SIGGRAPH2010

The People Behind the Pixels

Uncharted 2: Character Lighting and Shading

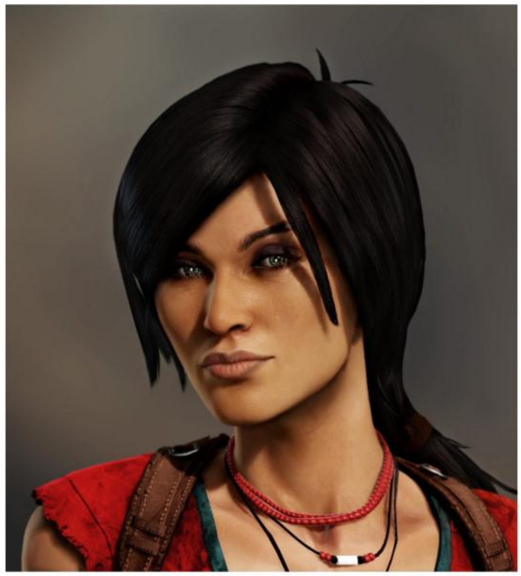
John Hable
Naughty Dog

Focus: Characters

Drake

You play as Drake, the loveable rogue. Check out this link for more character development: http://www.penny-arcade.com/comic/2009/10/19/.

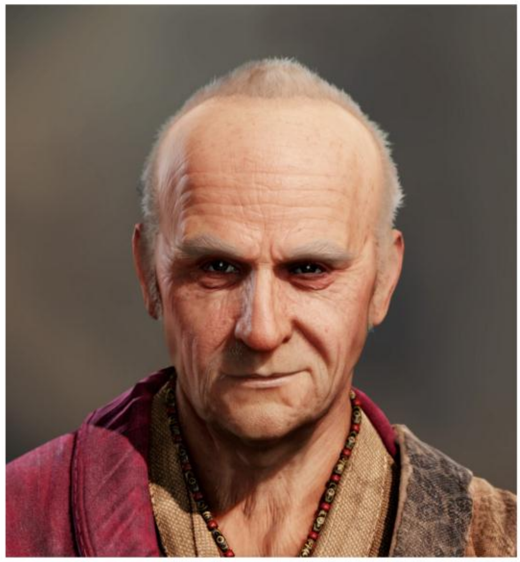
Chloe



Elena

Lazaravic

Shafer

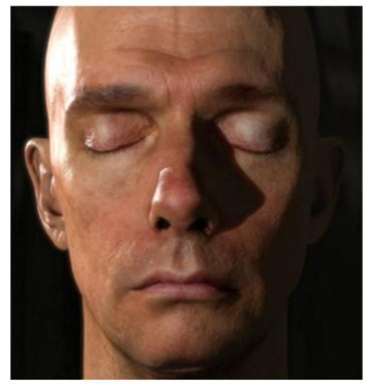


Todo List:

- Skin
- Hair
- Cloth
- 5 Secrets

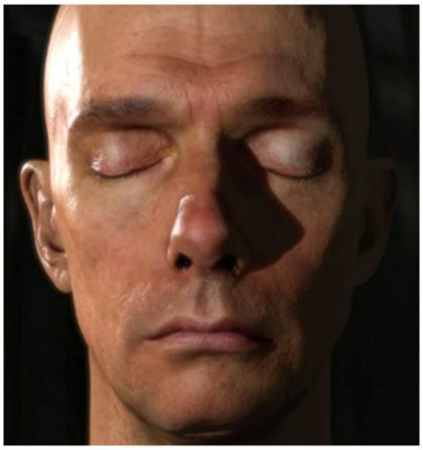
Skin

- Efficient Rendering of Human Skin, Eugene d'Eon, David Luebke, and Eric Enderton, Eurographics 2007
- NVIDIA Human Head Demo
- Compare with real shots.



The best implementation of skin in realtime that I’ve seen is the NVIDIA Human Head demo.

