TAMING THE SHADOW TERMINATOR

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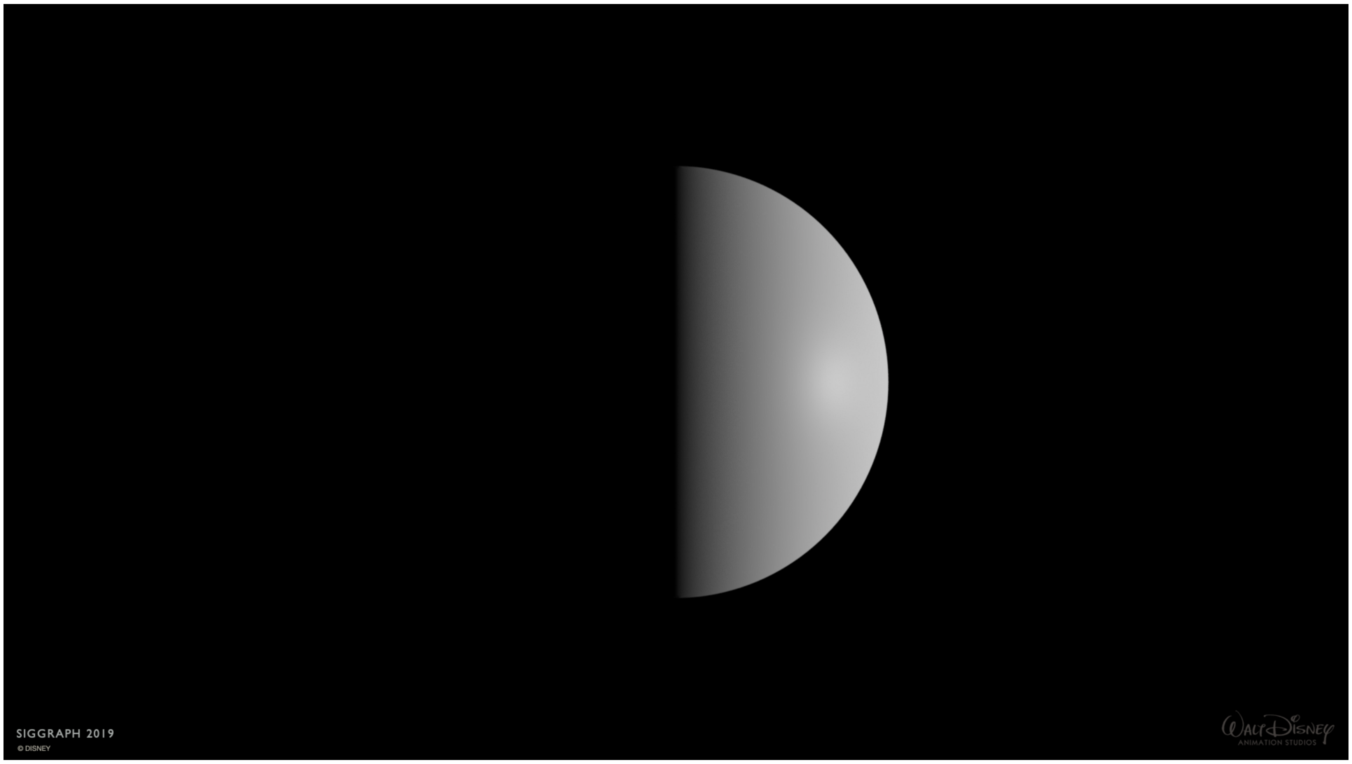
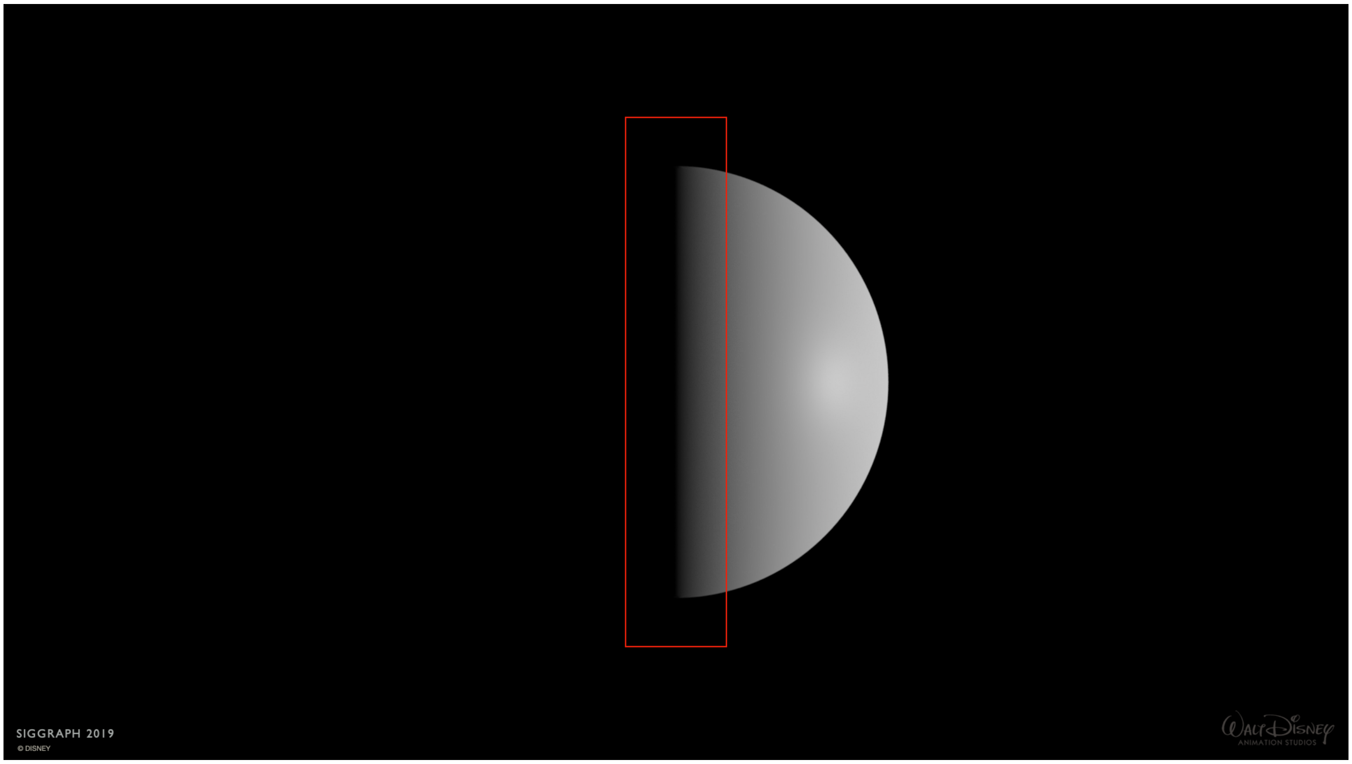
Please refrain from photographing or recording.

THANK YOU!



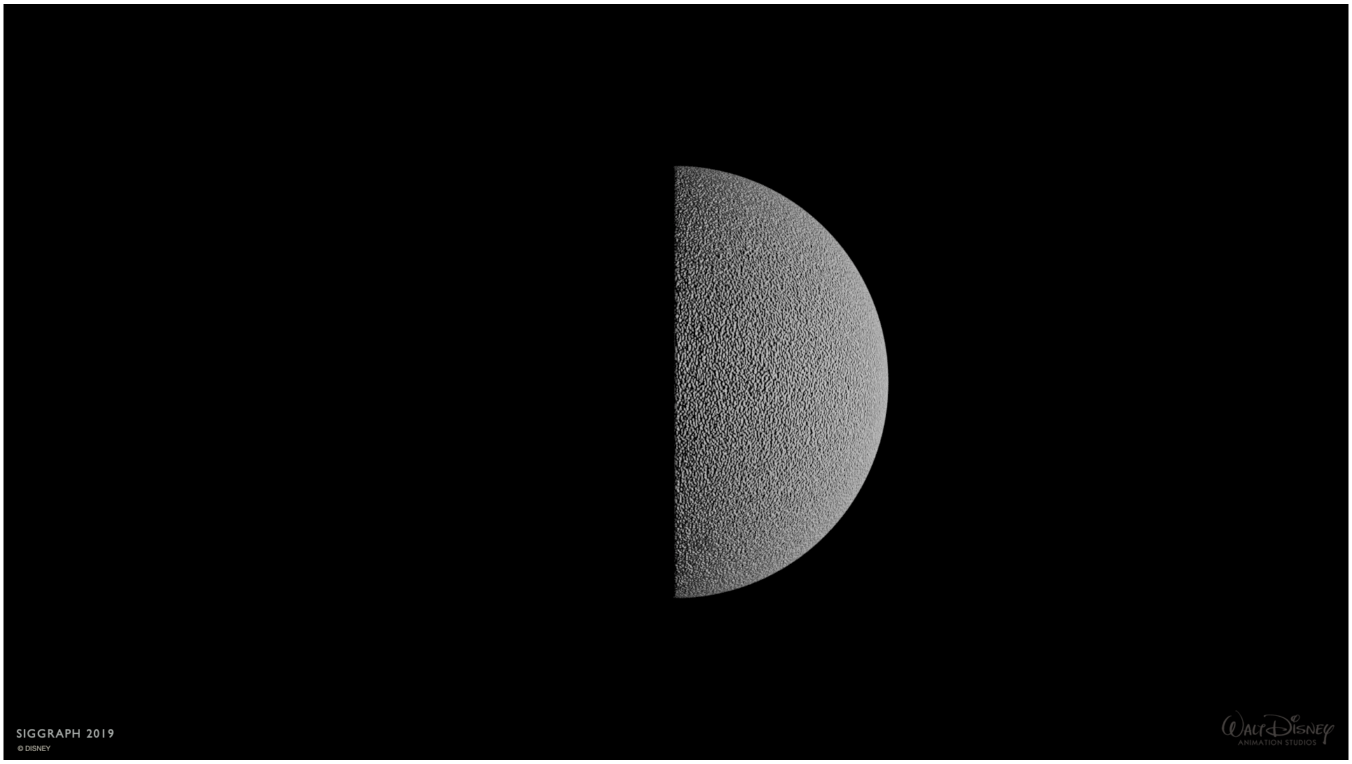
So what is a shadow terminator?

Here we are looking at a smooth sphere, lit from the right side of the screen. You can see that going from the lit area to the shadowed area…



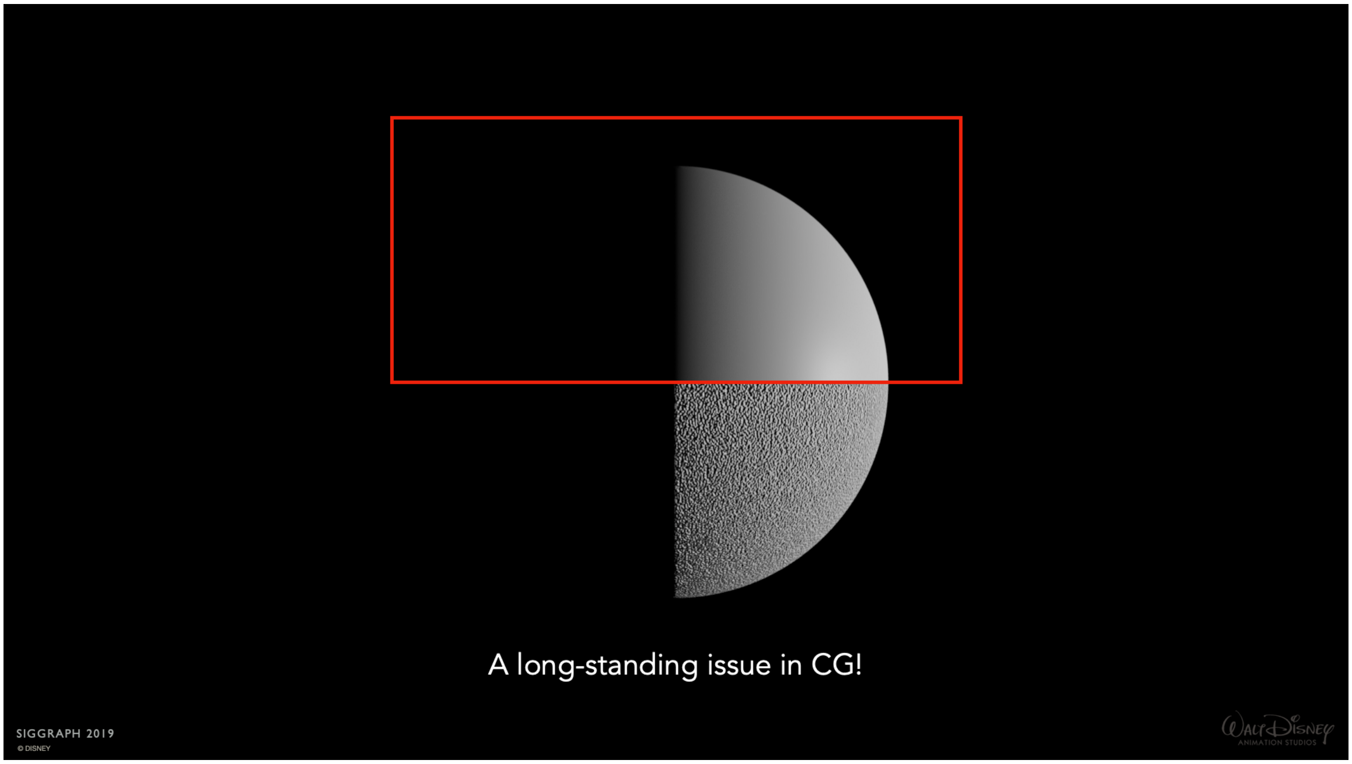
it goes through a transition zone which is what we call the “shadow terminator”. And you can see that on a smooth surface, the shadow terminator tends to look pretty smooth and soft.

However, more often than not a “smooth” surface is not enough, to make things look more interesting, we would usually like to add more surface details. And to achieve this we often rely on some sort of high frequency shading normal either through bump mapping or normal mapping.



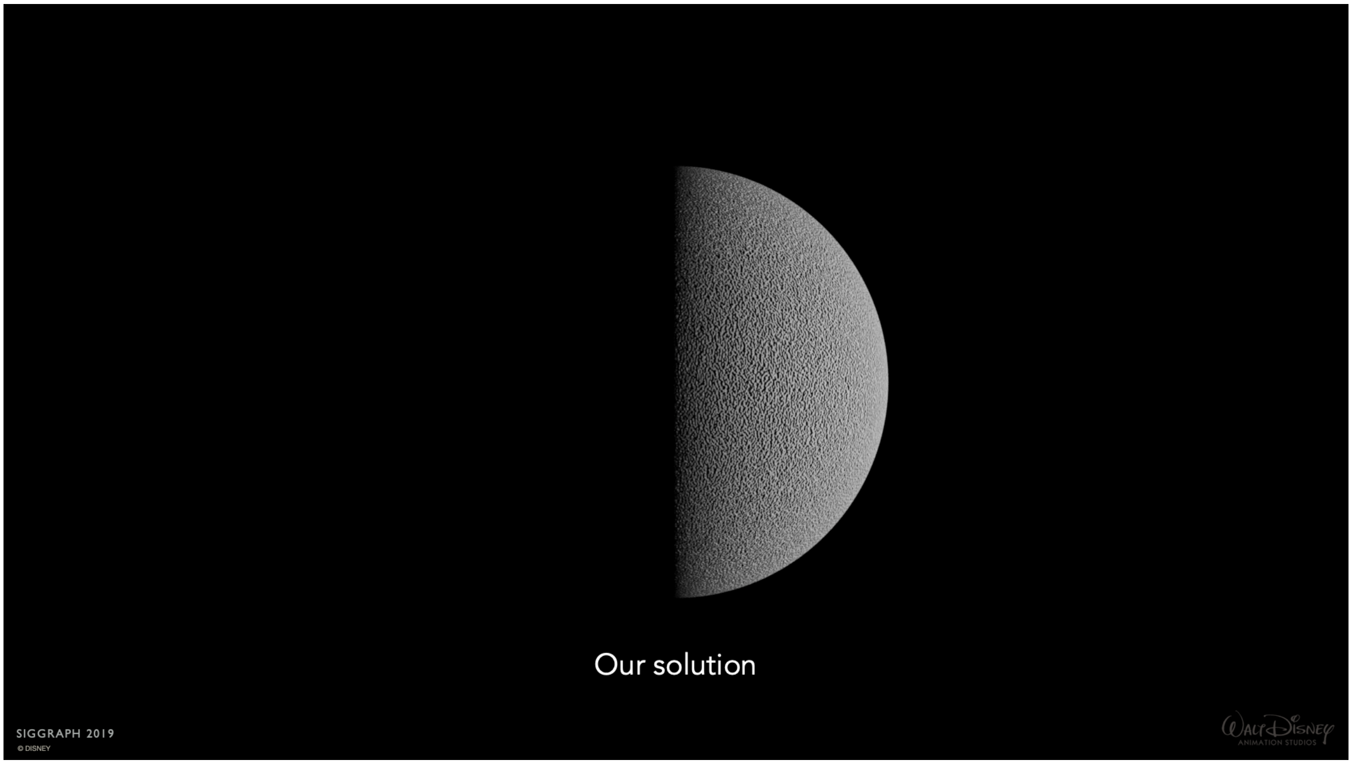
And here is what it looks like.

Unfortunate, there is a problem with shading normals. The shading normals produced by the bump map here suddenly make the shadow terminator really harsh!

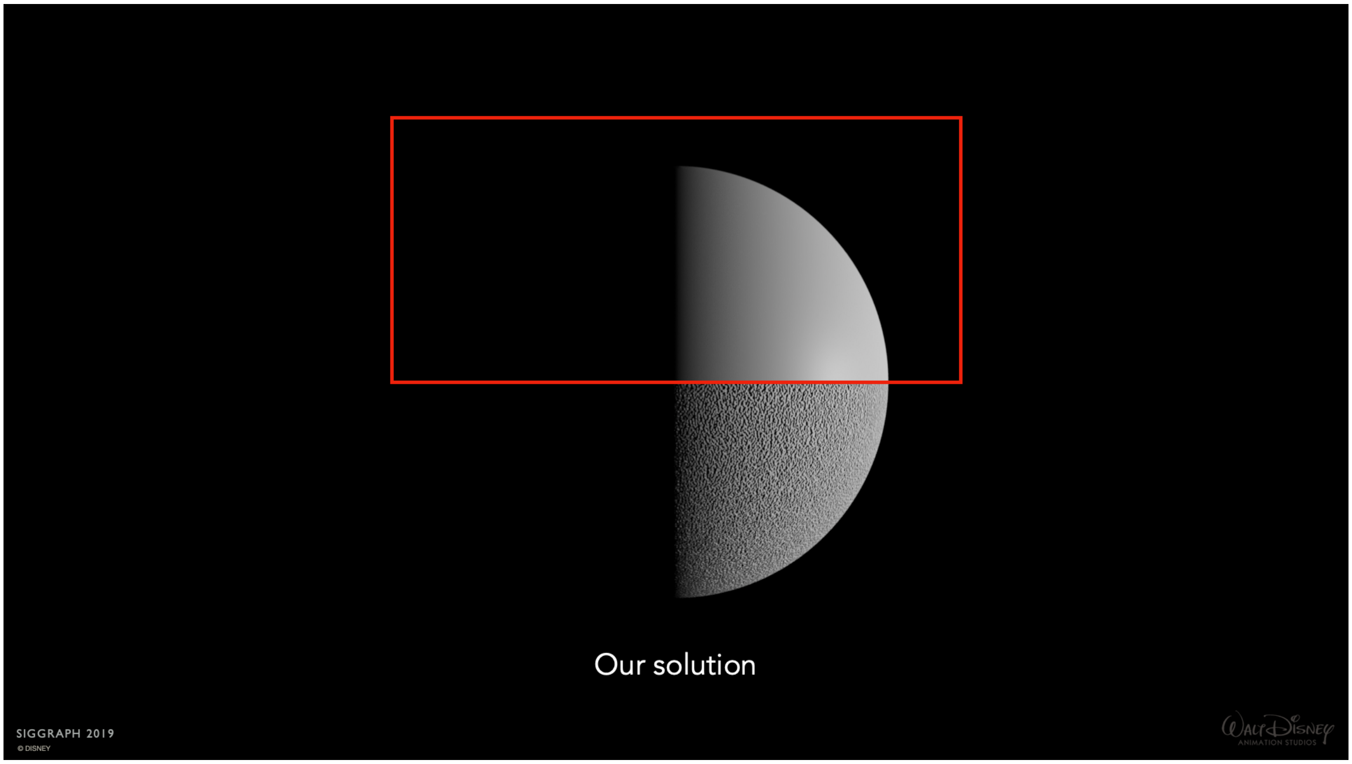


Here you can see it better from a side-by-side comparison with the original smooth sphere.

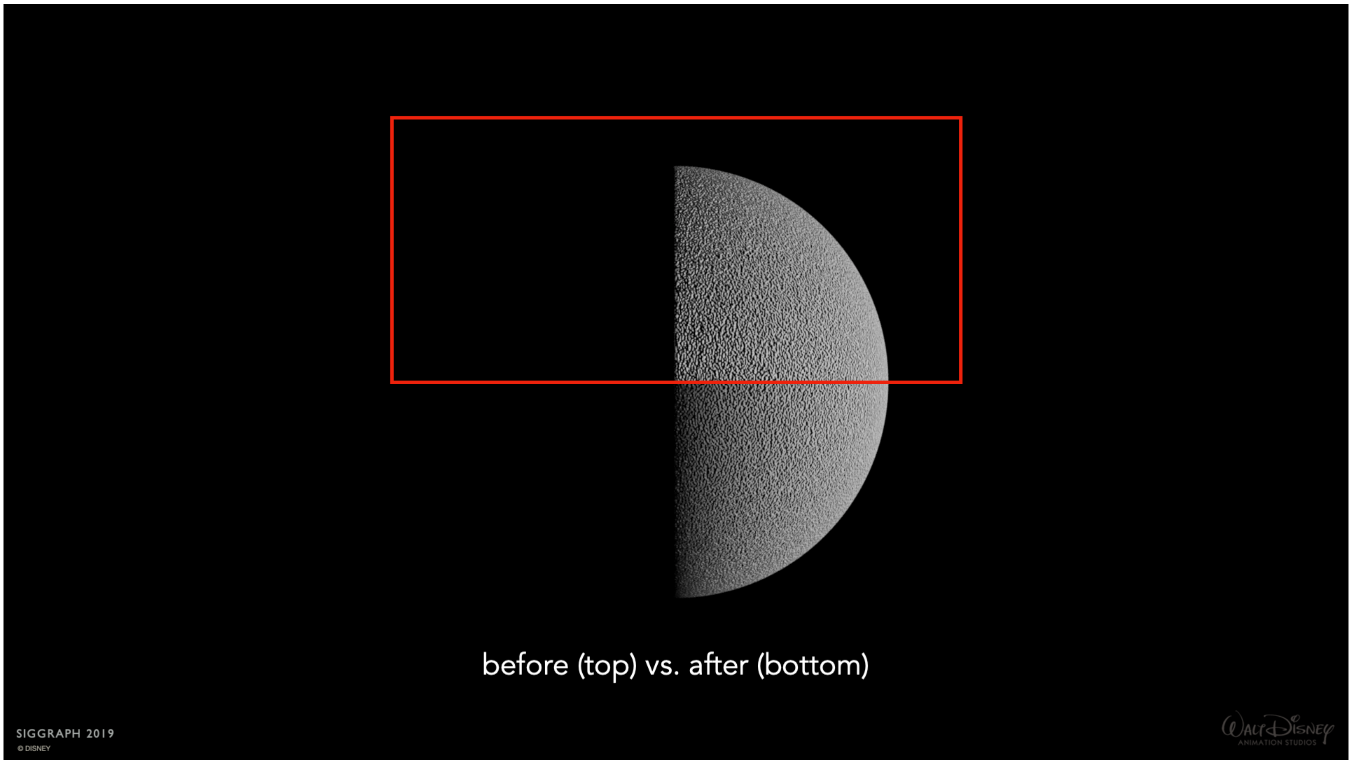
This has been a long-standing issue in computer graphics.



