, `RixOpacity::GetOpacity()` (or both) will be executed on the object, and pattern inputs relevant to both *presence* and *opacity* components should be fully evaluated.

Presence (scalar *Final Opacity*)

Consider the case of trying to render a tree leaf. Rather than model it as a polygon mesh, it's common to represent a leaf as a cheap bilinear patch with an associated mask texture representing the leaf shape. Where the mask is zero, there is no leaf. We use the term **presence** rather than opacity to capture this use case. The leaf-shaped map is a **scalar presence map**.

It is important to note that in this usage, *presence* conceptually has no bearing on light scattering (and vice-versa). Where a material is partially present, its light scattering properties do not change. Instead, this is interpreted as the material scattering less often, with each scatter event being identical to what would happen with a totally present material. Critically, this mean that **presence is not a way to model transparent surfaces** such as glass, because the light scattering and refractive properties of the glass cannot be modeled by presence alone.



A leaf rendered with PxrDiffuse, using a leaf texture map as input to the presence parameter.

Bxdfs wishing to use a non-trivial presence must do the following:

- implement the `RixBxdfFactory::GetInstanceHints()` method and return a bit vector which includes the `k_ComputesPresence` bit
- implement the `RixBxdfFactory::BeginOpacity()` method and return a `RixOpacity` object that implements the`RixOpacity::GetPresence()` method

The `RixOpacity` object is bound to a shading context, similarly to a `RixBxdf` object. `RixOpacity::GetPresence()` will typically use this shading context (along with any pattern inputs) to return an array of presence values. There are `RixShadingContext::numPts` presence values in the array. Th ese presence values need to range from 0 to 1, where:

- 1 is fully present
- 0 is fully absent
- any value in between denotes a probabilistic presence for anti-aliasing

Opacity (colored *Final Opacity*)

As explained in the *Presence* section, it would be the responsibility of a semi-translucent thin glass-like bxdf to capture light transport across its surface (instead of using *presence*). However, when it comes to *transmission rays*, requiring a similar responsibility is problematic for two reasons:

- Transmission rays do not bend: they are usually fired to compute the amount of light flowing *directly* along a straight line between two points. Typically, one of these points is on the surface, the other is on the light. This means that any physically plausible object which requires refraction **s hould be opaque** to transmission rays.
- Transmission rays typically outnumber camera and indirect rays, so the cost of running a full shader to obtain a transmission value is worth minimizing

Nonetheless, it can be desirable to have a method by which approximate colored shadows can be efficiently produced. These are often preferable to the physically realistic, but noisy, color shadows produced by considering indirect paths. RenderMan allows the bxdf to return an *opacity* color, to influence the colors of shadow resulting from tracing *transmission rays*. An opaque object would yield black shadows, as if returning an *opacity* of [1 1 1].

Note that *opacity* describes the transmittance *straight* through the surface (no bending)

Below is an example using *opacity* to yield colored volumetric shadows. The box encloses both the angel statue and a volume. The only light source is behind the stained glass window (the right wall of the box).

If we were to model the stained glass window as a physically accurate piece of glass, complete with full refraction, then the crepuscular rays (also called *"G od rays"*) shining through the volume would be very expensive to render because the only lighting that could be considered for the volume is entirely indirect; the glass would have to be an opaque object and transmission rays from the volume would not reach the light source.

If we instead model the stained glass window as a thin, non-physically accurate piece of glass with colored opacity, then transmission rays from the volume can now directly reach the light (running the *opacity* shader of the glass window along the way to get a colored contribution). This allows the scene to be rendered with the direct lighting optimization, which allows for a much faster render.

Note that when writing a bxdf for a thin translucent surface, careful consideration should be given as to whether *indirect rays* should also be fired *through the surface*. If colored *opacity* is being used (and depending on the circumstances) it is quite likely that such rays should not be fired, otherwise the lighting contribution will be doubled.

Historically, colored *final opacity* would only be used for transmission rays, but it is now possible for it to affect camera and indirect rays. Similarly to the explanation above, special care needs to be taken by the bxdf to make sure there is no double contribution.

Volumetric crepuscular rays, efficiently rendered using direct lighting by means of stained glass using colored opacity

Bxdfs wishing to use a non-trivial *opacity* must implement do the following:

- implement the `RixBxdfFactory::GetInstanceHints()` method and return a bit vector which includes the `k_ComputesOpacity` bit
- implement the `RixBxdfFactory::BeginOpacity()` method and return a `RixOpacity` object that implements the `RixOpacity::GetOpacity()` method

The RixOpacity object is bound to a shading context, similarly to a RixBxdf object. RixOpacity::GetOpacity() will typically use this shading context (along with any pattern inputs) to return an array of *opacity* values. These *opacity* values need be colors, ranging from [0 0 0] (black) to [1 1 1] (white), where each channel is:

- 1 is opaque
- 0 is non-opaque
- any value in between will yield colored transmission shadows (the shadow color is 1 - *opacity*)

Combined presence and opacity

When the `RixOpacity` API returns both a *presence* and an *opacity* value, they are combined (multiplied) together. In this case, one could think of the *pres ence* component as the 'intensity' and the *opacity* component as the 'color'.