Doug Jones



http://www.omnipop.com/artist-details.php?BID=69
http://www.collider.com/uploads/imageGallery/Doug_Jones/doug_jones.jpg

When you look at the render on the left vs. an actual picture of Doug Jones, there is a certain fleshiness that is hard to explain. That’s what I like about the NVIDIA technique. On some level, it just “feels” like skin.

Benjamin Button

- Yikes!

Obviously, movies can go much farther than we can in realtime. We'll catch up eventually…I hope.

Let's Test!

- Lazaravic
- RenderMonkey

This next section with show lots of pictures using Lazarevic from U2. Note that these tests are in Rendermonkey, not the game engine.

Compare 5-ish Approaches

1. Standard Diffuse
2. Nvidia Approach

3a. 12-Tap Separate

- Do 12-Tap blur as separate shader.

3b. 12-Tap Combined

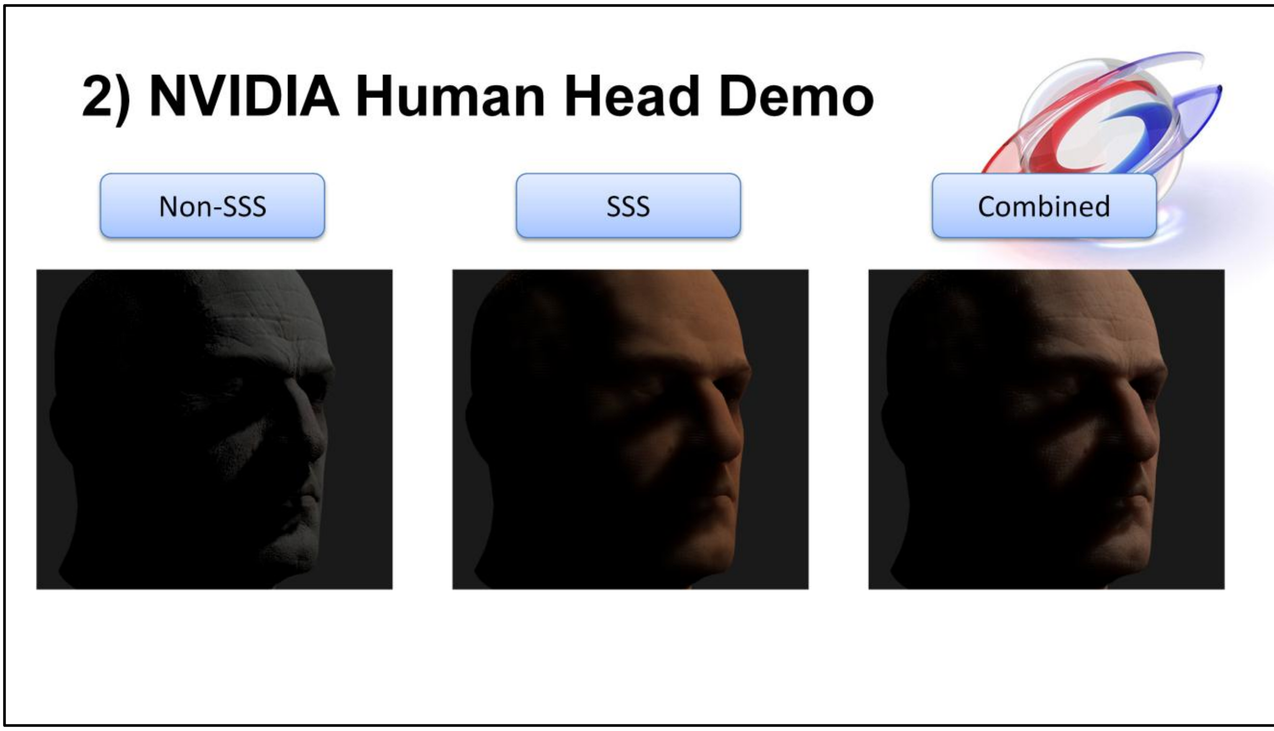
- Do 12-Tap blur in final render pass.