We recently came up with a new technique that solves this problem.



Compared to the original sphere, you can see that with our new technique, we can now have the best of both worlds, that is, surface details from bump mapping, while preserving a softer shadow terminator.



And here is before and after our fix. Hope it is easy to tell which one is which.

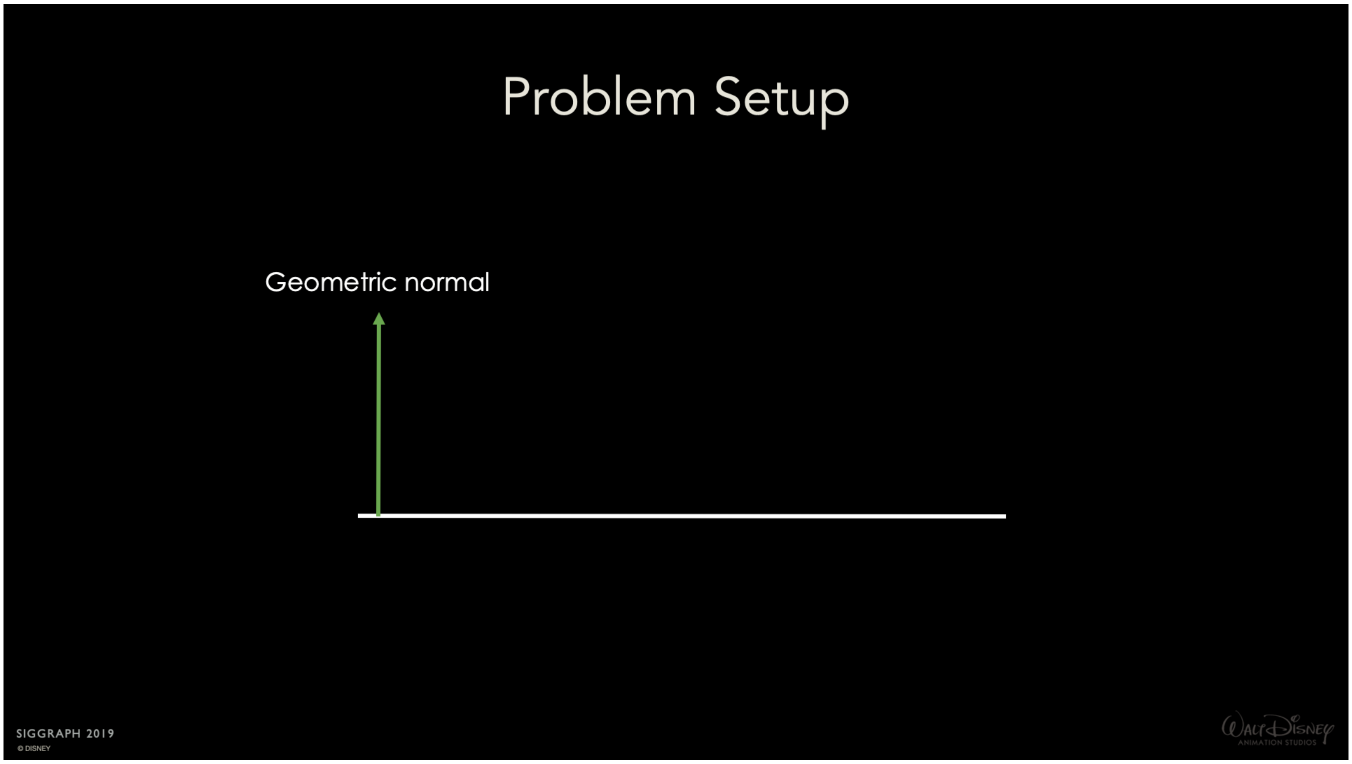
I would like to mention that one obvious solution to this problem is to use displacement. But it is not all affordable for every case. In practice we use a combination of shading normals and displaced normals in production rendering. So this was still a problem to us.

So how does this translate to more complex examples? Here's a skirt without any bump maps applied.

When we apply bump mapping to the same skirt, you can see that such harsh shadow terminator really impacts the visual interpretation of what the surface orientations are and even what the materials are.

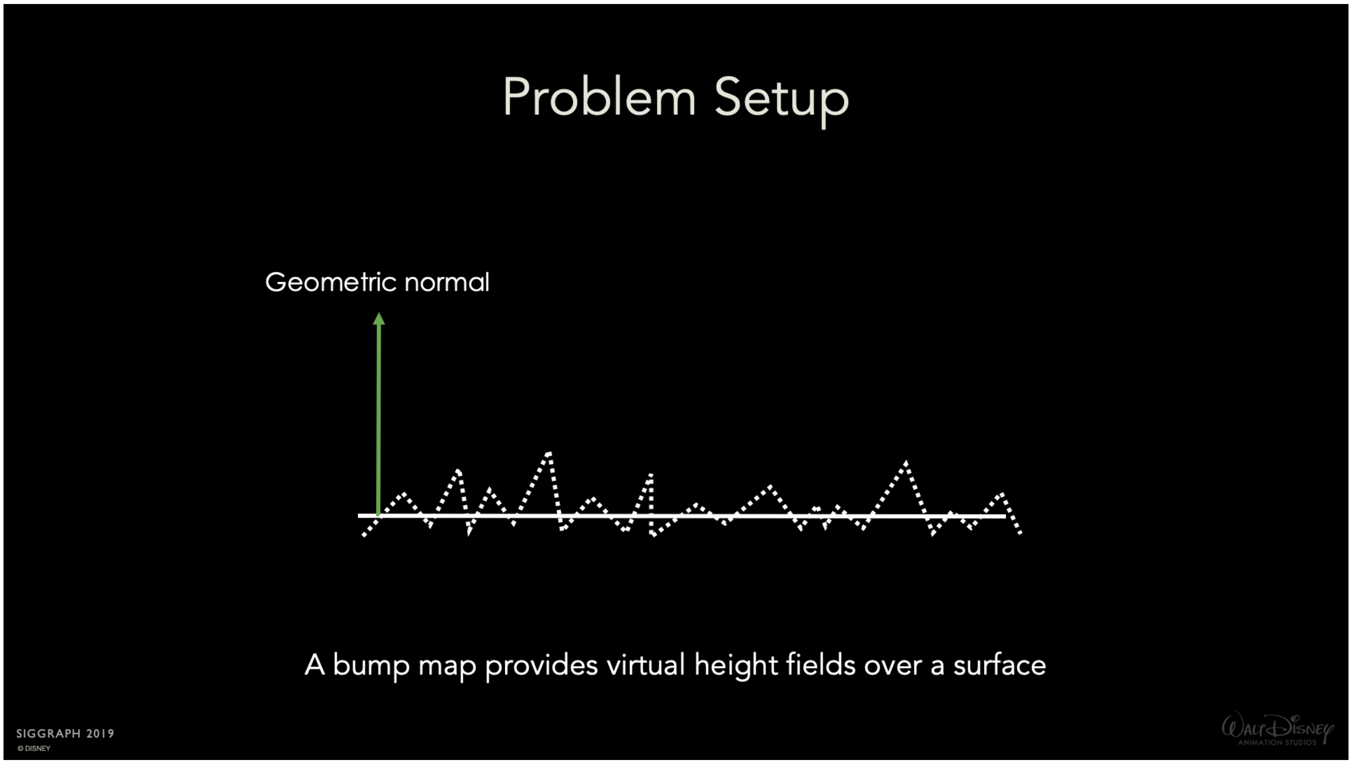
This generally caused a lot of pain for look and lighting artists. Artists usually have to fall back to displacement maps or use larger area lights to try to soften the shadow terminator.

However with our fix, everything automatically looks smoother and matches what the original shape is intended to be.

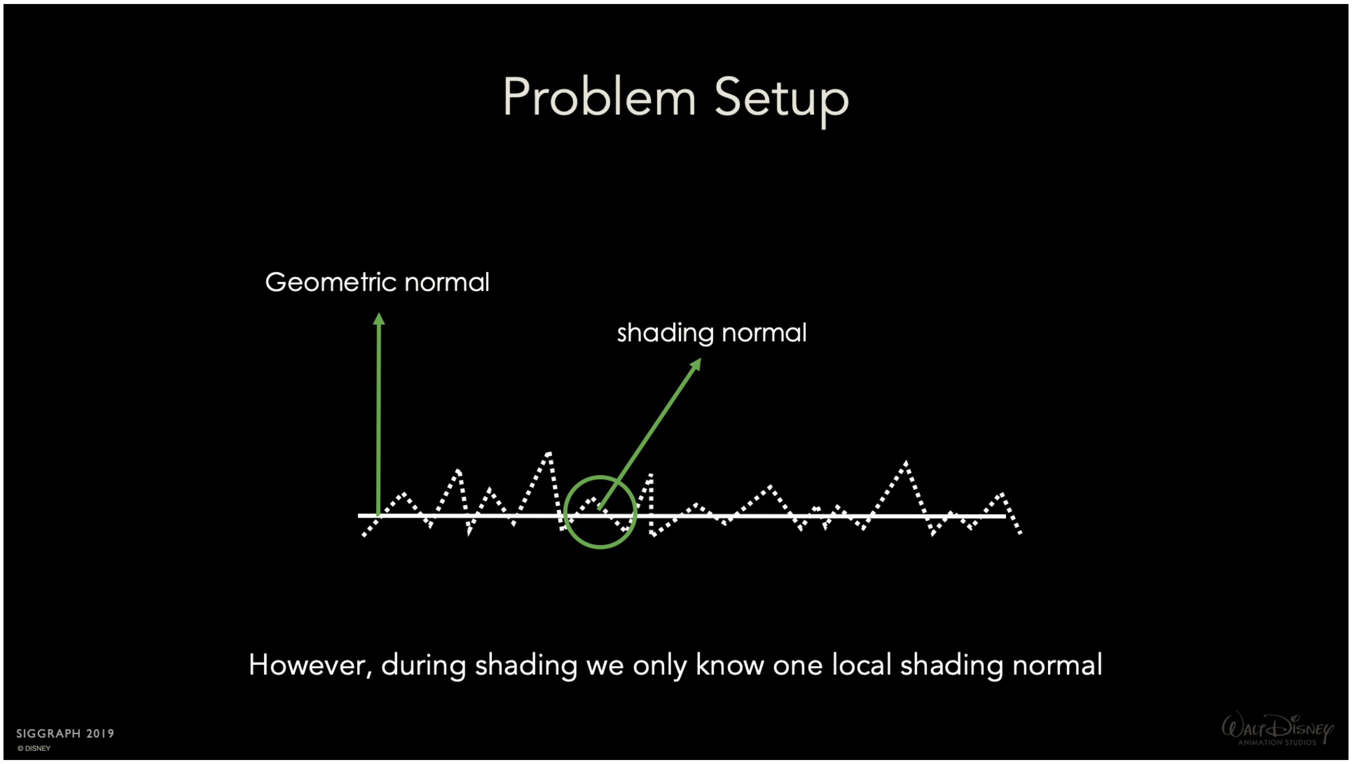


Now I'm going to explain why we ran into this problem and how we fix this problem.

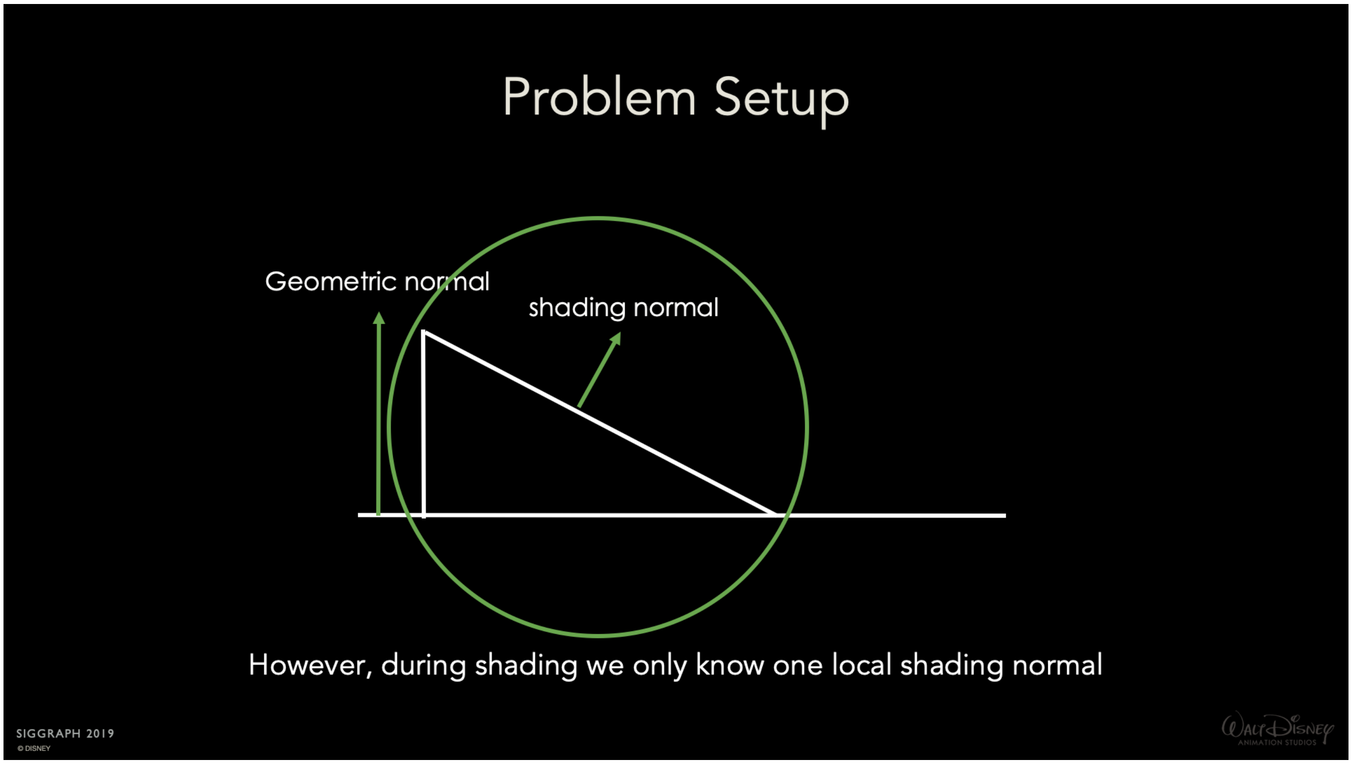
Here we have a piece of smooth surface, you can imagine it is the smooth sphere we showed earlier.



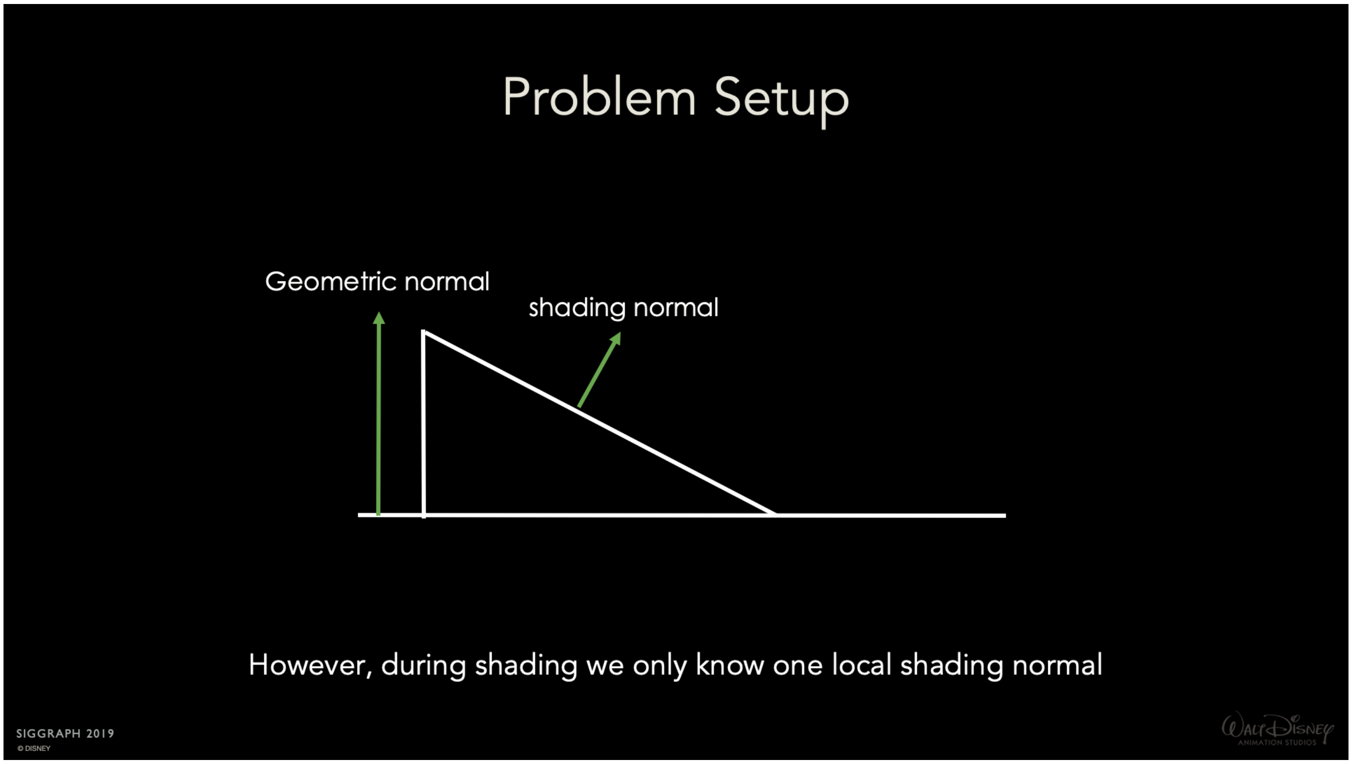
With bump mapping, it provides virtual height-field over the surface. It virtually alters the surface normal for shading calculation, as an "efficient" way to add surface details.



However, at each shading point we only know one such local shading normal. We don't have any global knowledge about what the nearby virtual height-field is like.

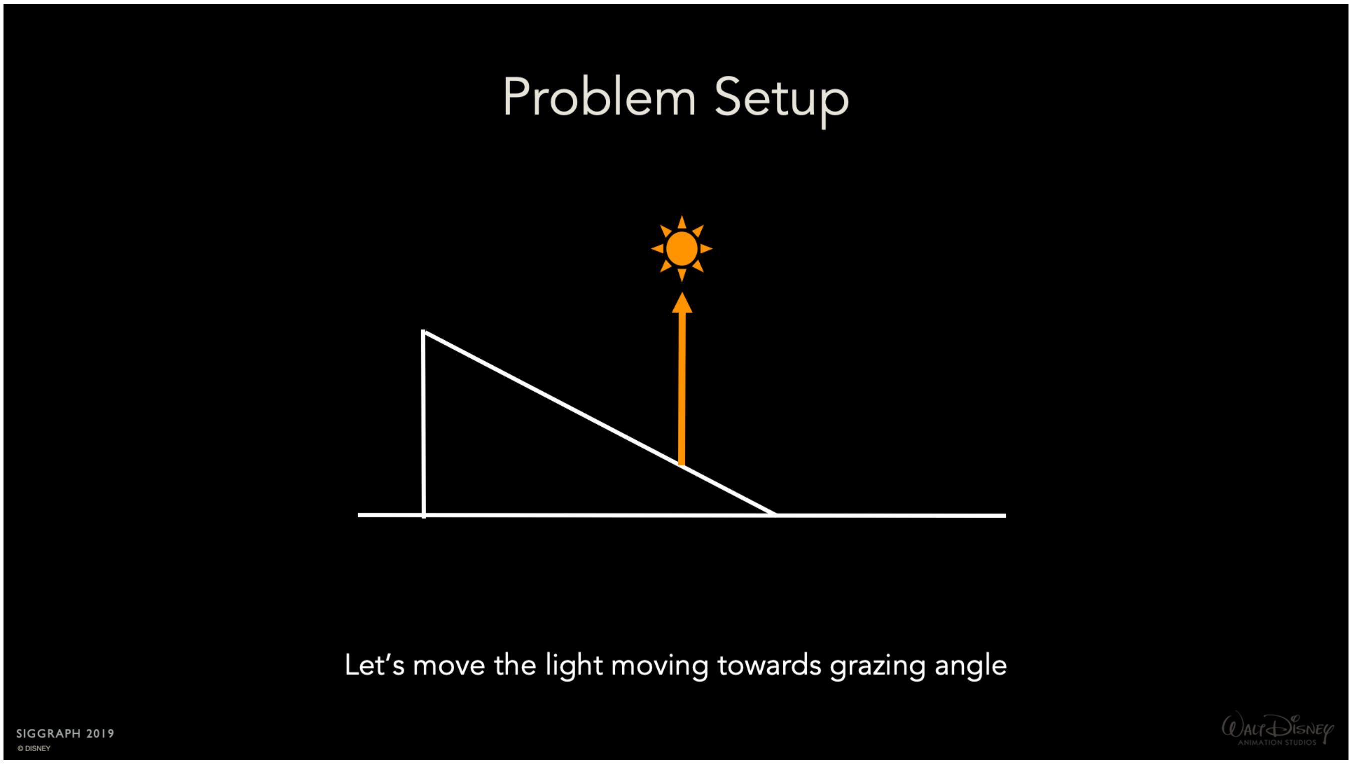


So when we zooming into this one shading point..