Probabilistic hit-testing vs. blend-and-continue

The *final opacity* can be used in two ways:

- as a probability that the surface is present (historical use of the *presence* scalar component)
- as a coloring of the light transmitted through the surface (historical use of the *opacity* color component)

The former would usually use *probabilistic hit-testing*, where each camera ray would use the (scalar) *presence* value as a probability to hit the surface, and either result in an actual hit, or a continuation (without a hit). In this case, for each original ray, only one shading event is computed (on the actual hit), although multiple presence *evaluations* may have happened.

The latter would usually use *blending-and-continuation*. On hitting a surface with (colored) *opacity*, shading would be computed, and weighted by (1 - *opacit*). A continuation ray would then be traced from this hit point (carrying a colored weight equal to *opacity*), and the process repeats, until hitting a surface with full opacity. In this case, for each original ray, multiple shading events may be computed (and special care needs to be taken to prevent a combinatoric explosion of the number of rays and shading events).

In RenderMan RIS 22, it is possible to use both approaches in all cases, independently of the *final opacity* being scalar or colored. This means:

- a colored *final opacity* can be used with *probabilistic-hit testing*. In this case, additional colored weights are provided through the `RixShadingContext` so that the (converged) results are identical to the ones obtained with the *blending-and-continuation* approach.
- a scalar *final opacity* can be used with *blending-and-continuation*. In this case, a mono-chromatic value is used for blending, and continuation rays are traced. This would yield results identical to the ones obtained with *probabilistic-hit testing*, with a lot less noise, at the cost of additional shading computations.

Note that:

- if the *final opacity* is zero, the renderer will always skip the hit. This means `RixShadingContext` should never yield hits whose (final) opacity is zero.
- using *blending-and-continuation* for indirect rays may yield a combinatoric explosion of rays and shading event

Cached Presence and Opacity

RenderMan offers an additional service that may improve performances for scenes making heavy use of *presence/opacity/final opacity* (e.g. a forest of trees with presence-mapped leaves).

By having `RixBxdfFactory::GetInstanceHints()` return a bit vector that includes the `k_PresenceCanBeCached` bit, the bxdf can request RenderMan to cache *presence* values. This would prevent re-evaluation of the *presence* component for every ray that intersects the surface.

By having `RixBxdfFactory::GetInstanceHints()` return a bit vector that includes the `k_OpacityCanBeCached` bit, the bxdf can request RenderMan to cache *opacity* values. This would prevent re-evaluation of the *opacity* component for every ray that intersects the surface.

However, note that as with most of the caching systems, this may introduce bias, manifesting itself as blurred results due to interpolation from the cached values. *Presence* and *opacity* caching efficiency is driven by the *opacitycachememory* setting – a speed vs memory trade-off. The more memory is allocated to this cache, the more efficient the opacity reuse will be.

It is also important to consider the effect of caching and view-dependent shading signals. It is not possible to meaningfully cache any presence or opacity values when these depend on the viewing direction (e.g. facing ratio). In case it is attempted the caching of a view-dependent signal, the result will not be deterministic, varying on which ray hit will trigger the evaluation of the opacity for a portion of a surface.

[Historical] Presence vs. Bxdf Continuation

When dealing with opaque objects using *presence* maps, it is usually the case that the objects are either entirely present or not present at all. In practical terms: the *presence* map is used as a cut-out map, and consists mostly of 0-or-1 values. RenderMan takes advantage of this by combining *presence* with *probabilistic hit-testing*, actually interpreting the presence value as the *probability that we actually hit a surface*.

The compelling advantage of this approach is that for *camera rays* and *indirect rays*, the renderer only needs to shade the surface and run the associated bxdf when the surface is actually hit (due to a non-zero presence). This means the renderer doesn't need to institute a policy of *automatic continuation rays*.

Presence should **not** be used for cases where the intention is to model a thin semi-transparent surface (rather than an opaque object). Instead, the bxdf should generate a *transmitted bxdf sample*, with the appropriate properties (transmission color for example). Even if those samples are generated in the exact same direction as the incoming ray, without refraction (i.e. to model a thin translucency), they have to be generated by `RixBxdf::GenerateSample()`, which means that the presence needs to be 1. Depending on the intention, this transmitted sample may be generated as a *continuation* sample.