4. Bent Normals
5. Blended Normals

1) Standard Diffuse

Lazaravic with standard dot(N,L) lighting.

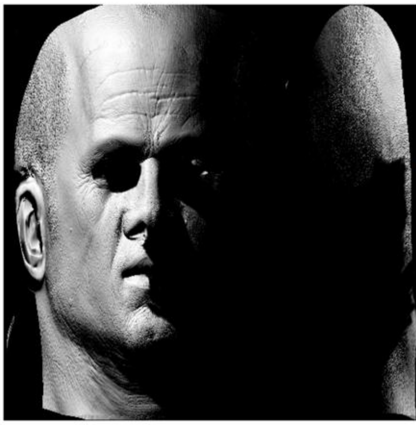
Lighting-Only



The NVIDIA technique divides light into diffuse light that gets absorbed and immediately retransmitted, versus light that bounces around inside the skin for a while before exiting. Not that the SSS light is more red-ish.

2) NVIDIA Human Head Demo

- Efficient Rendering of Human Skin, Eugene d'Eon, David Luebke, and Eric Enderton, Eurographics 2007



2) NVIDIA Approach

- Combine Blurs

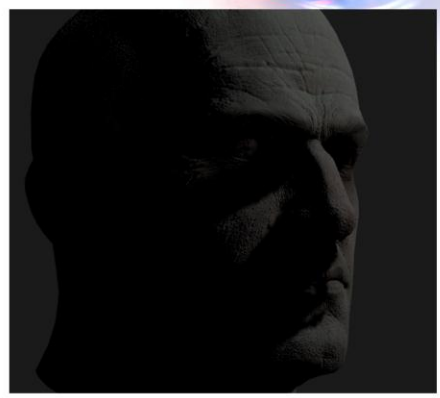
diffColor = **direct***float3(.233,.455,.649);
diffColor += **lm1***float3(.100,.336,.344);
diffColor += **lm2***float3(.118,.198,.0);
diffColor += **lm3***float3(.113,.007,.007);
diffColor += **lm4***float3(.358,.004,.0);
diffColor += **lm5***float3(.078,0,0);

Their approach uses essentially 6 layers of blur.

2) NVIDIA Approach

- Combine Blurs

```
diffColor = direct*float3(.233,.455,.649);
diffColor += Im1*float3(.100,.336,.344);
diffColor += Im2*float3(.118,.198,.0);
diffColor += Im3*float3(.113,.007,.007);
diffColor += Im4*float3(.358,.004,.0);
diffColor += Im5*float3(.078,0,0);
```



The first layer is essentially no blur. This simulates light that gets absorbed and immediately retransmitted.

2) NVIDIA Approach

- Combine Blurs

```
diffColor = direct*float3(.233,.455,.649);
diffColor += lm1*float3(.100,.336,.344);
diffColor += lm2*float3(.118,.198,.0);
diffColor += lm3*float3(.113,.007,.007);
diffColor += lm4*float3(.358,.004,.0);
diffColor += lm5*float3(.078,0,0);
```

The use weights for all 5 lightmaps to simulate the light that bounces inside the skin.

2) NVIDIA Approach

- Combine Blurs

diffColor = **direct***float3(.233,.455,.649);
diffColor += **lm1***float3(.100,.336,.344);
diffColor += **lm2***float3(.118,.198,.0);
diffColor += **lm3***float3(.113,.007,.007);
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diffColor += **lm5***float3(.078,0,0);

2) NVIDIA Approach

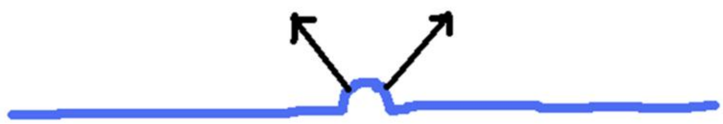
Lighting-Only

- Lambertian vs. NVIDIA

The left side is a standard dot(N,L) and the right is with the NVIDIA skin shading.