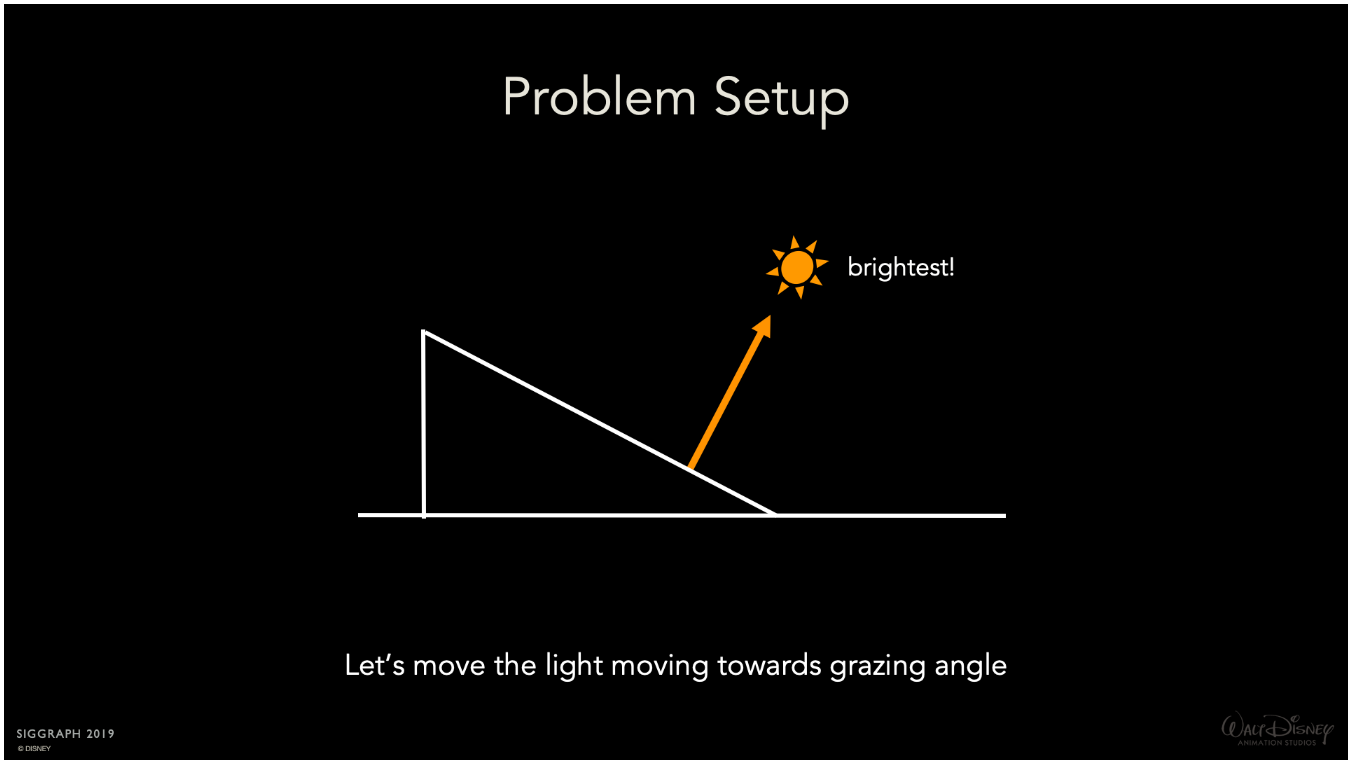


We can imagine that we have a single facet that is orientated towards this shading normal direction.

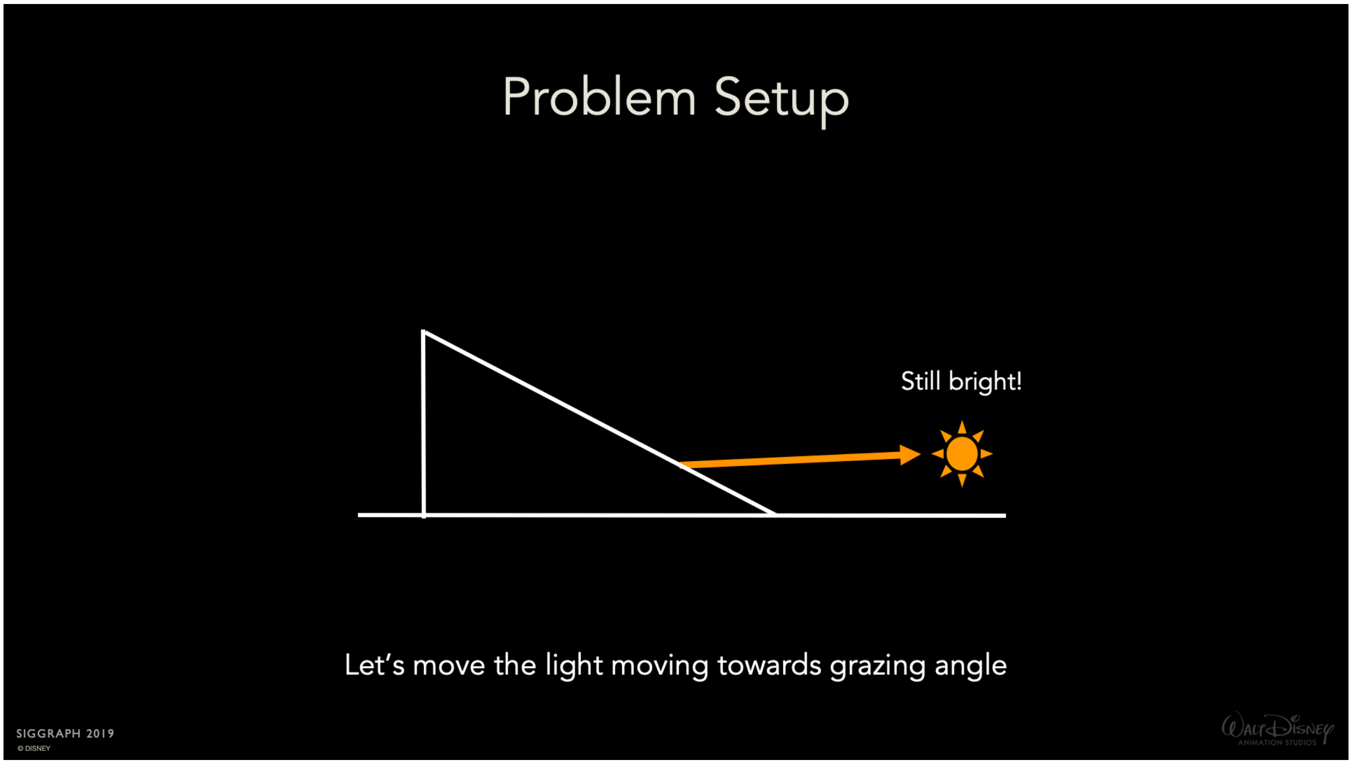
And this facet is what we do shading calculation with.



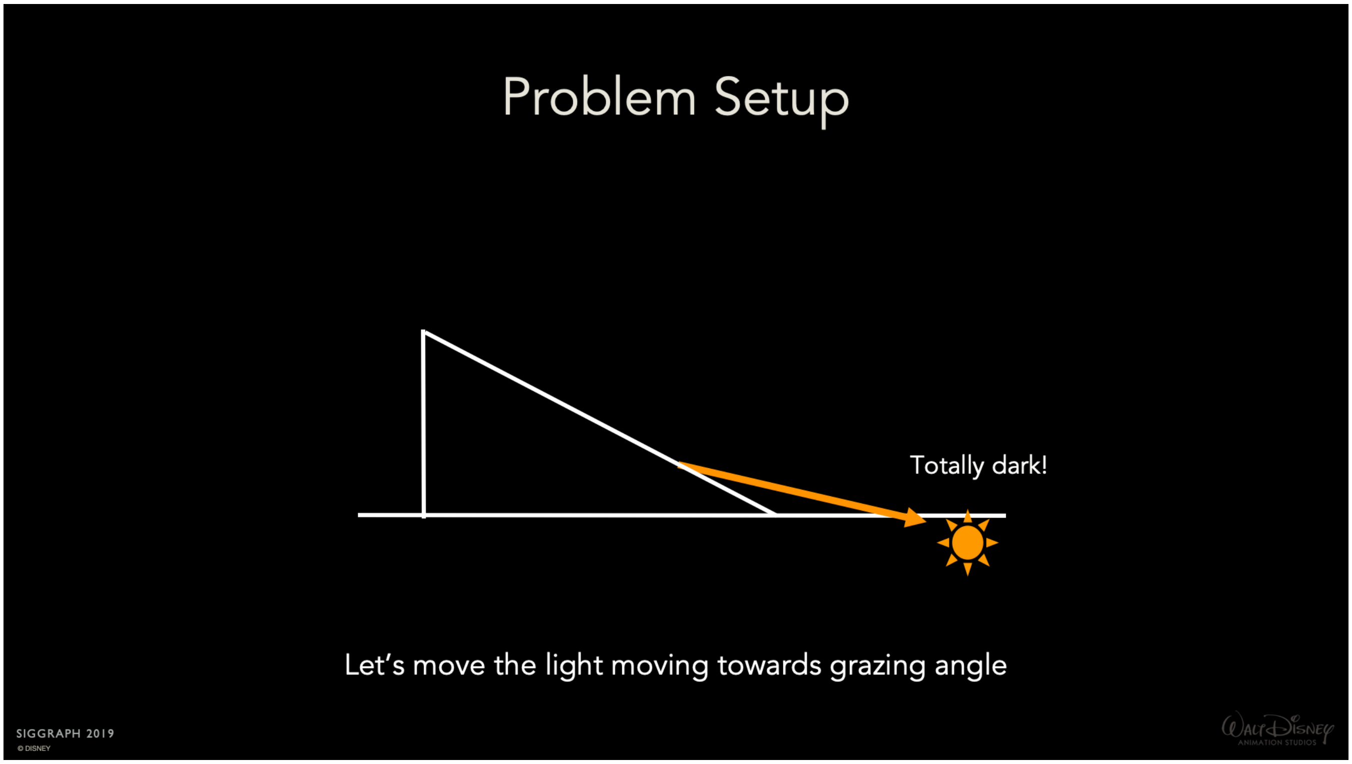
Now let's see what happens at the shadow terminator. Here we slowly move the light towards the grazing angle.



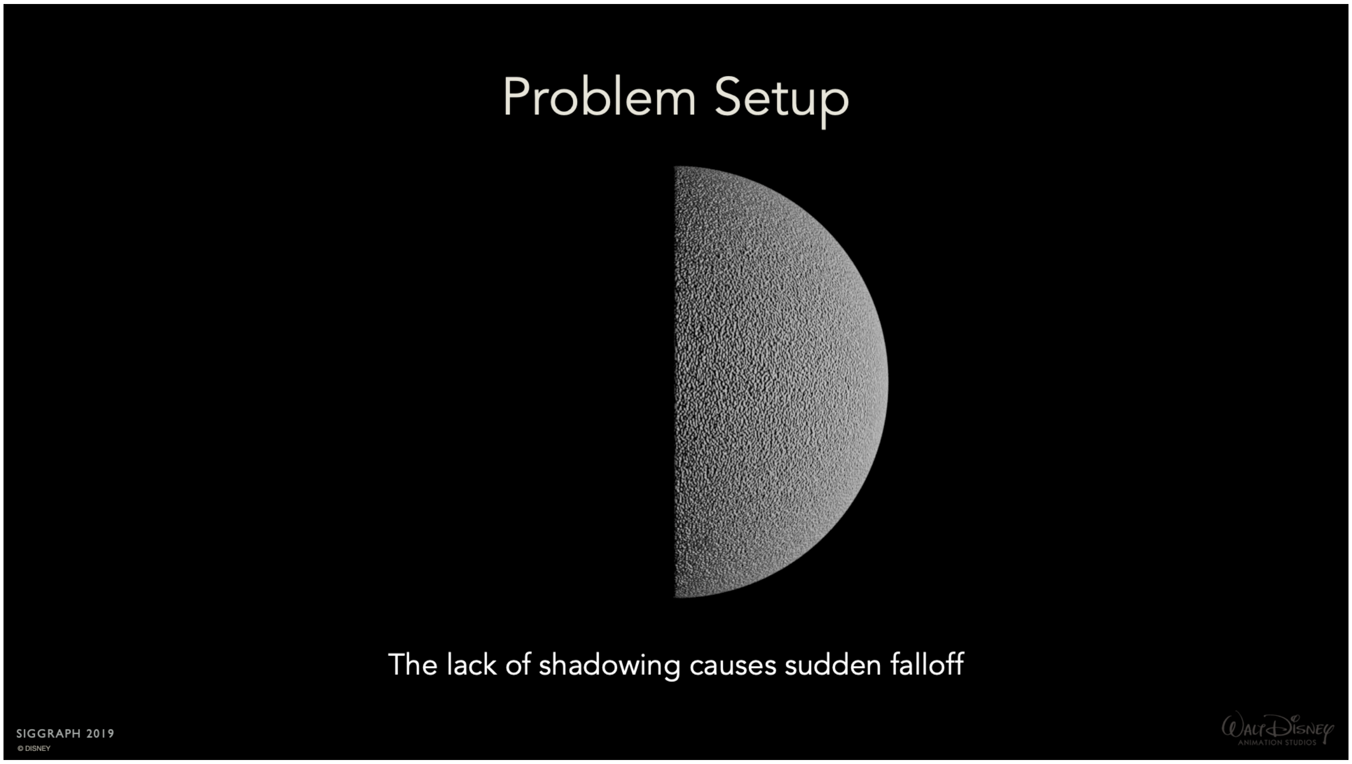
The shading result reaches the peak brightness, when the light is parallel to the shading normal.



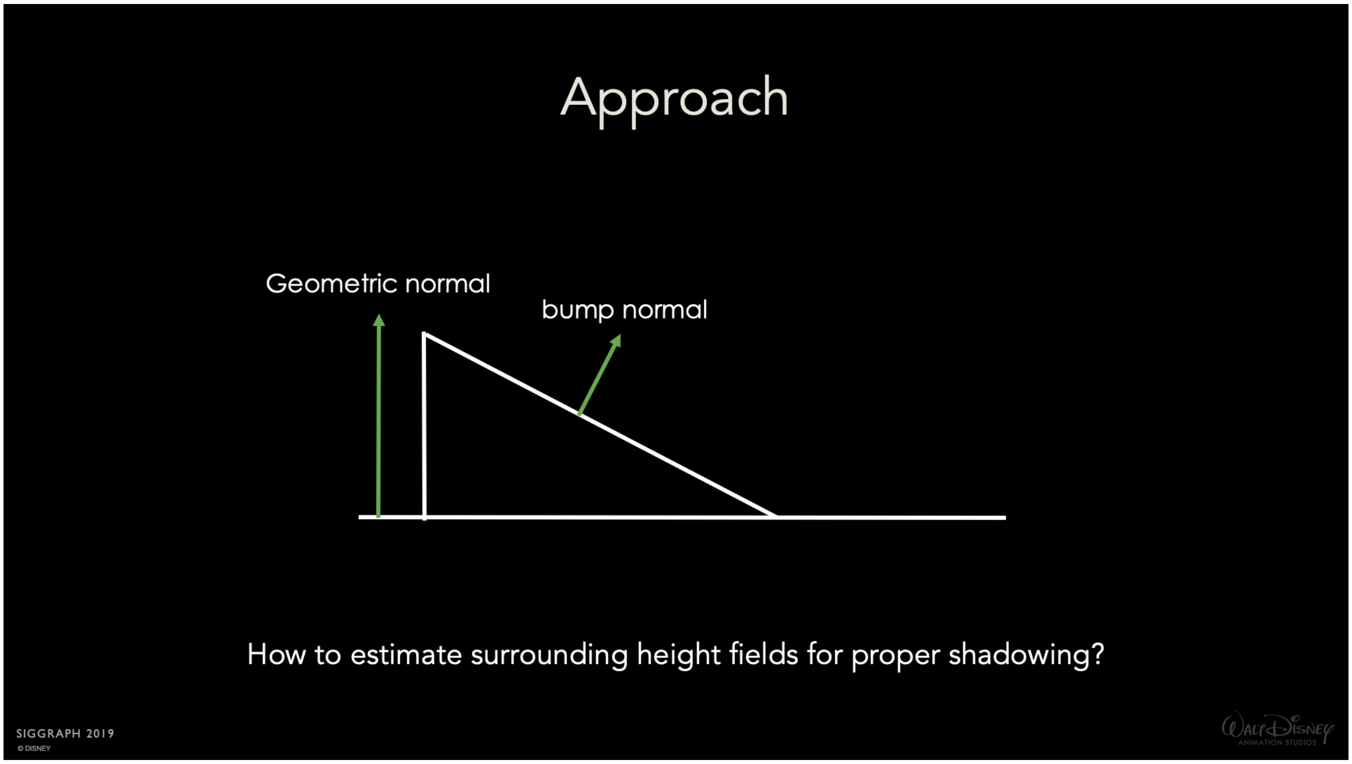
Even when the light is pretty close to the horizon it is still bright.



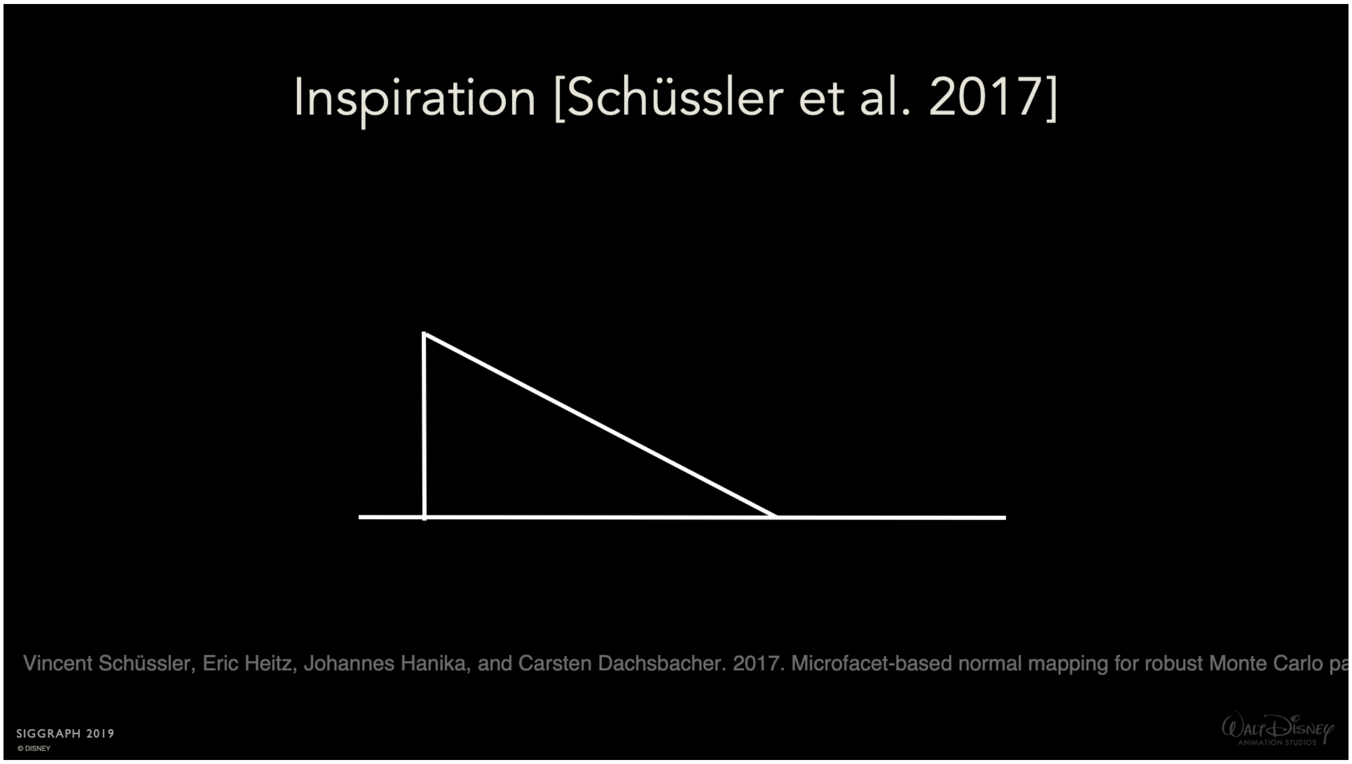
But suddenly the light is totally cut off by the geometric terminator.



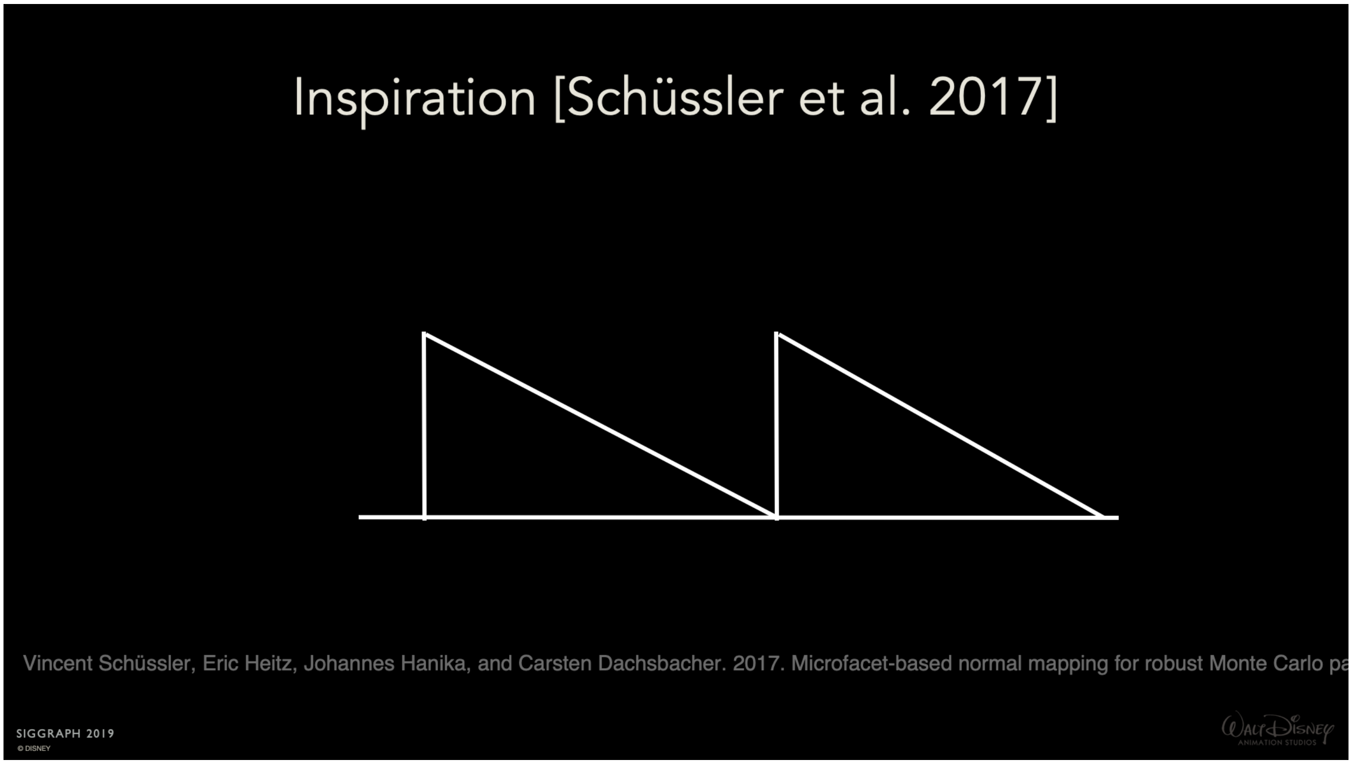
This is basically why we see such sudden falloff at the shadow terminator. It is mainly due to the lack of any shadowing from nearby virtual height-field.