Why it works?

- Red bleeds
- Blue/Green not so much
- Towards Light: Cyan-ish
- Away From Light: Red-ish



Key point: The normals that point towards the light tend to look more cyan-ish and the normals that point away tend to be more red-ish.

Lighting-Only

- Lambertian vs. NVIDIA

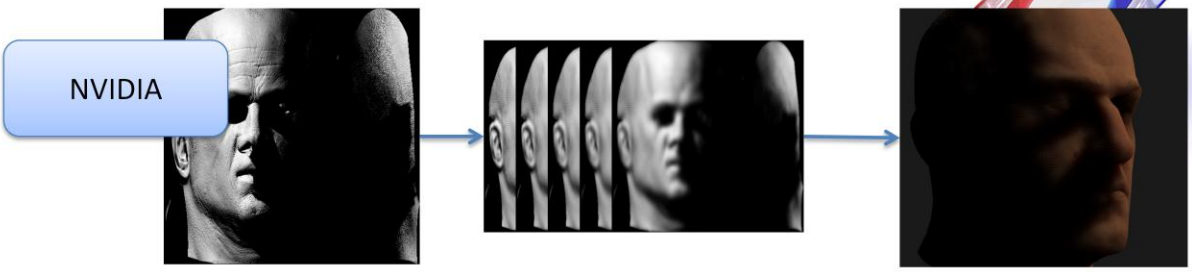
Comparison of pure dot(N,L) diffuse to the NVIDI SSS technique.

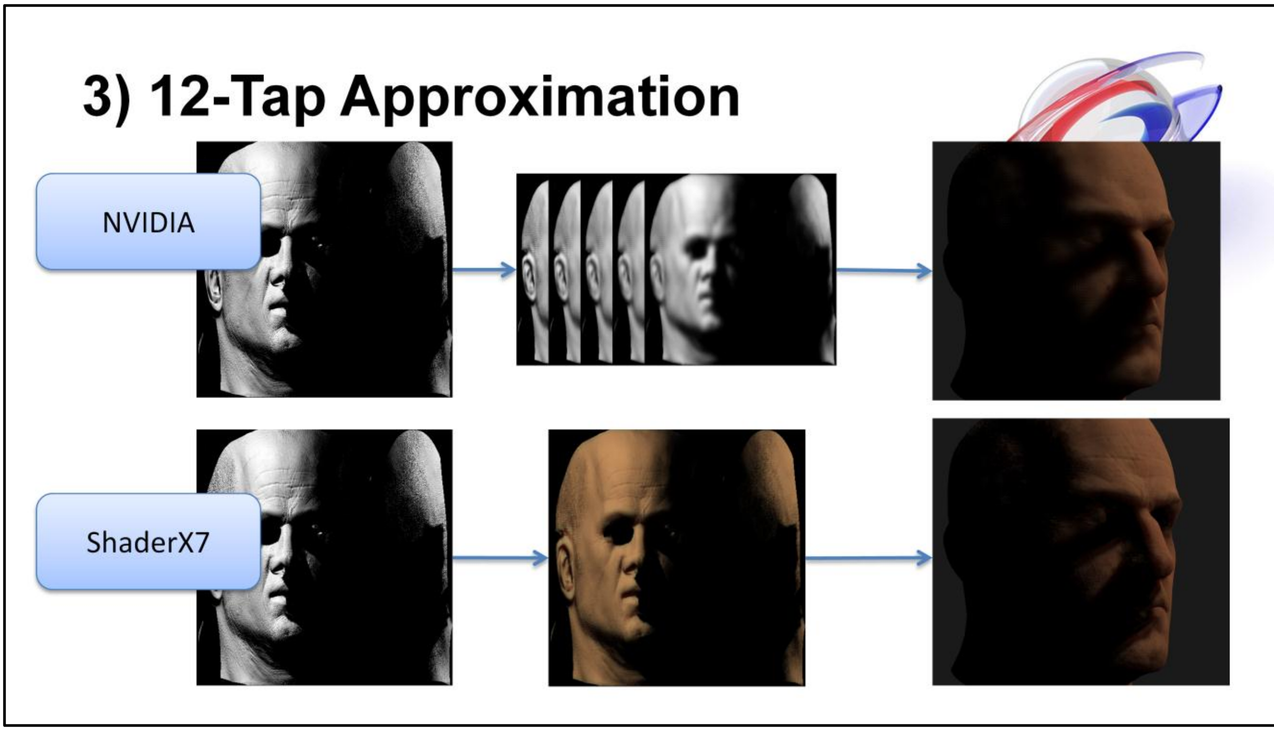
2) NVIDIA Approach

- Looks awesome
- Final blur is 100x100
- Exact calculation of blur with 10k samples
- Lots of passes
- Lots of blurs
- Lots of memory
- Cheaper way that looks close enough?

Their approach looks great, but is very expensive in both memory.

3) 12-Tap Approximation





Instead of using 5 gaussian blurs, we'll try to approximate that with a single 12-tap blur. It's not as good, but much, much cheaper.

3) 12-Tap Approximation

- From ShaderX7 (Hable, Borshukov, and Hejl)
- Do a single 12-tap blur

```
float3 blurJitteredWeights[13] =
{
        { 0.220441, 0.437000, 0.635000 },
        { 0.076356, 0.064487, 0.039097 },
        { 0.116515, 0.103222, 0.064912 },
        { 0.064844, 0.086388, 0.062272 },
        { 0.131798, 0.151695, 0.103676 },
        { 0.025690, 0.042728, 0.033003 },
        { 0.048593, 0.064740, 0.046131 },
        { 0.048092, 0.003042, 0.000400 },
        { 0.048845, 0.005406, 0.001222 },
        { 0.051322, 0.006034, 0.001420 },
        { 0.061428, 0.009152, 0.002511 },
        { 0.030936, 0.002868, 0.000652 },
        { 0.073580, 0.023239, 0.009703 },
};
```

```
float2 blurJitteredSamples[13] =
{
        { 0.000000, 0.000000 },
        { 1.633992, 0.036795 },
        { 0.177801, 1.717593 },
        { -0.194906, 0.091094 },
        { -0.239737, -0.220217 },
        { -0.003530, -0.118219 },
        { 1.320107, -0.181542 },
        { 5.970690, 0.253378 },
        { -1.089250, 4.958349 },
        { -4.015465, 4.156699 },
        { -4.063099, -4.110150 },
        { -0.638605, -6.297663 },
        { 2.542348, -3.245901 },
};
```

Check the ShaderX7 chapter for more detail.

3) 12-Tap Approximation

```
float3 blurJitteredWeights[13] =
{
        { 0.220441, 0.437000, 0.635000 },
        { 0.076356, 0.064487, 0.039097 },
        { 0.116515, 0.103222, 0.064912 },
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}
```

3) 12-Tap Approximation

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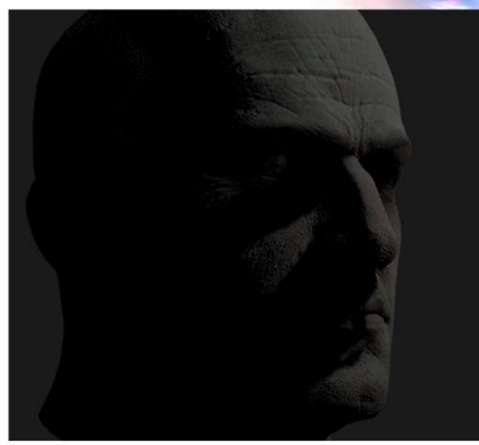
        { 0.061428, 0.009152, 0.002511 },
        { 0.030936, 0.002868, 0.000652 },
        { 0.073580, 0.023239, 0.009703 },
}
```



3) 12-Tap Approximation