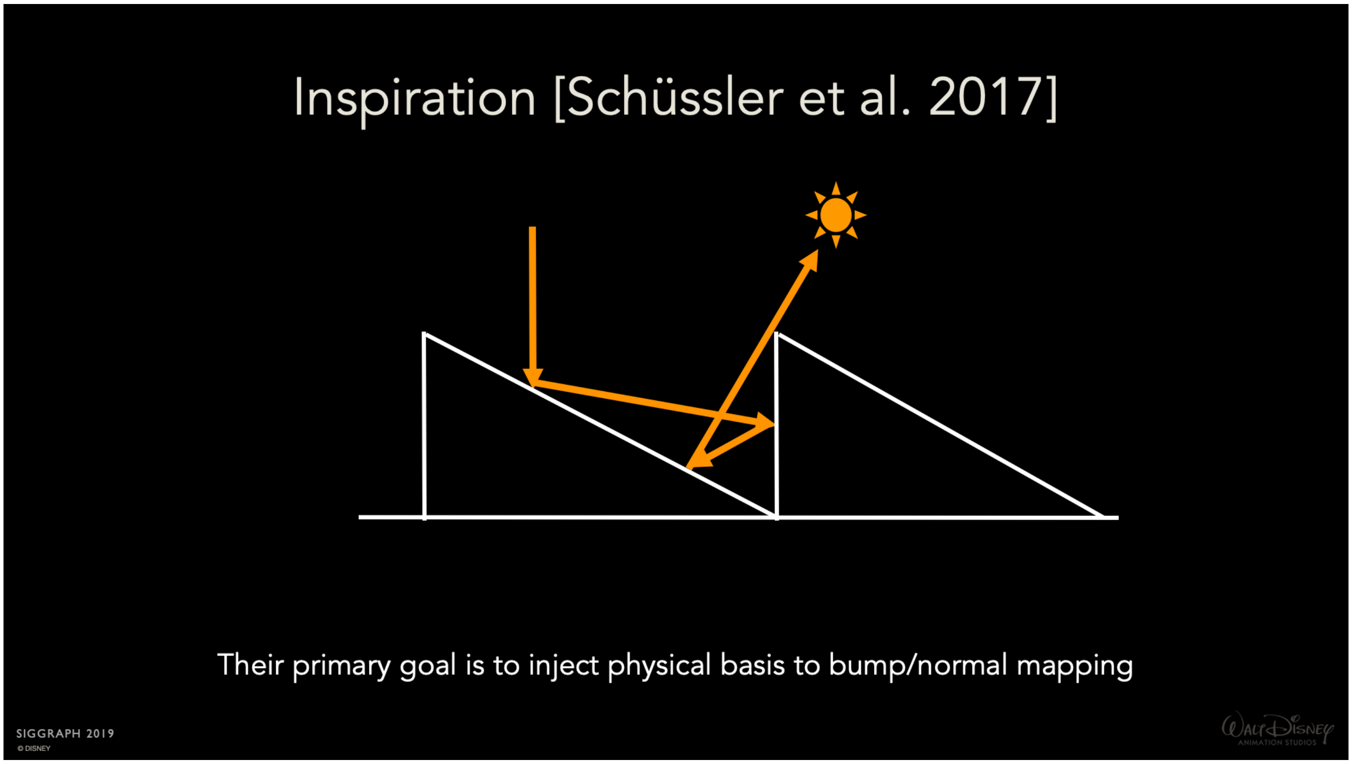
So now we know what we need. The question is: how do we estimate surrounding height-field so that we can calculate proper shadowing.



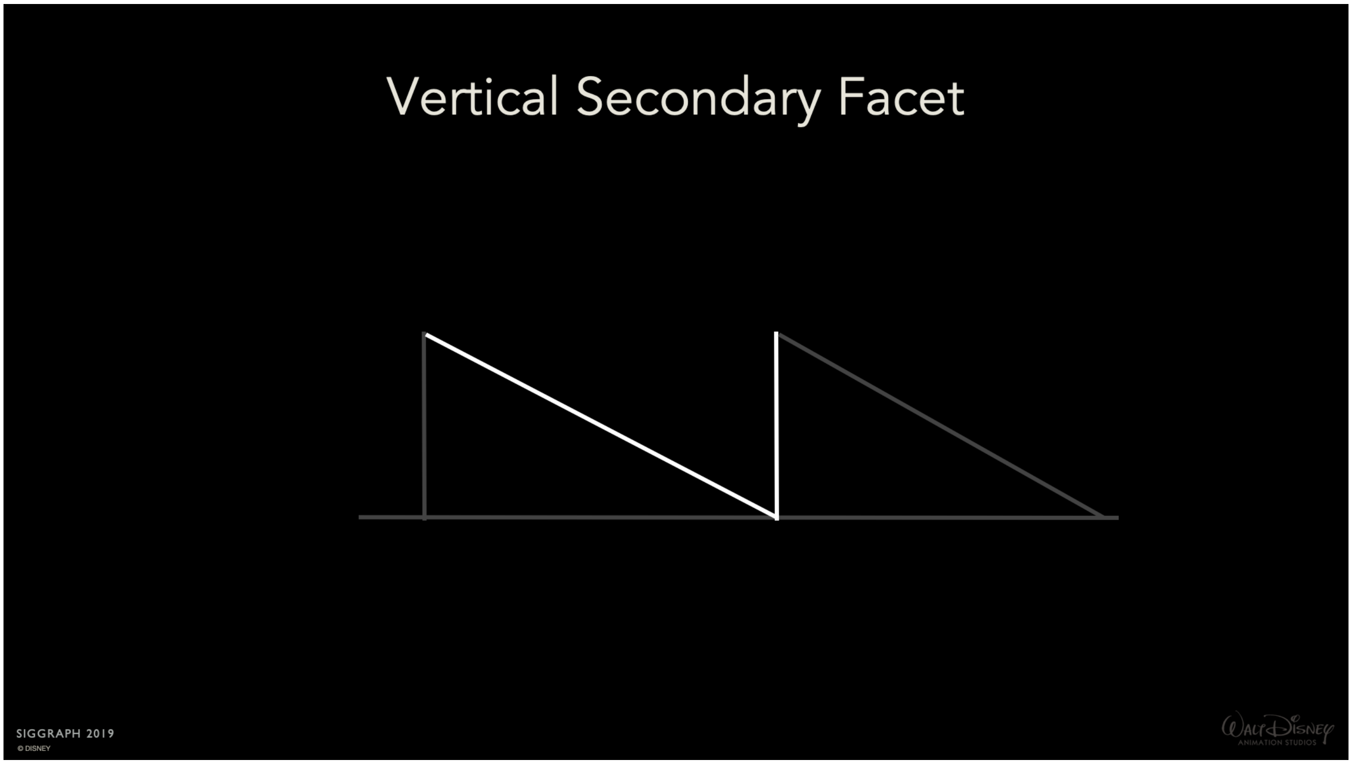
We are inspired by the work from Schussler et al.



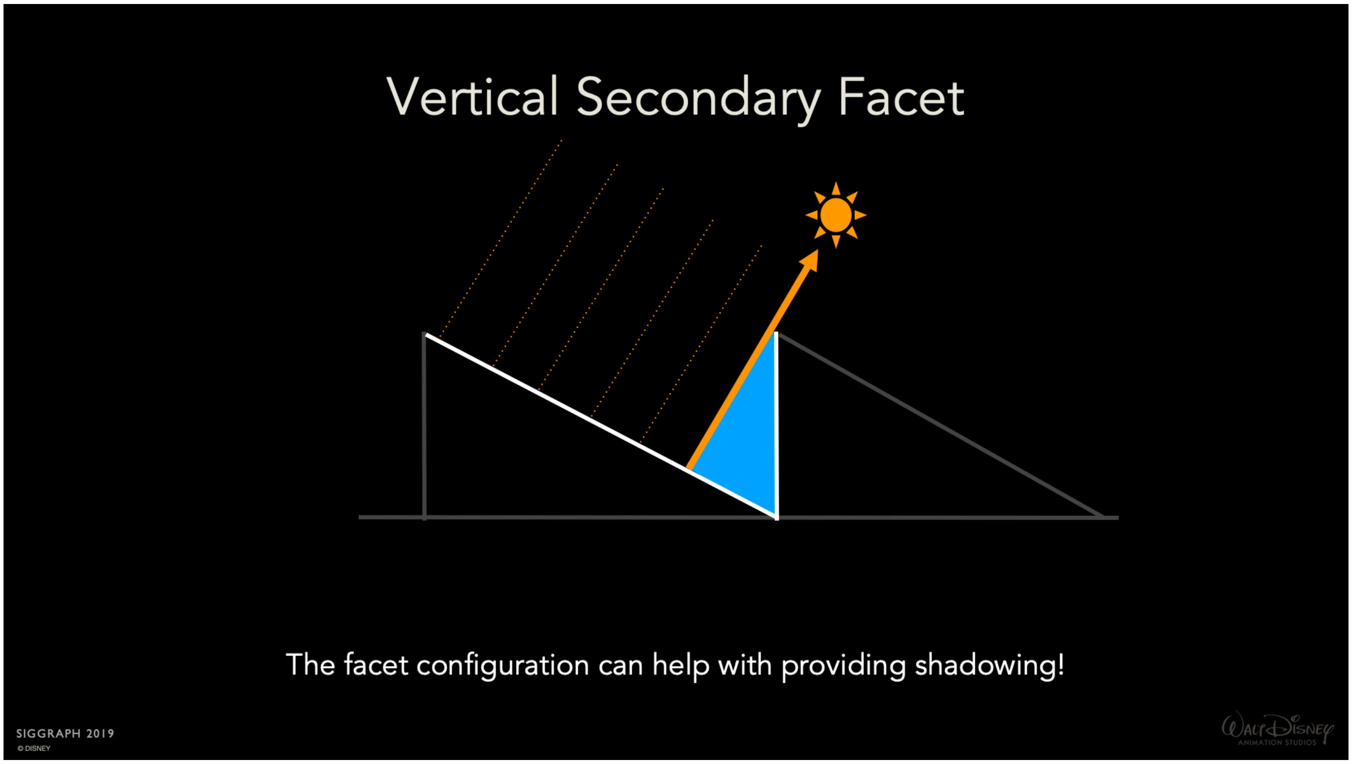
, where they imagine a secondary facet that looks like this.



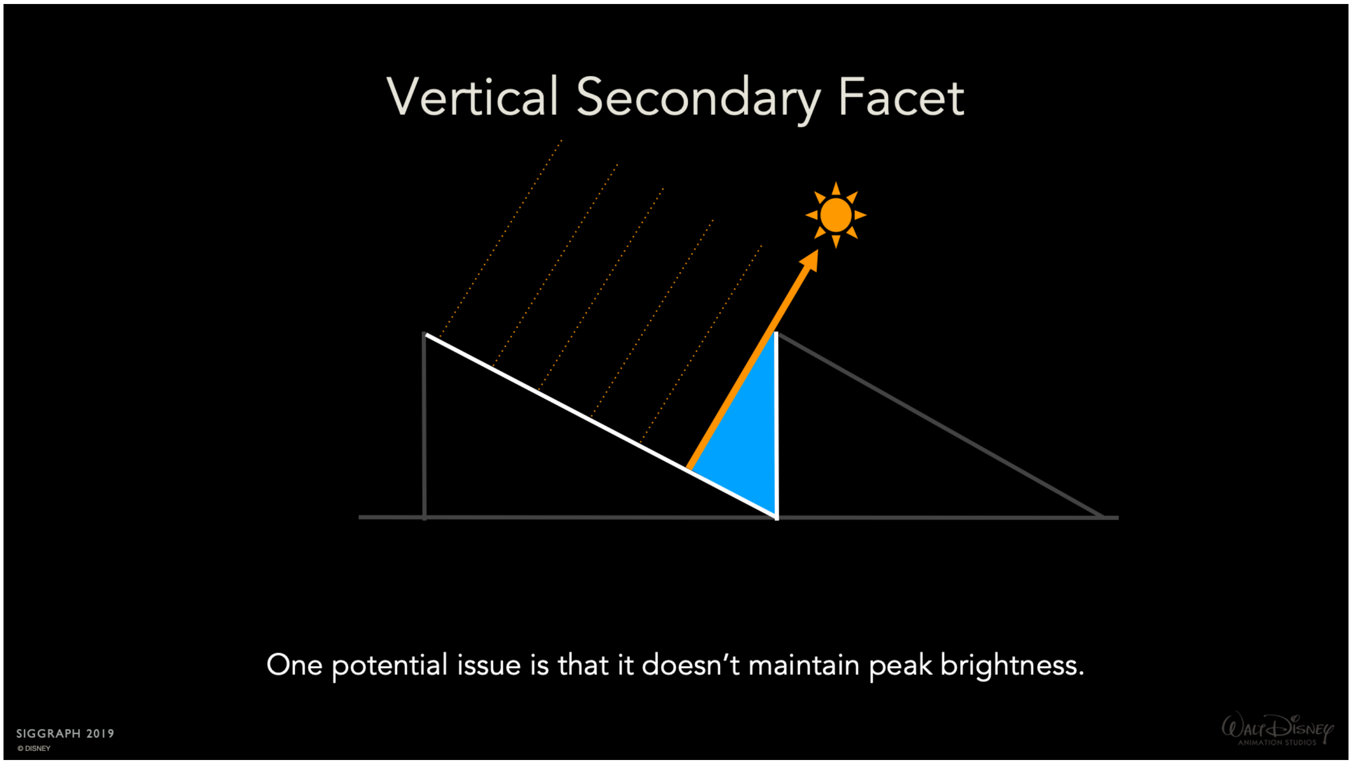
Their primary goal is to address energy loss when rendering with shading normals. So with such secondary facet, they are able to account for things like inter-reflections between the primary and the secondary facets.



And let's call such configuration "vertical secondary facet".

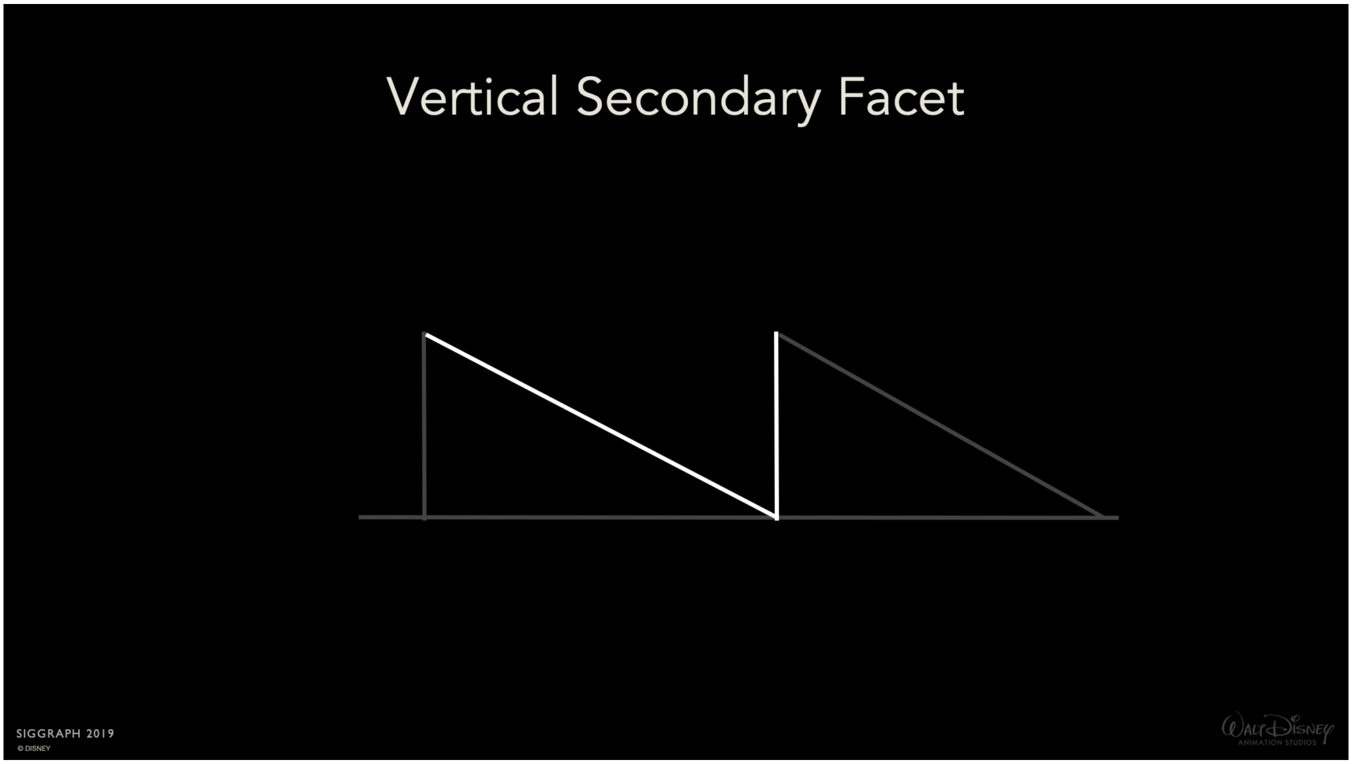


What we realized is that, even though we are solving a completely different problem, such secondary facet configuration can actual help with providing shadowing!

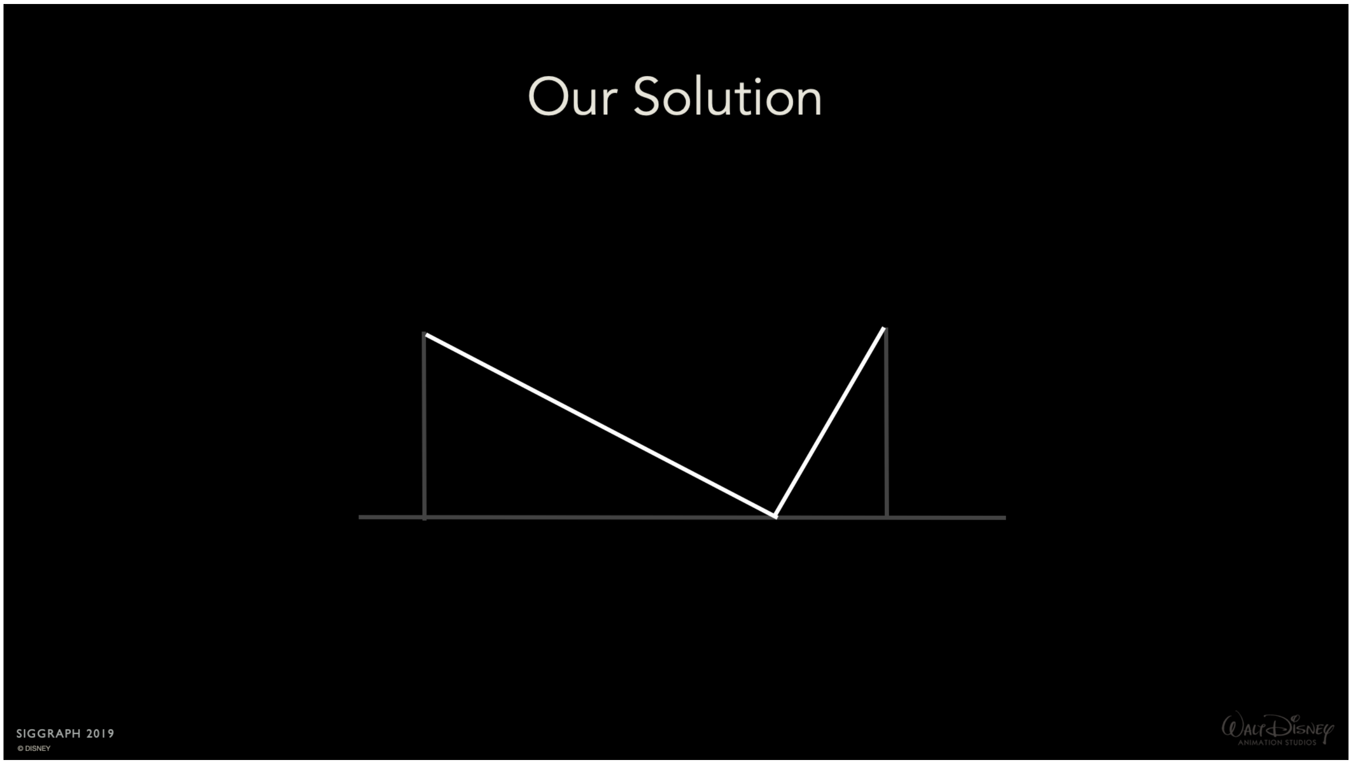


However, one potential issue is that it doesn't maintain peak brightness. As you can see that it produces shadowing where the light is parallel to the shading normal.