```
float3 blurJitteredWeights[13] =
{
        { 0.220441, 0.437000, 0.635000 },
        { 0.076356, 0.064487, 0.039097 },
        { 0.116515, 0.103222, 0.064912 },
        { 0.064844, 0.086388, 0.062272 },
        { 0.131798, 0.151695, 0.103676 },
        { 0.025690, 0.042728, 0.033003 },
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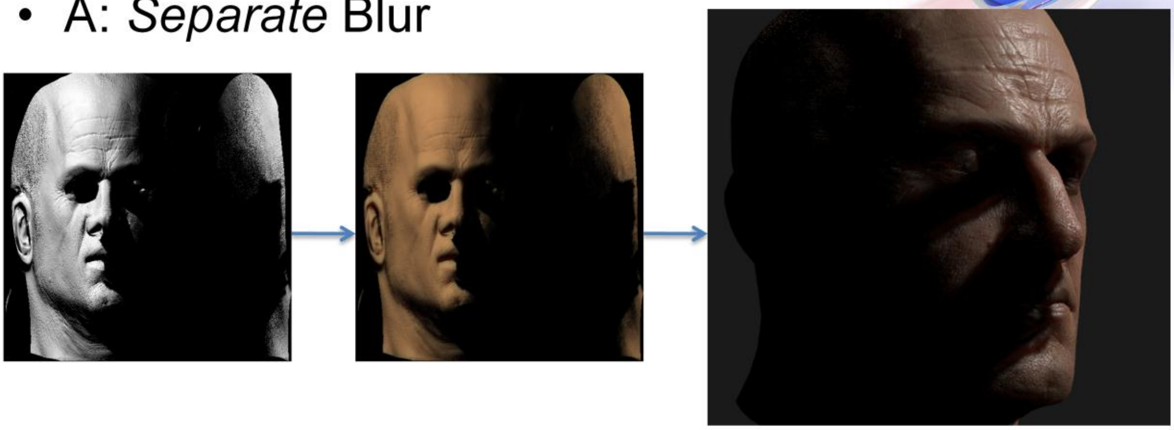
        { 0.048092, 0.003042, 0.000400 },
        { 0.048845, 0.005406, 0.001222 },
        { 0.051322, 0.006034, 0.001420 },
        { 0.061428, 0.009152, 0.002511 },
        { 0.030936, 0.002868, 0.000652 },
        { 0.073580, 0.023239, 0.009703 },
}
```

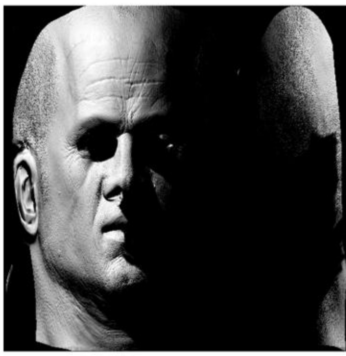
3) 12-Tap Approach

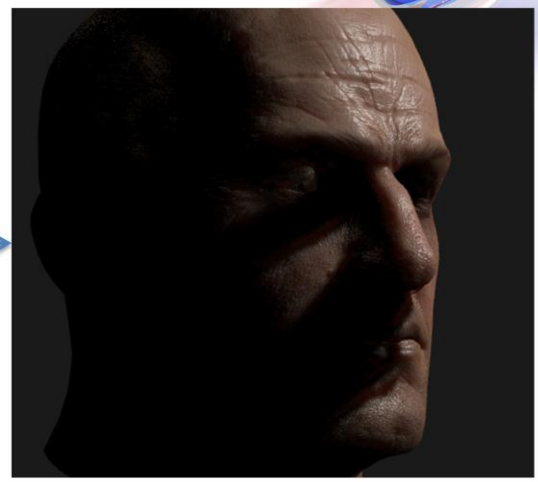
- A: *Separate* Blur



3) 12-Tap Approach

- B: *Combined* Blur





3) 12-Tap Approximation

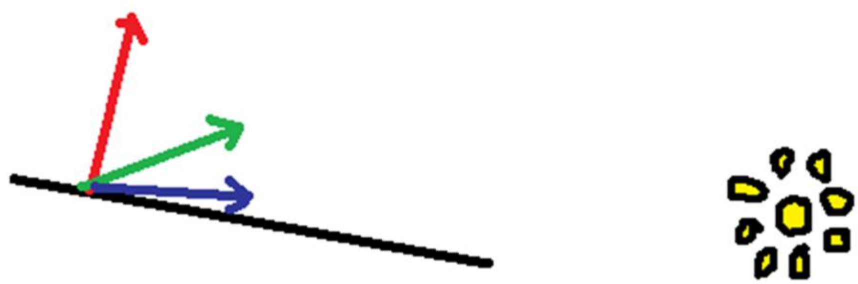
- *Separate* Blur
  - Render to Lightmap
  - Blur Lightmap with 12 taps
  - Render Final Scene
- *Combined* Blur
  - Render to Lightmap
  - Render Final Scene, with 12 taps from lightmap
- Both are fine

12-Tap Separate

12-Tap Combined

4) Bent Normals (?)

- Pretend R/G/B come from different Normals
- R closer to Geometry, GB closer to Normal Map
- Diffuse Calculation 3 Times



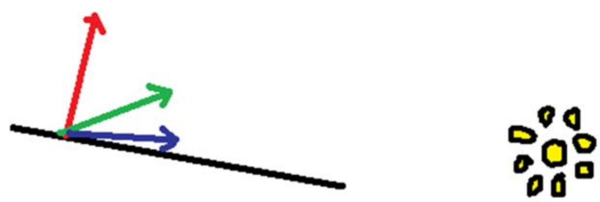
4) Bent Normals

4) Bent Normals

Notice how using different normals for R/G/B seems to cause some blue spottiness.

Why so blue?

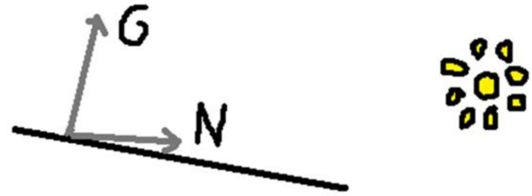
- Dot Products
- At extreme angles, you can have cases where diffuseR = 0 and diffuseB = 1
  - Or vice-versa



That’s because you have cases where the blue diffuse is near 1 and the red diffuse is near 0.

5) Blended Normals (?)

- Another Hack
- Diffuse(L,G), Diffuse(L,N), and Lerp
- Blue/Green stays put, Red bleeds
- Can have Red but no Blue/Green
- Can **NOT** have Blue/Green but no Red



Another approach is to do a diffuse calculation for the Geometry and Normal Mapped normals, and lerp between them taking more red from the Geometry normal and more Green/Blue from the normal mapped normal.

5) Blended Normals

Still Kinda Blue

Recap

1. Standard Diffuse
2. Nvidia Approach
3. 12-Tap Combined
   - Do 12-Tap blur as separate shader.

3a. 12-Tap Merged
   - Do 12-Tap blur in final render pass.

4. Bent Normals
5. Blended Normals

1) Straight Diffuse

2) NVIDIA Approach

3a) 12-Tap Separate

3b) 12-Tap Combined

4) Bent Normals

5) Blended Normals

1) Standard Diffuse

2) NVIDIA Approach

3a) 12-Tap Separate

3b) 12-Tap Combined

4) Bent Normals

5) Blended Normals

What did we do?

- Cutscenes:
  - 3b) 12-Tap Combined
- In Game
  - 5) Blended Normals
  - 12-Tap Combined cost .4ms per head
  - Difference didn't balance the cost

Cutscenes

Cutscenes

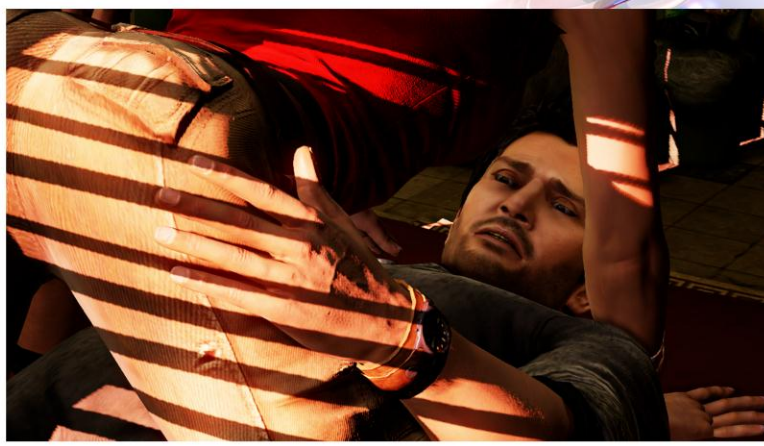