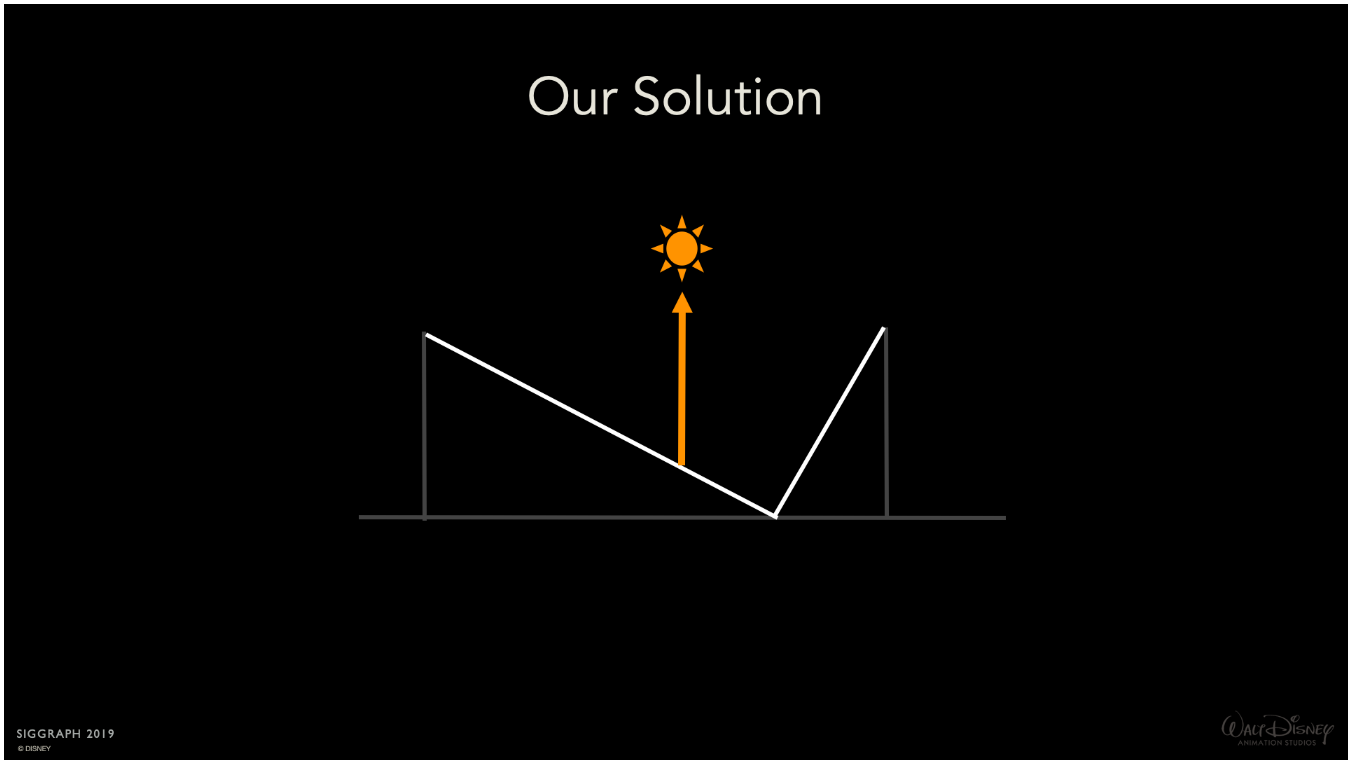
Maintaining peak brightness is essential for bump mapping since the surface details are mostly from the shading contrast.



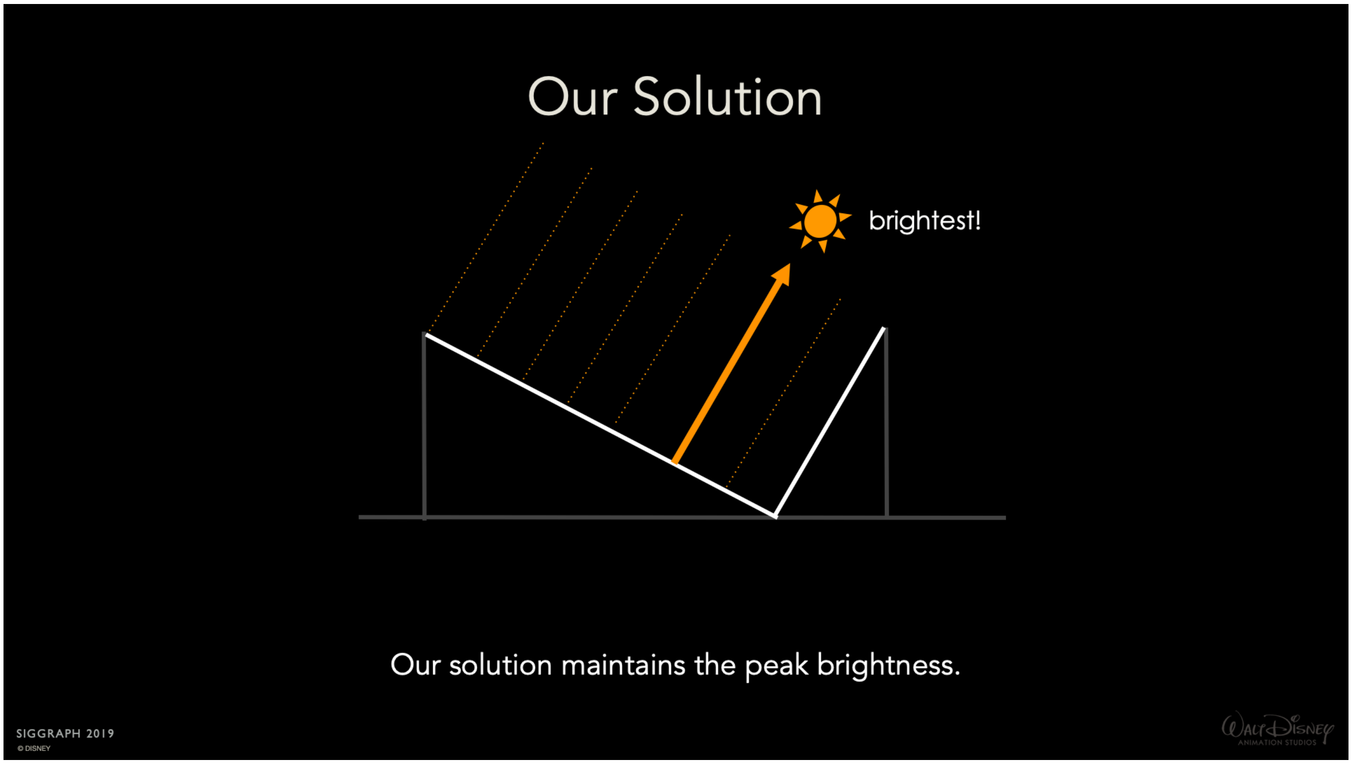
So to improve upon such configuration



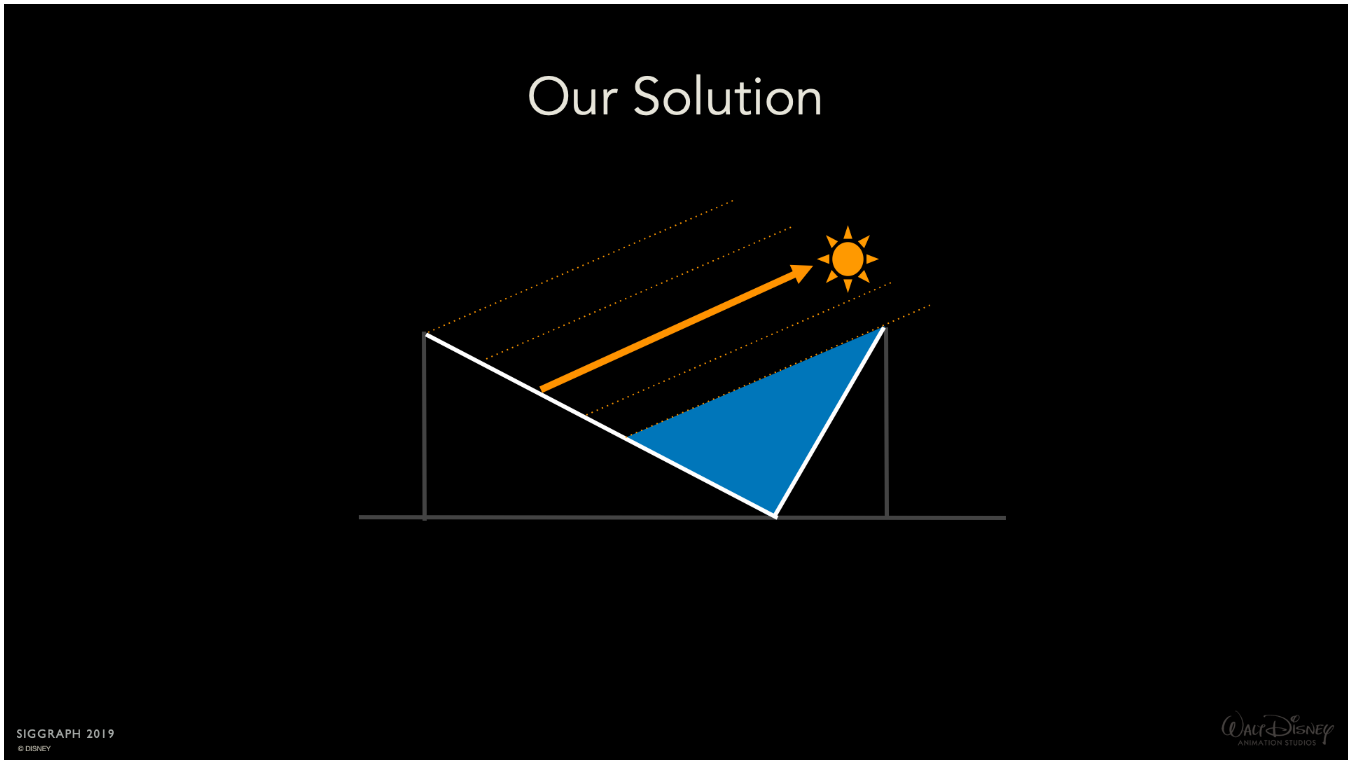
we came up with a different secondary facet configuration, where we made it perpendicular to the shading normal.



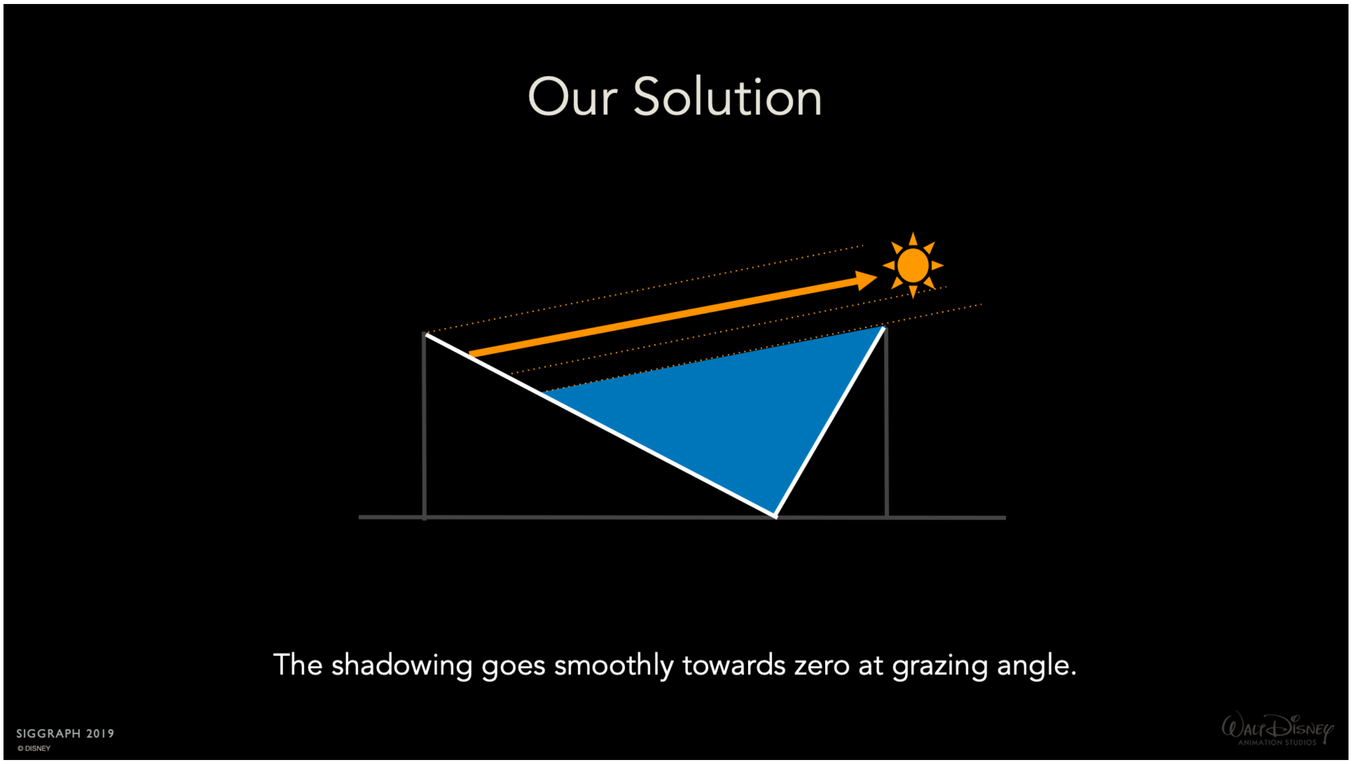
So that when the light is slowing moving towards the grazing angle.



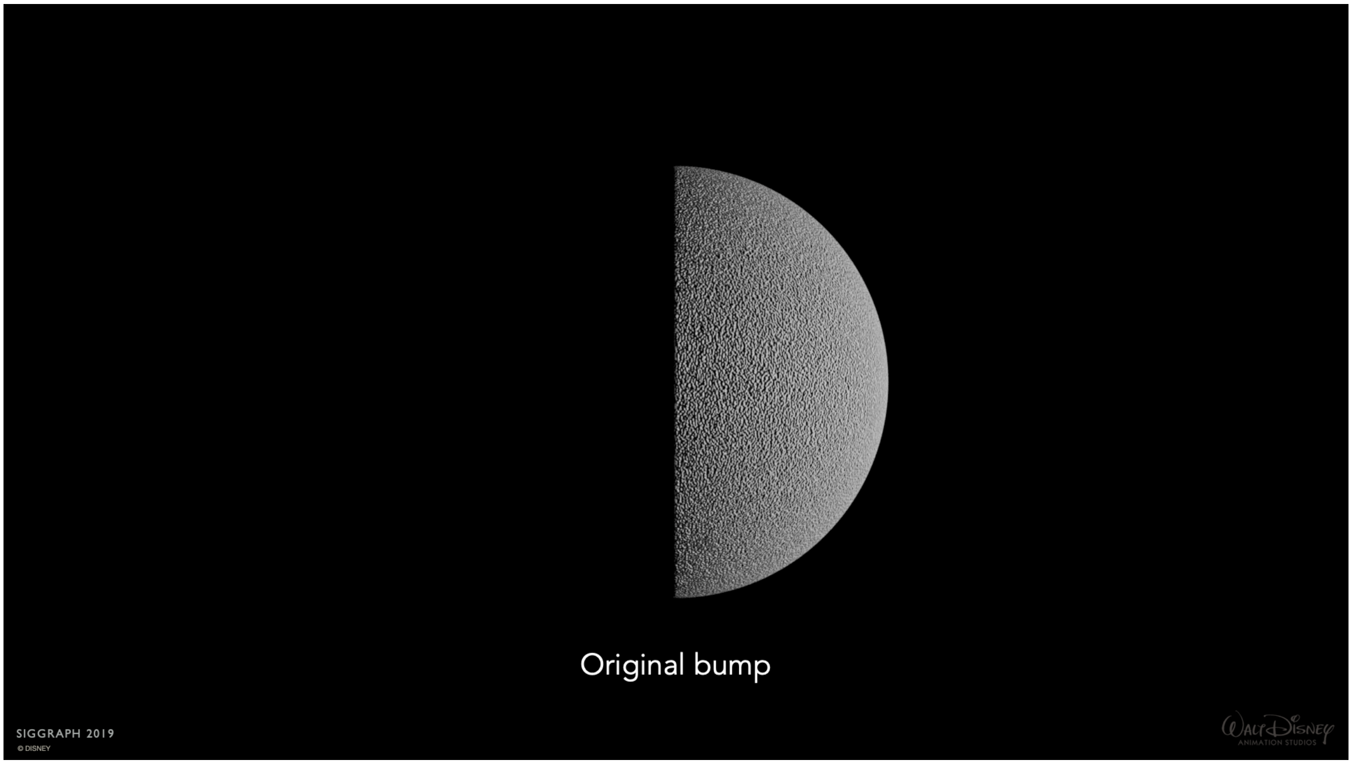
It maintains the peak brightness by not producing any shadowing when light is parallel to the shading normal.



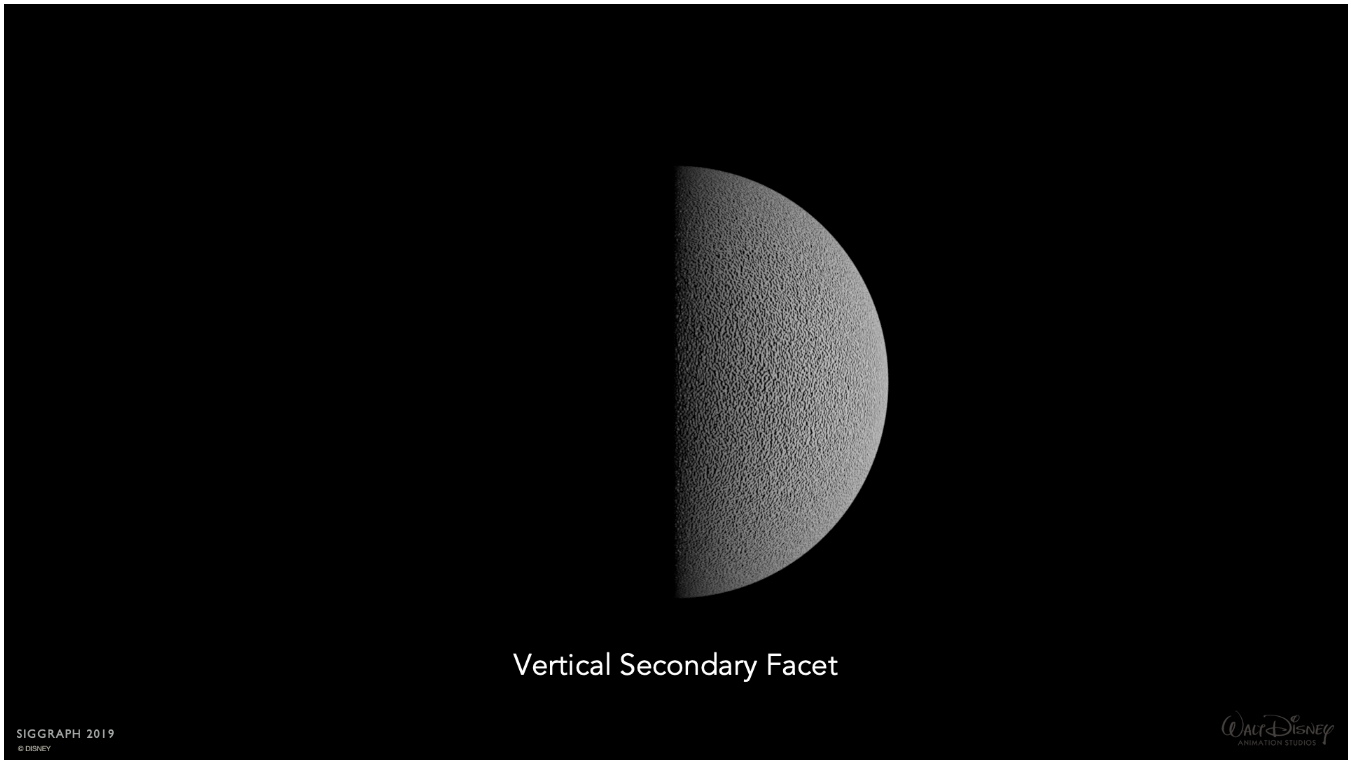
And instead it only produces shadowing past that point.



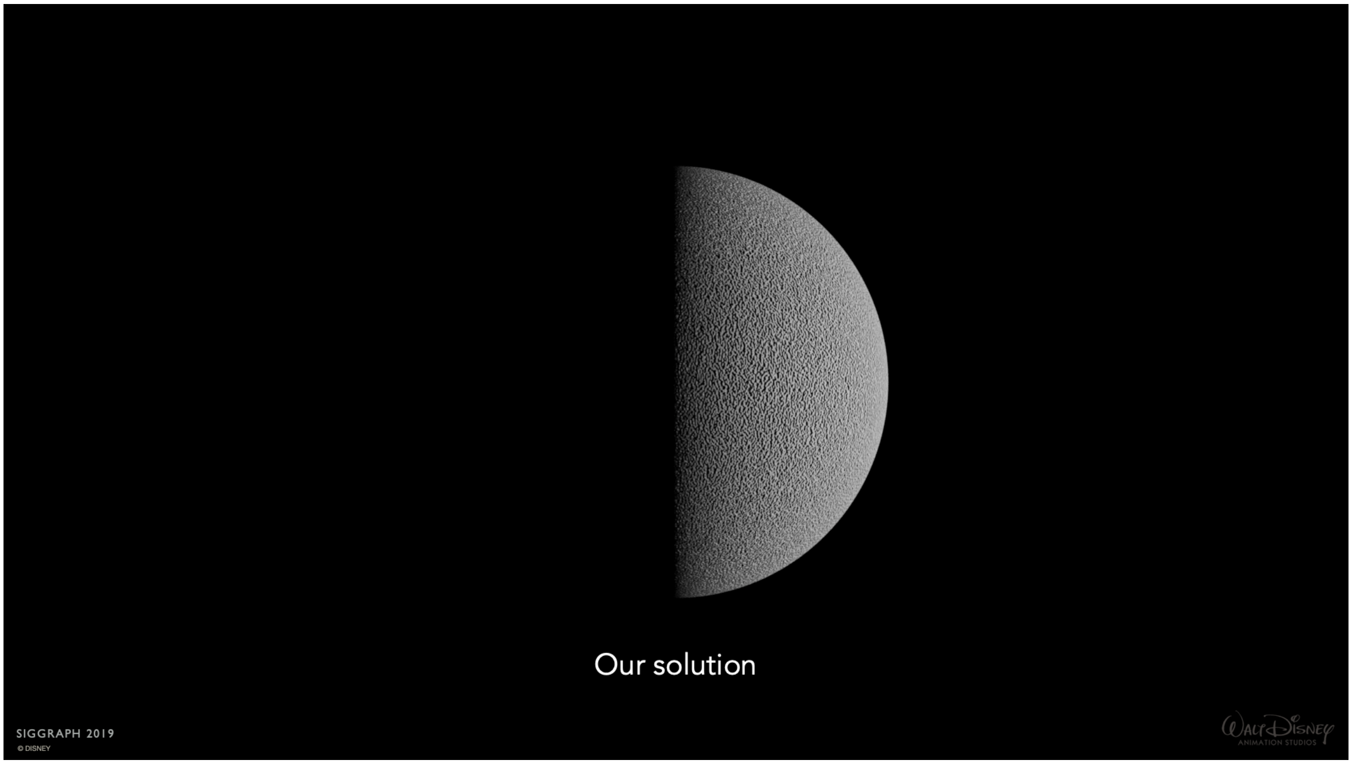
Also, here you can see that with the help of the secondary facet, the shading can now go smoothly towards zero at the grazing angle.



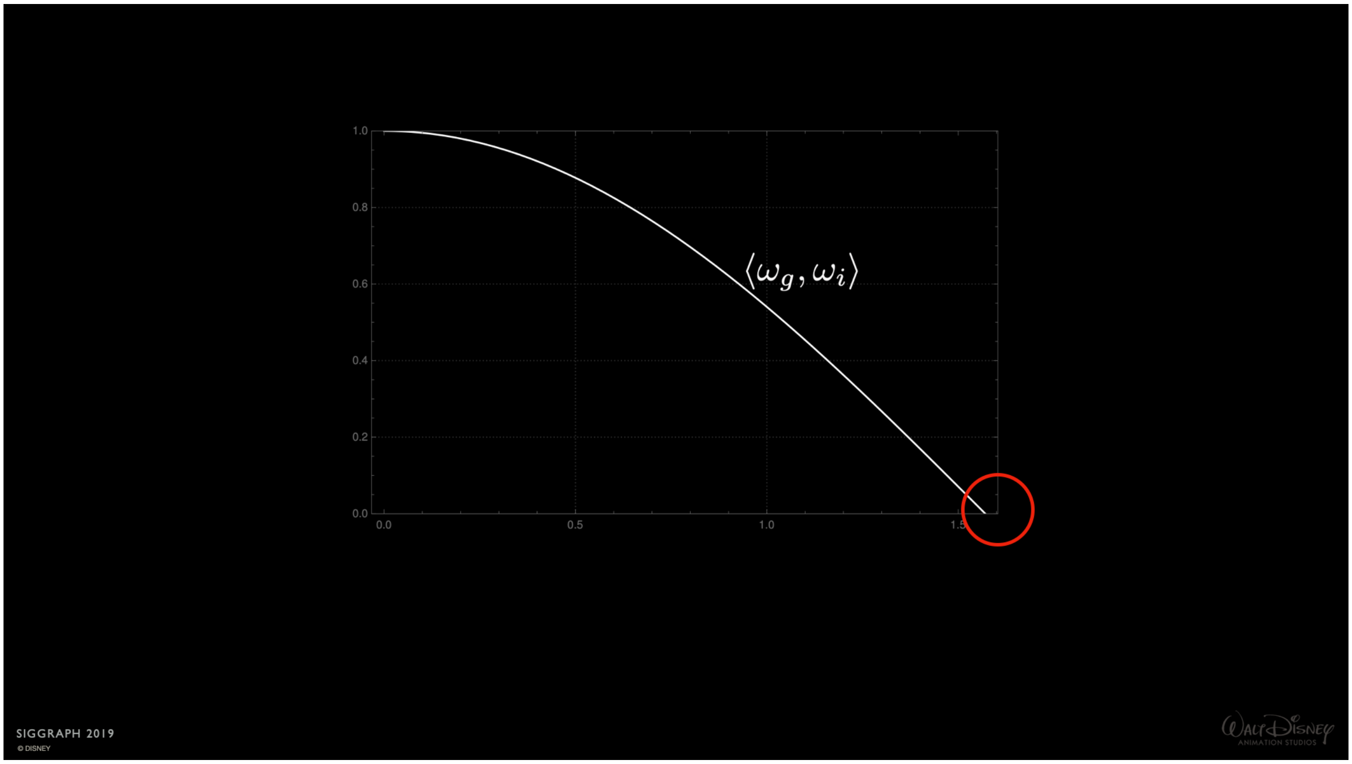
Now let's look at some renderings. This is the sphere we saw earlier with bump mapping and harsh shadow terminator.



With the help of a secondary facet, it definitely helps smooth out the terminator. Here we use the secondary facet configuration inspired by Shussler et al.

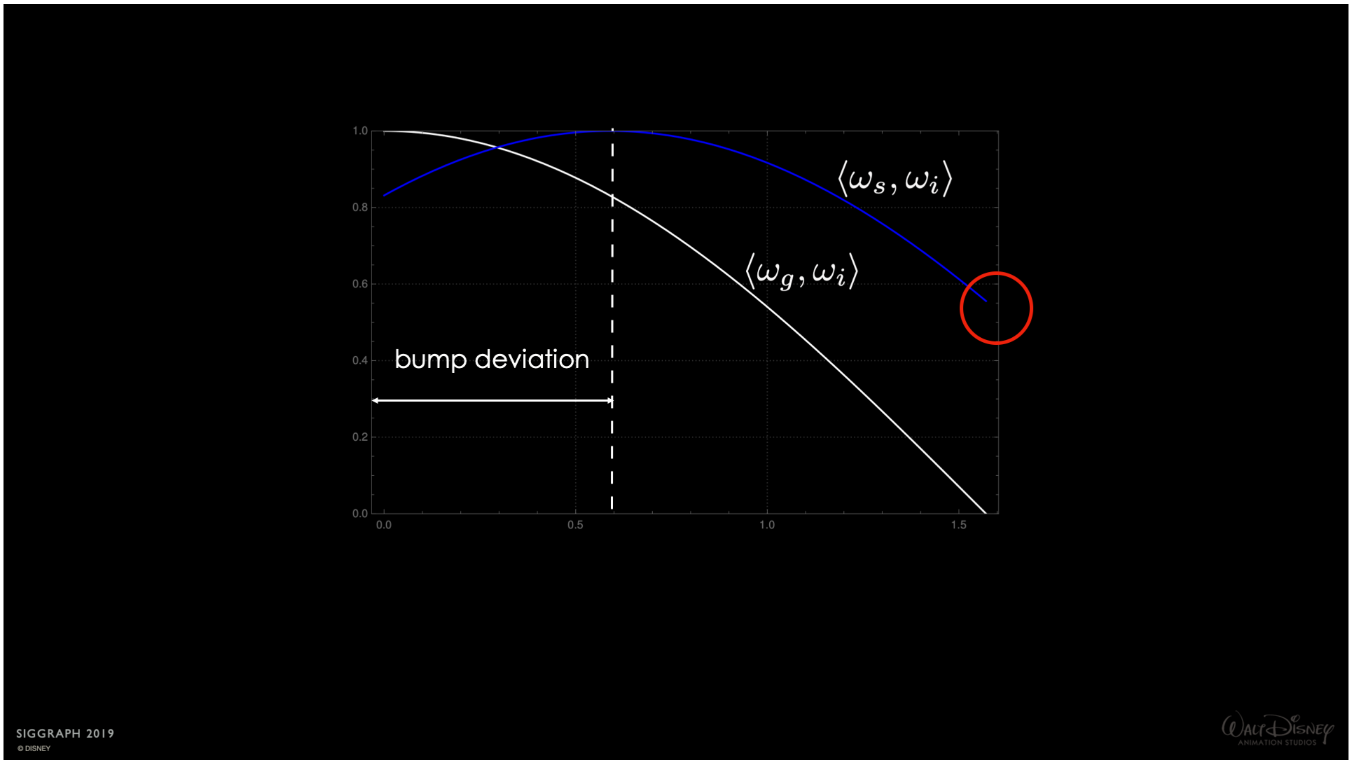


Here we use the new secondary facet configuration we proposed.
(flip)
Since the facet configuration we proposed maintains the peak brightness, it darkens the shading less and also showcases the surface details better. It's especially true at top and bottom part of the sphere.

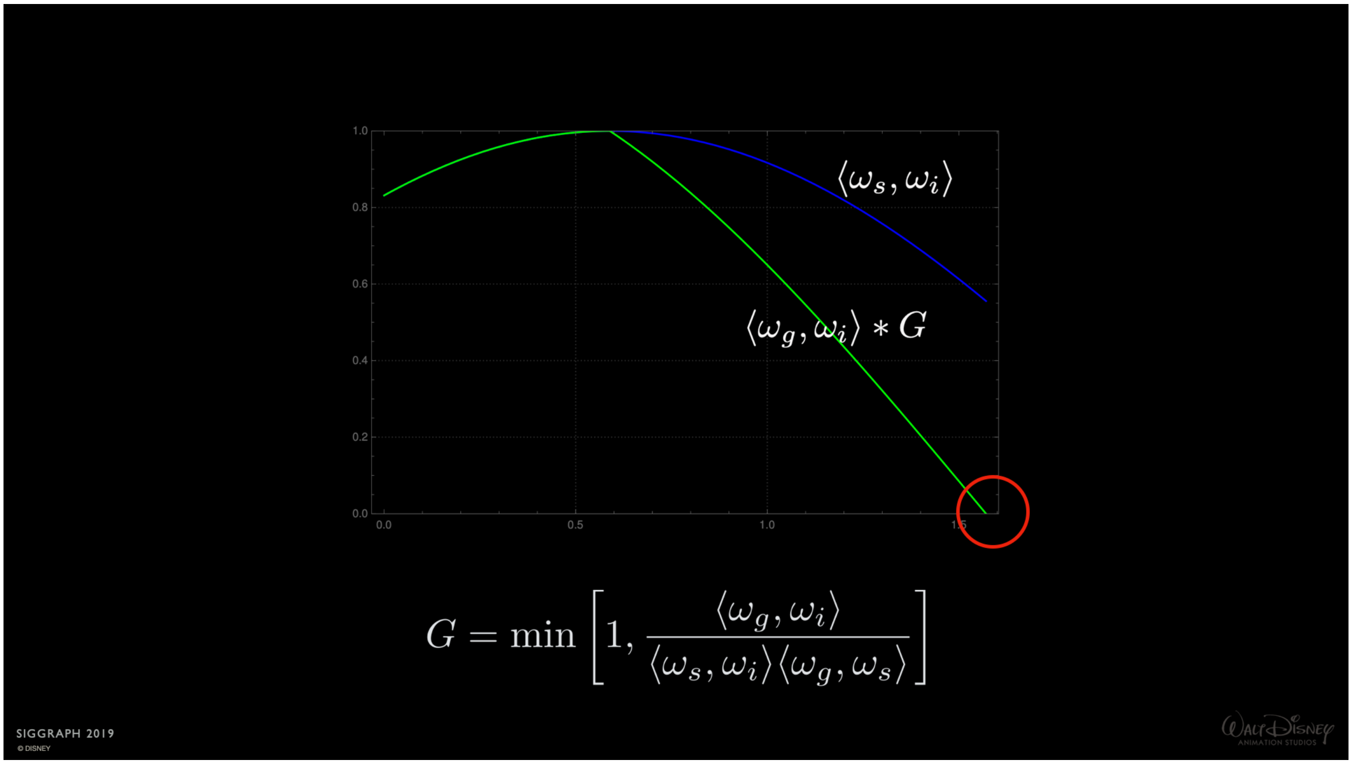


Before we introduce the final mathematical formulation of our method. Here is another way of looking at this shadow terminator problem.

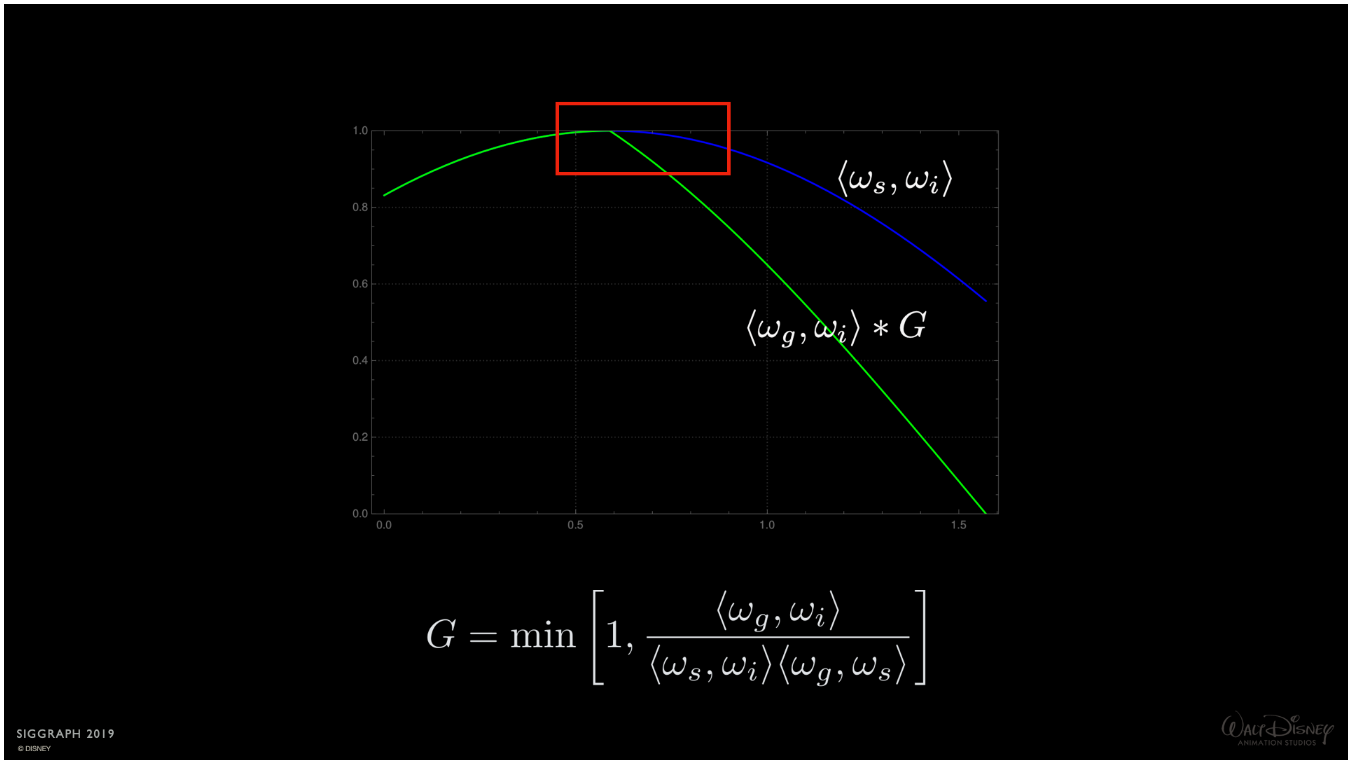
Here we plot a typical shape of the shadow terminator. It is essentially a cosine fall-off formed by the dot product of shading normal and light direction. In this plot the shading normal is the same as the geometric normal so that the terminator smoothly goes to zero.



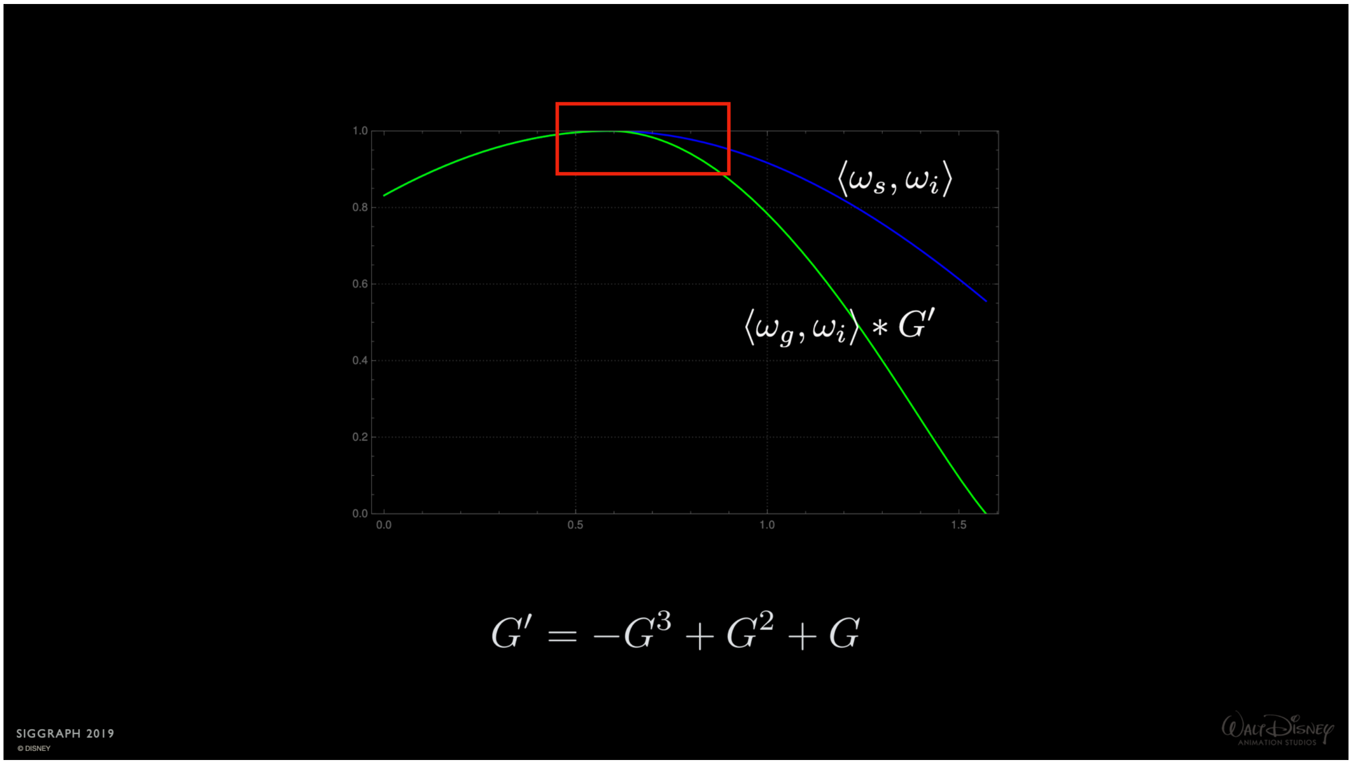
Here we introduce some bump deviation so that the shading normal is now deviated from the geometric normal towards the light. You can see that the terminator now doesn't fall to zero like it should.



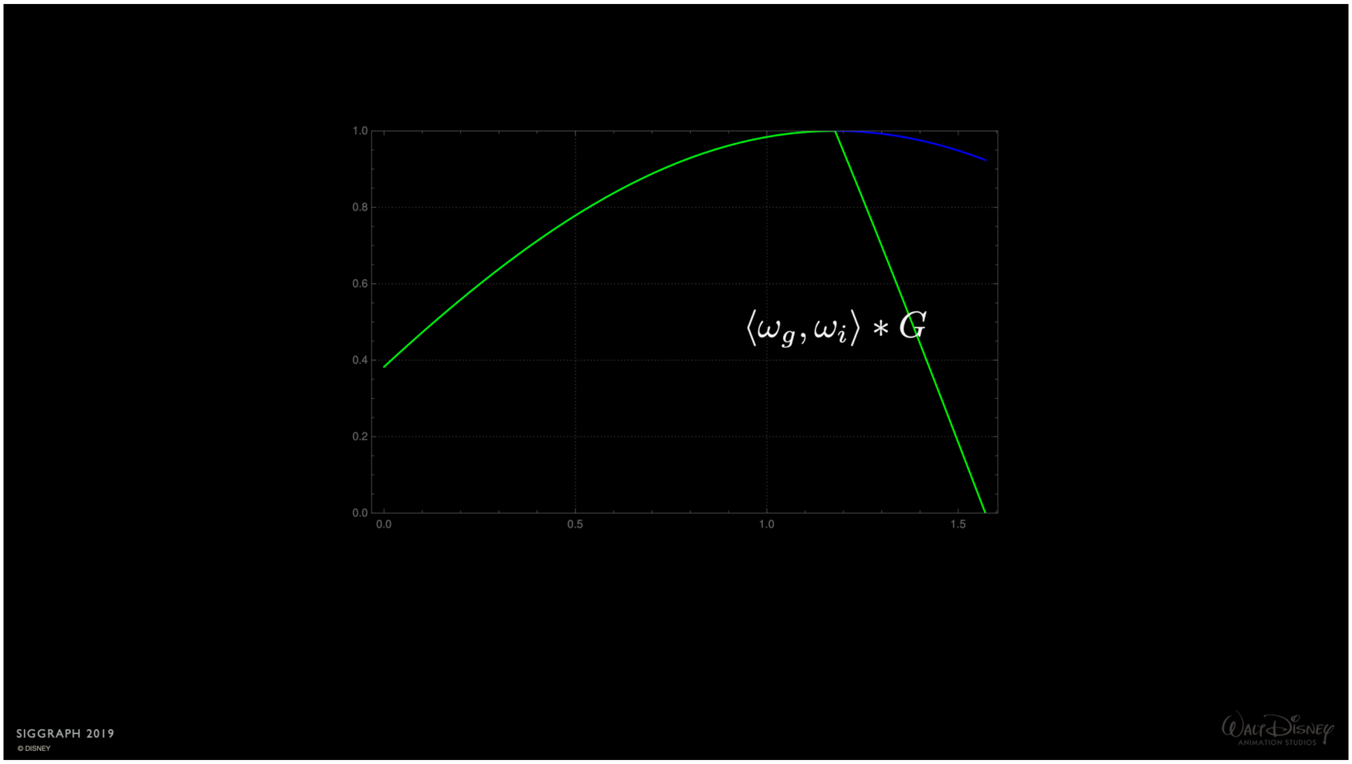
Here we introduce the shadowing term calculated by the new facet configuration we talked about earlier. And you can see it from the plot, it successfully forces the terminator drops to zero.



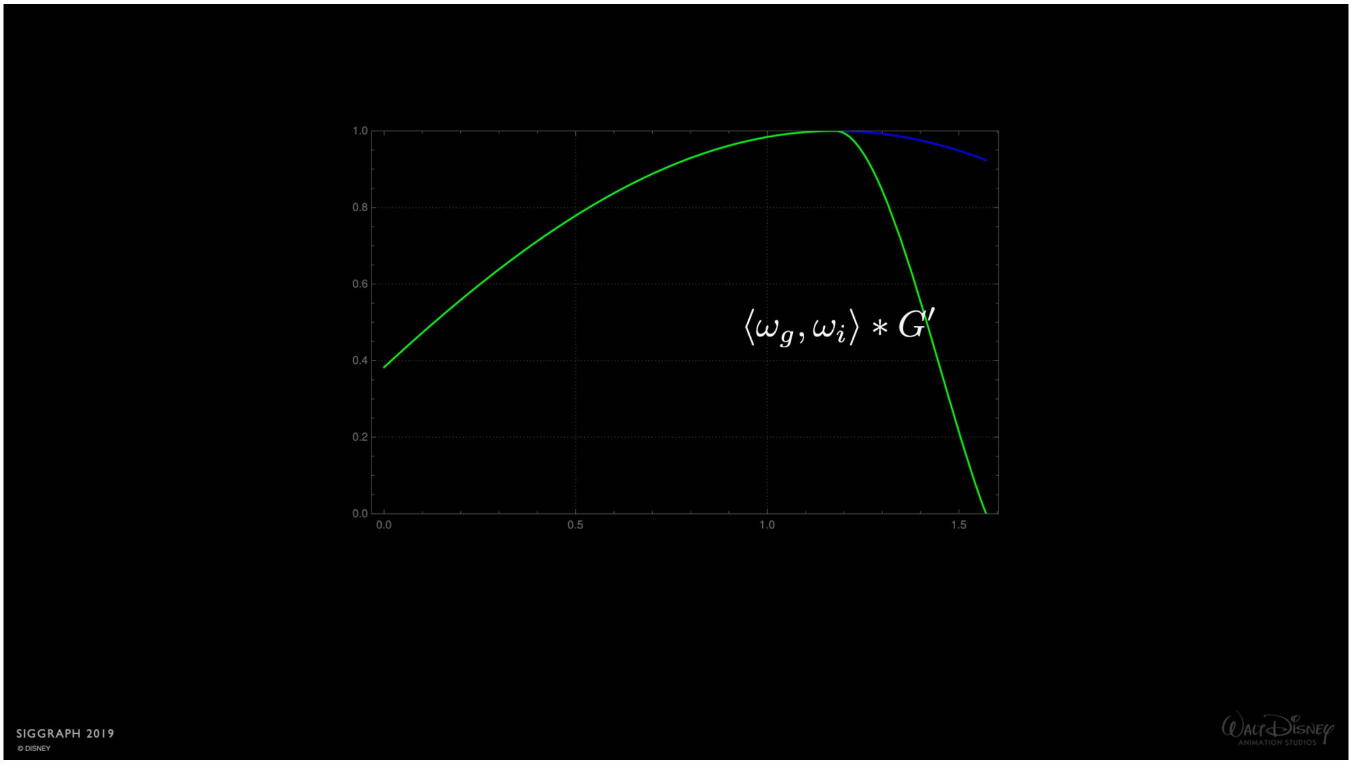
However, it also introduces this kink right at where the shadowing term kicks in.



To alleviate such slope discontinuity, we use Hermite interpolation to smooth it out.



Here is another example now with a larger bump deviation without smoothing.



and with smoothing.

$$G = \min\left[1, \frac{\langle \omega_g, \omega_i \rangle}{\langle \omega_s, \omega_i \rangle \langle \omega_g, \omega_s \rangle}\right]$$

$$G' = -G^3 + G^2 + G$$

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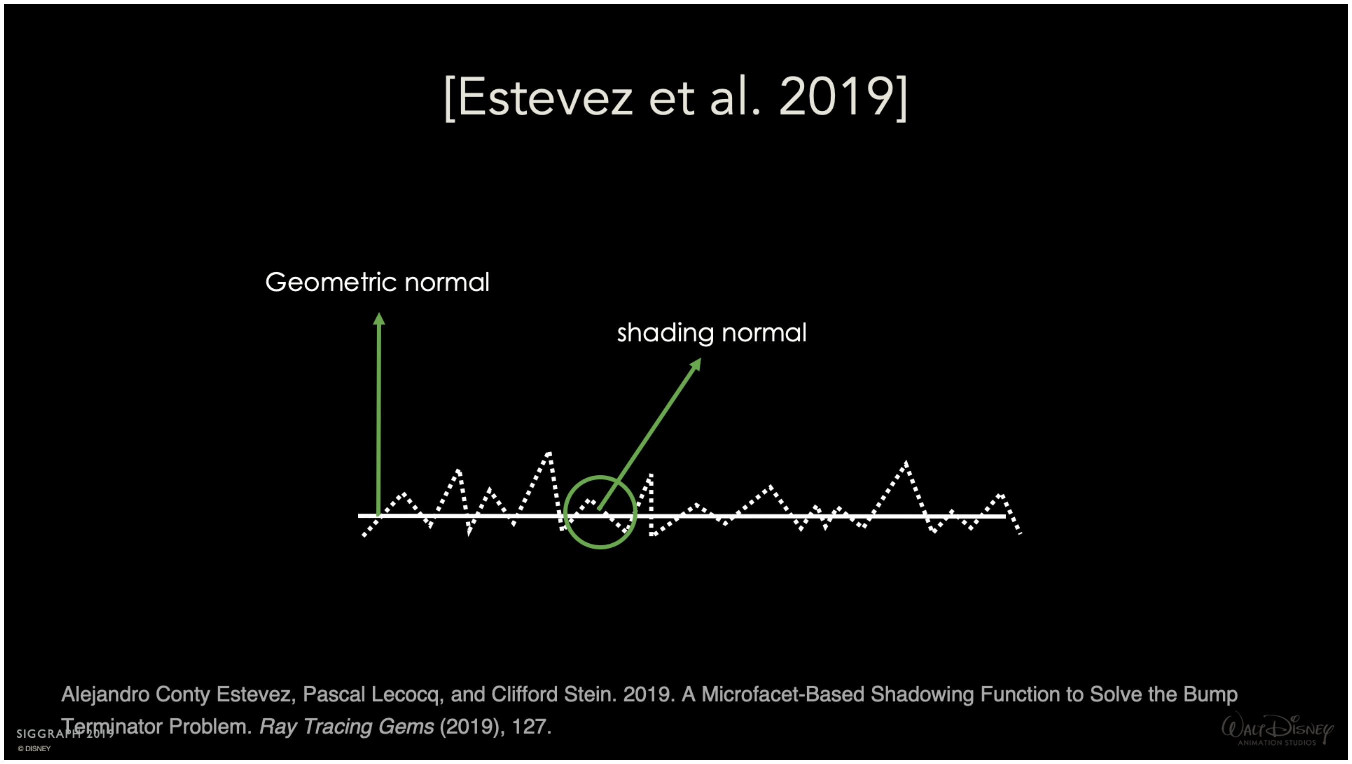
Here we arrive at the final smoothed shadowing term.

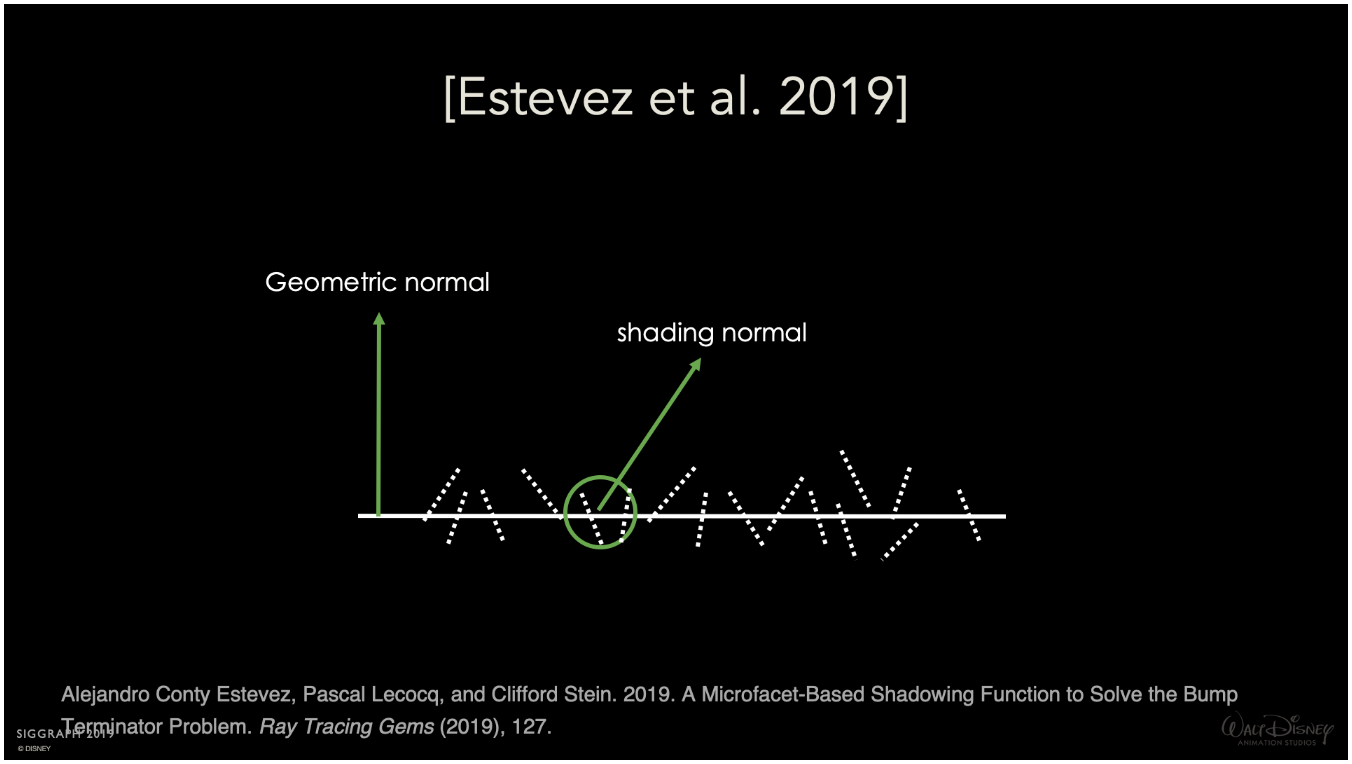
This is extremely simple to implement, efficient to calculate and yet very effective.



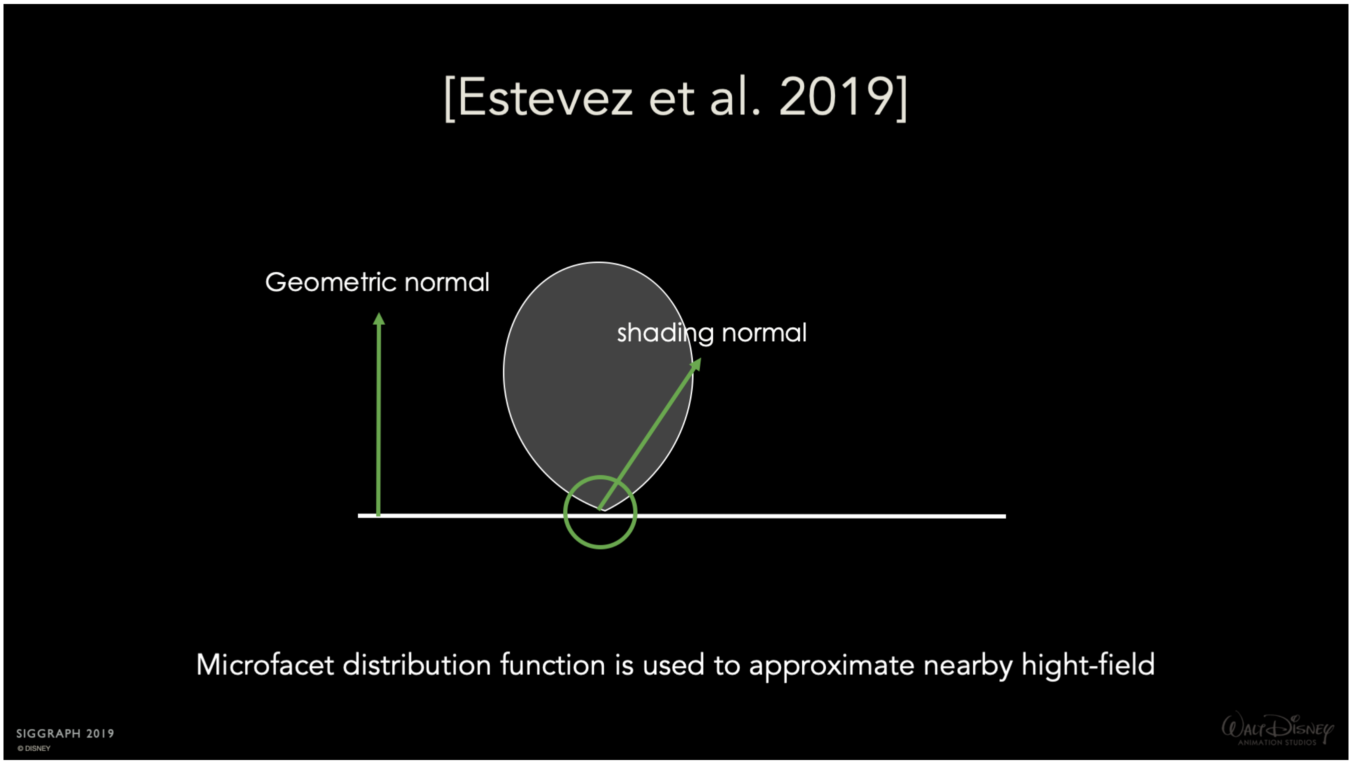
When we were preparing for this talk submission, we found there is a concurrent from Estevez et al. that also tackles the same problem. It works and also straightforward to implement.

Here I'm going to quickly go through their approach and highlight some of the visual difference from our results.

So their method also start from the same question: given one shading normal how do we approximate nearby height-fields and derive a shadowing term?



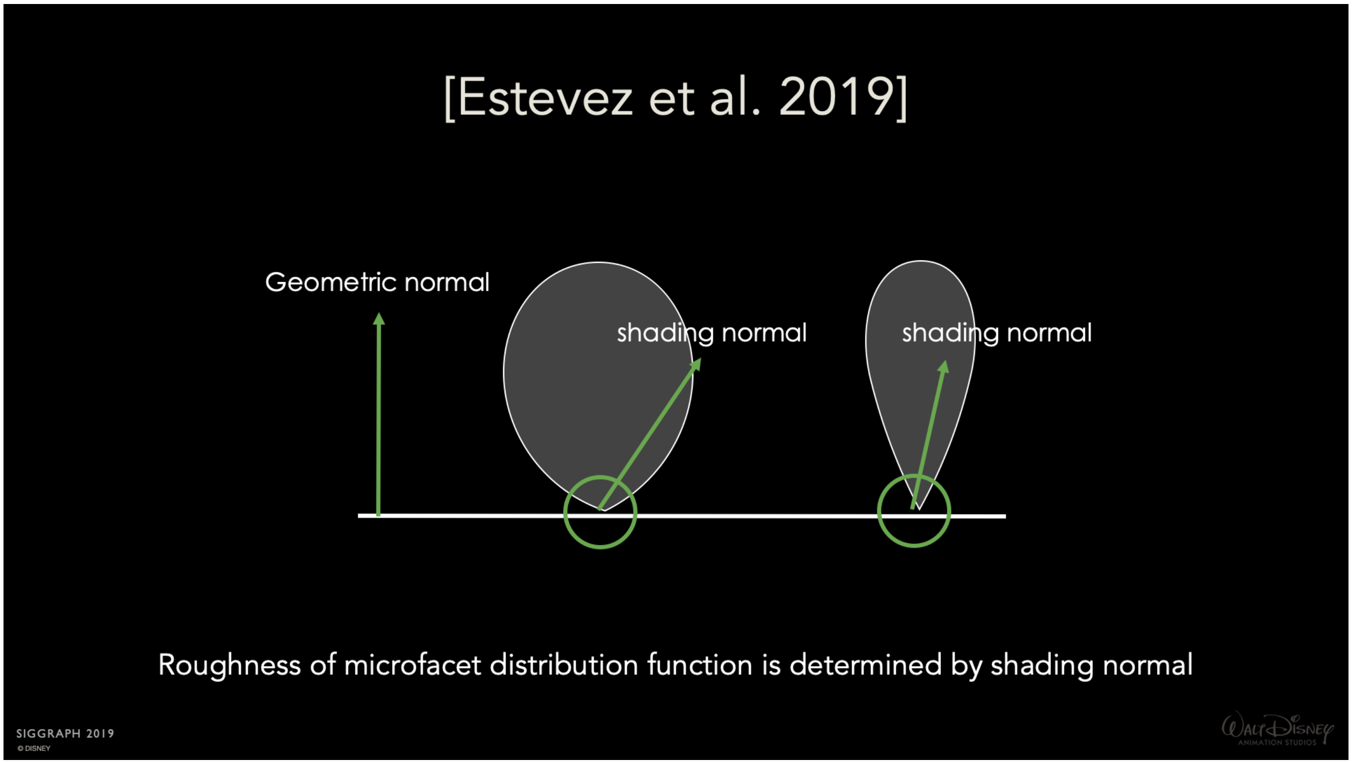
Instead of adding a secondary facet like us, they approximate the nearby geometry as a group of “microfacets”.



Or statistically a microfacet distribution function.

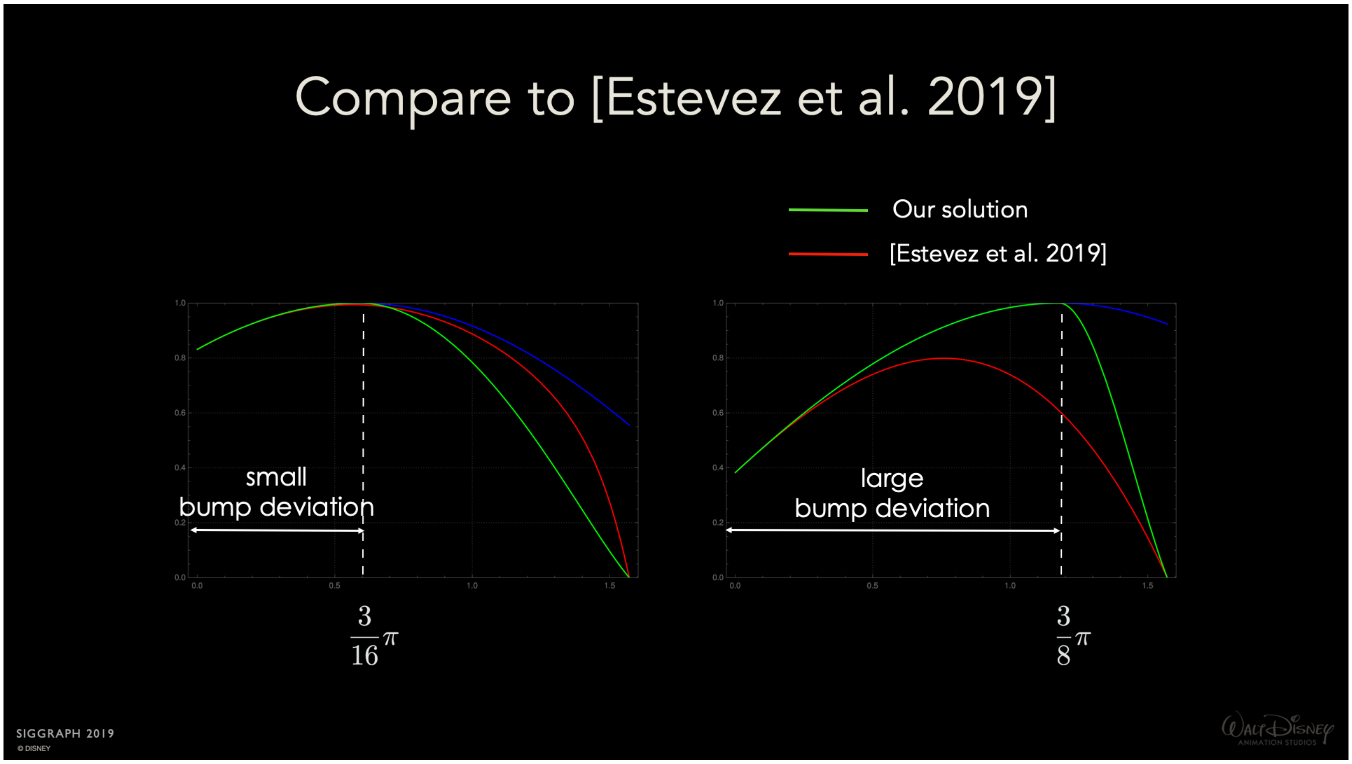
They then assumed the single shading normal at the shading point can be used to determine the characteristics of the microfacet distribution.

So bigger the bump deviation, higher the roughness.

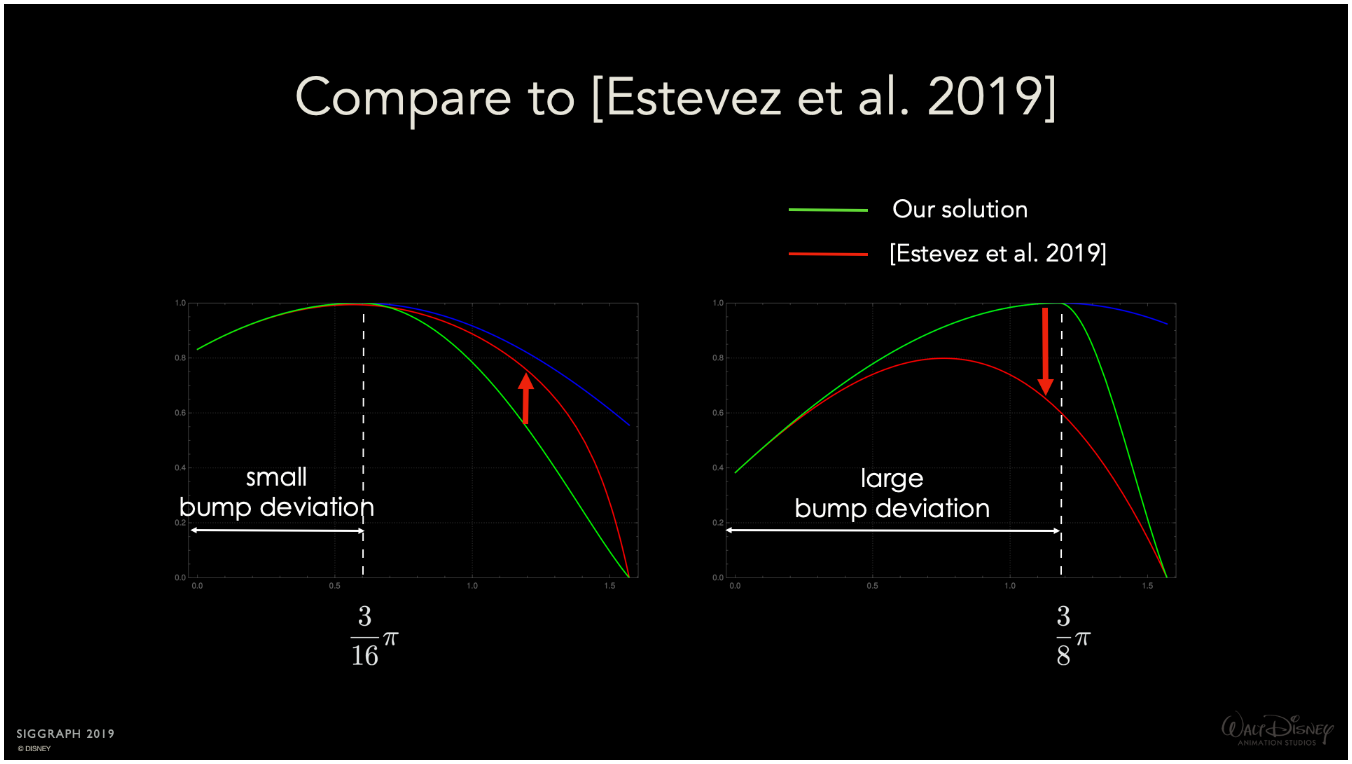


On the other hand, smaller the bump deviation, lower the roughness.

Naturally the Smith shadowing term derived from such microfacet distribution function can then be used directly to soften the shadow terminator.

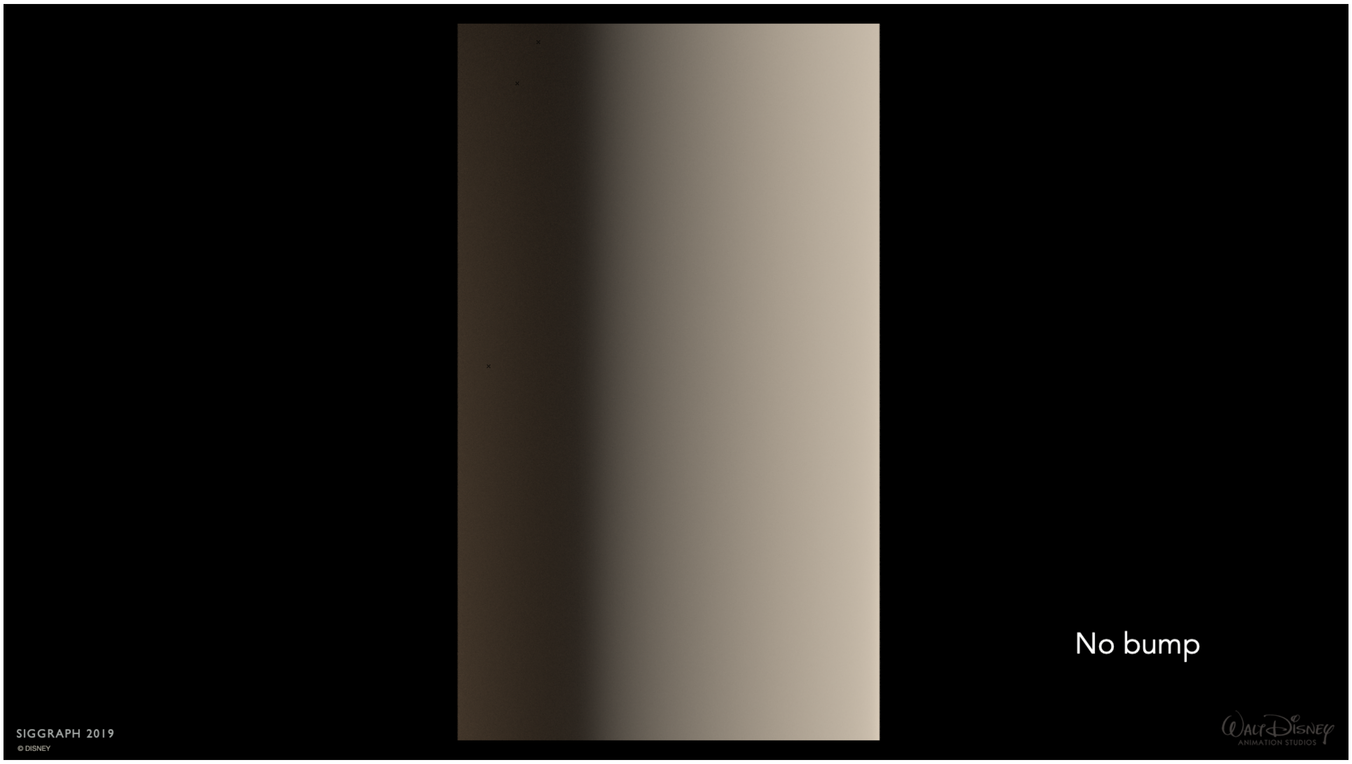


Here is how our methods compare in a plot.

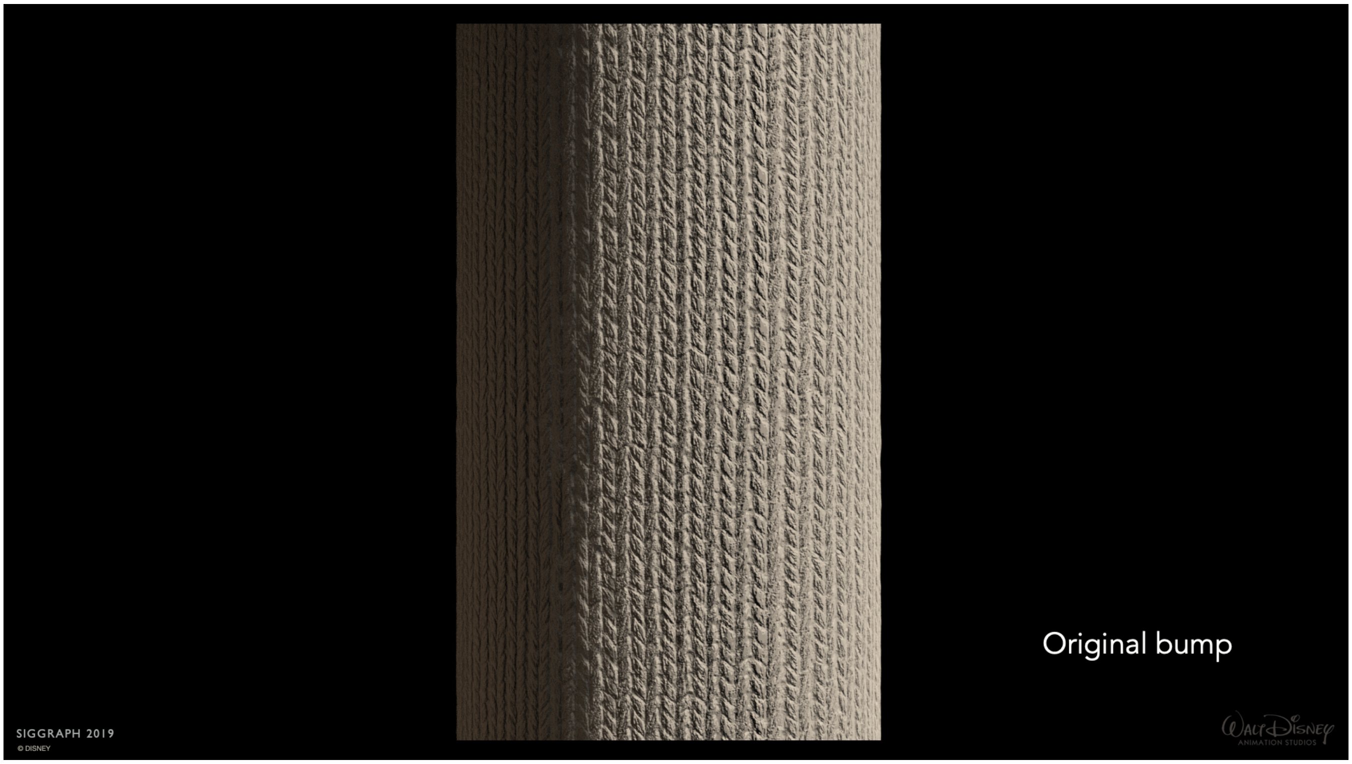


One of the difference between our methods is that with smaller bump deviation, their method provides brighter result, while with larger bump deviation their method provides darker results.

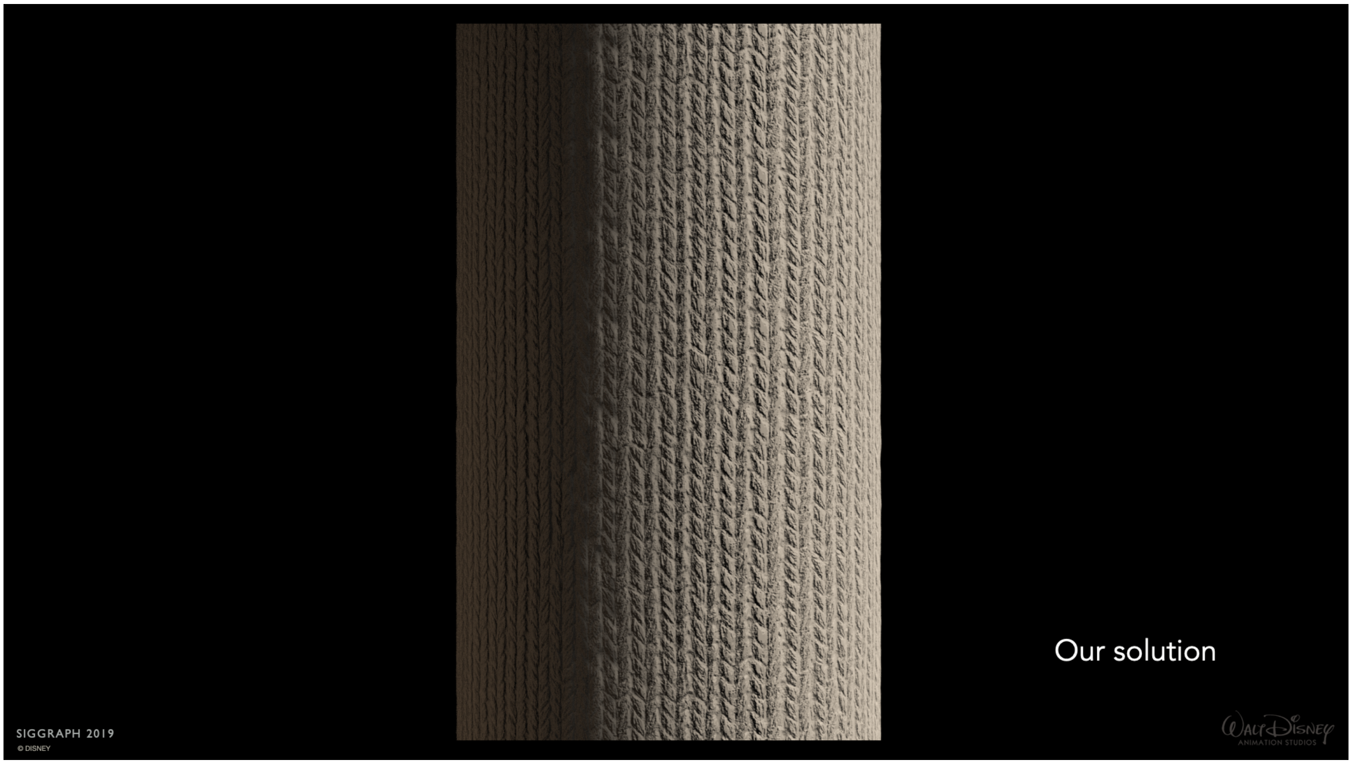
Our method generally produces slightly softer results and this might explain why.



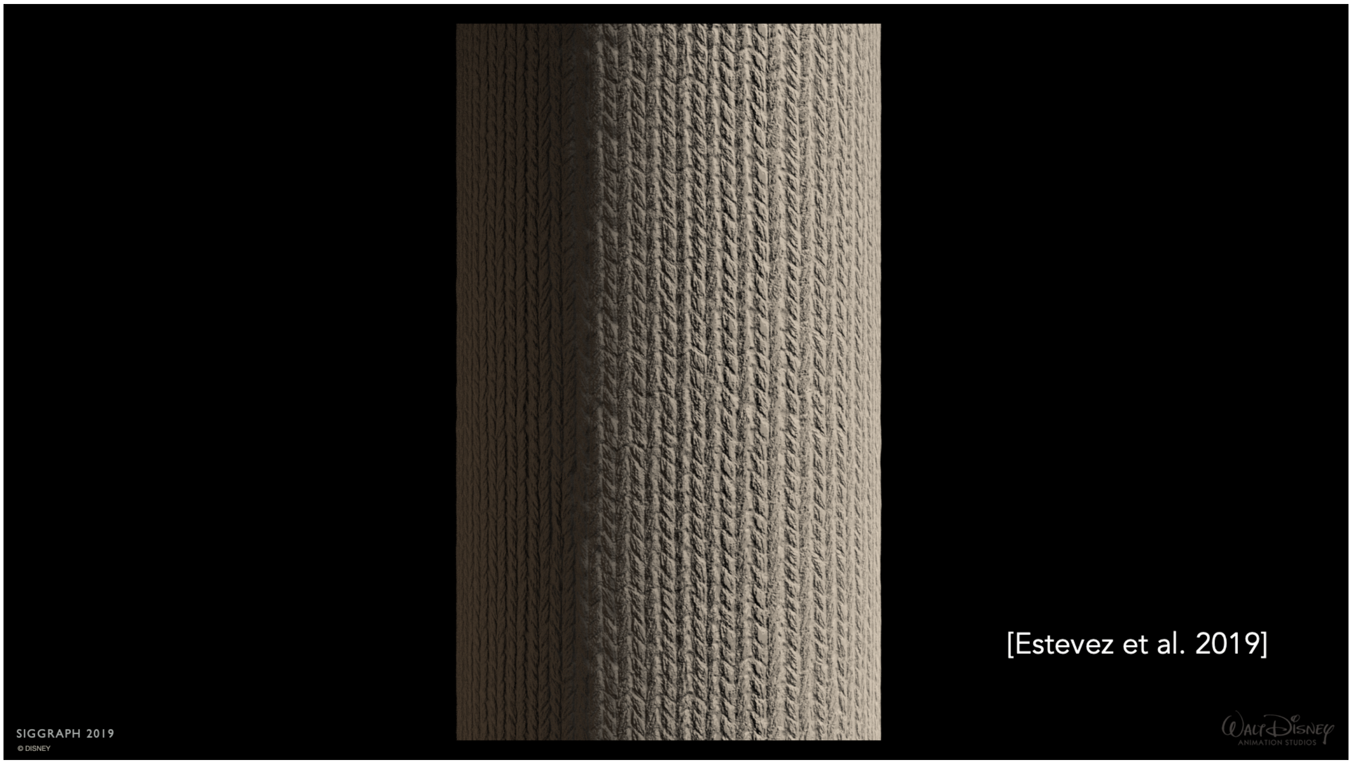
Let’s look at some visual comparison.



Here is with the original bump mapping.



Here shows our solution softens the shadow terminator.



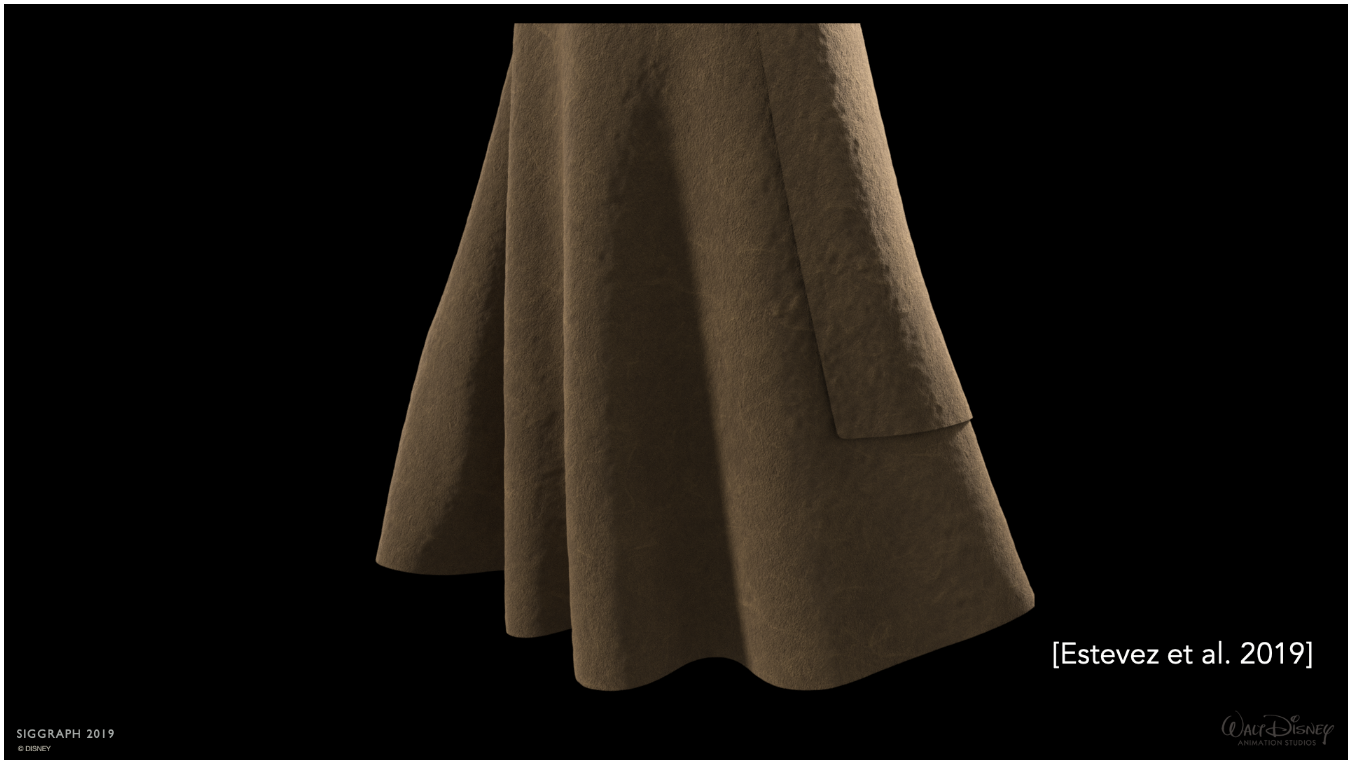
And here is the results from Estevez et al.

Again, the work from Esteves et al and ours are concurrent, and the visual difference is only subjective. Our artists like our result better for its slightly softer appearance. But the difference is very minor.

Here is another example with the skirt example we showed earlier.

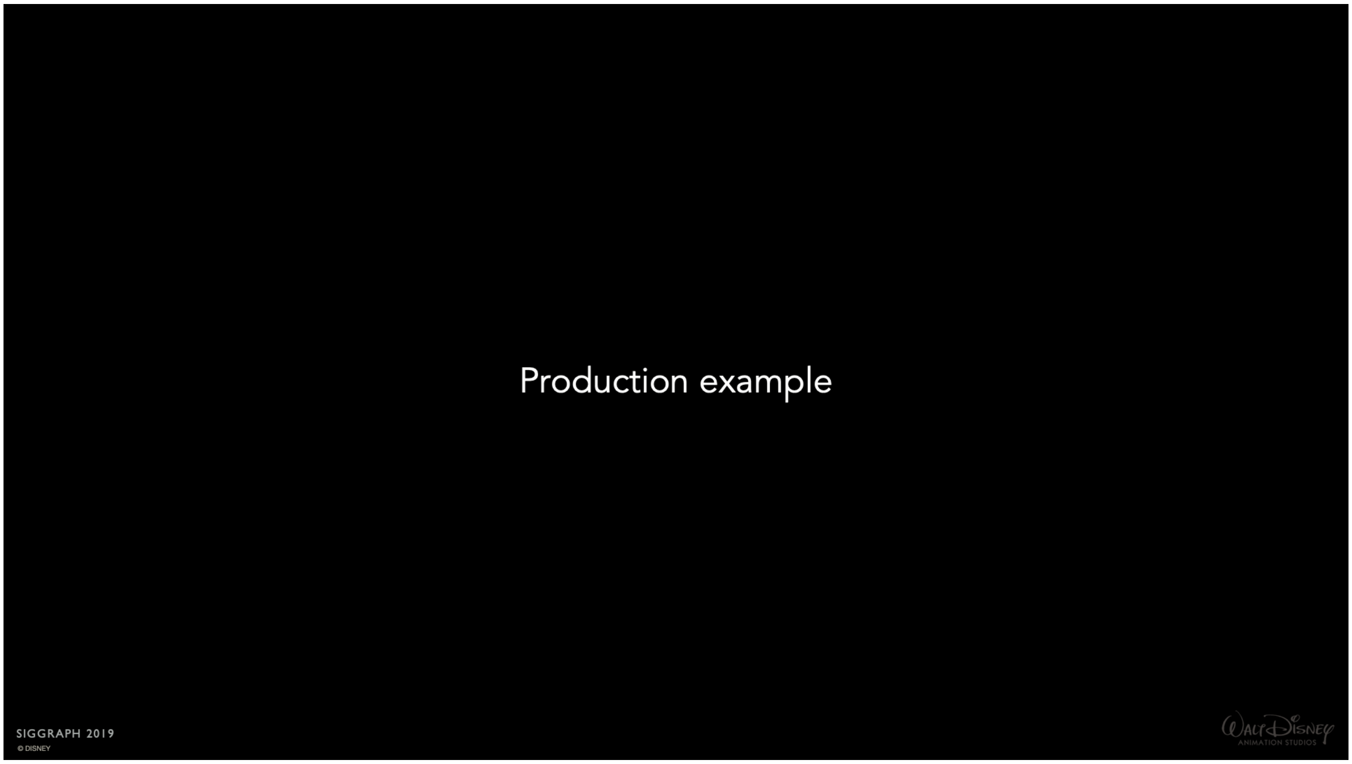
Here is with the original bump mapping.

Here is our result.



And here is the result from Estevez et al.

Again both methods solve this problem very effectively. Our method generates slightly softer shadow terminator.



Finally I'm going to show a production example.

Here's a character from the Frozen 2, rendered using our in-house renderer Hyperion before we added this fix.

We mentioned before the harsh shadow terminator really gives a wrong illusion of the surface shape. Note how her arms and torso look kind of boxy.

…and here is the same character, now with the soft shadow terminator fix applied. Her arms and torso now actually look round.

It’s a subtle change, but overall both improves the look and removes a big historical pain point for look and lighting.

We implemented this fix in Hyperion, and it has been rolled out to all production moving forward including Frozen 2.

Question?

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"a kite's tale"
Sun - Thurs | Times Vary
VR Theater - South Hall J

The Making of Disney's "a kite's tale"
Sunday | 2:00PM - 3:30PM
Room 150/151

Predictive & Proactive Pipelines
Sunday | 3:45PM - 5:15PM
Room 153

Machine-Learning Denoising
Monday | 3:45PM - 5:15PM
Room 403 AB

Optimizing Rig Manipulation
Thurs | 10:45AM - 12:15PM
Room 403 AB

Optimizing Large Scale Crowds
Thurs | 2:00PM - 3:30PM
Room 408 AB

Creating Ralphzilla
Thurs | 2:00PM - 3:30PM
Room 408 AB

Taming the Shadow Terminator
Thurs | 3:45PM - 5:15PM
Room 403 AB

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