Sometimes, in cutscenes, the shots get pretty close, so we need the quality.

Normal Gameplay

You spend most of normal gameplay staring at the back of Drake's neck, so a separate pass for SSS was not worth the cost.

Limitations

- Resolution
- Seams



Conclusion

- SSS really helps
- Do what makes sense for you
- Do better than Blinn-Phong

Hair

Hair

Hair

- Stolen from Thorsten Sheuermann
  - http://developer.amd.com/media/gpu_assets/Scheuermann_HairSketchSlides.pdf
- Kajiya-Kay

Specular Off

Combined

Notes

- Slight Wraparound Diffuse
- Kajiya-Kay Specular
- No self-shadowing
  - Looks into largest cascade w/extra bias
- Diffuse Map as Specular Mask
  - Partially Desaturated
- Deferred lights use Blinn-Phong

Conclusions

- Anisotropic
- Do better than Blinn-Phong

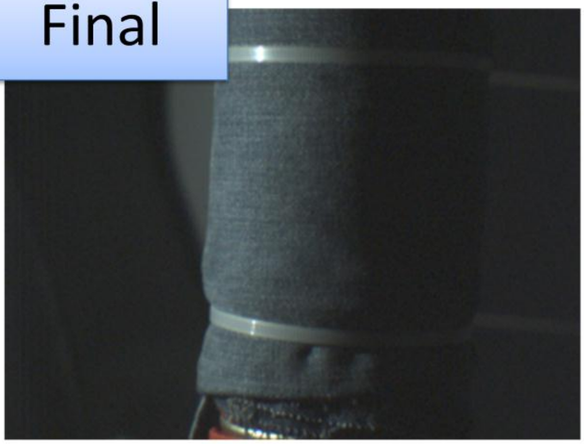
Cloth

Cloth

Diffuse-Only, Right?

Separated

Final

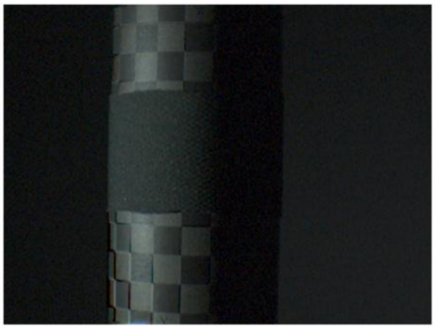


Diffuse

Specular

Specular

- Fresnel?



Cloth

- "Examples of completely diffuse materials include Cloth and Cardboard"
  - Nope!
  - Sidenote: Cardboard is actually really shiny
- Cloth has some Fresnel too

U2 Cloth

- Rim Lobe, Inner Lobe, Remaining Diffuse

U2 Cloth

- Final

OurCloth()

```
{
    VdotN = saturate( dot( V, N ) );
    Rim = RimScale * pow( VdotN, RimExp );
    Inner = InnerScale * pow( 1-VdotN, InnerExp );
    Lambert = LambertScale;

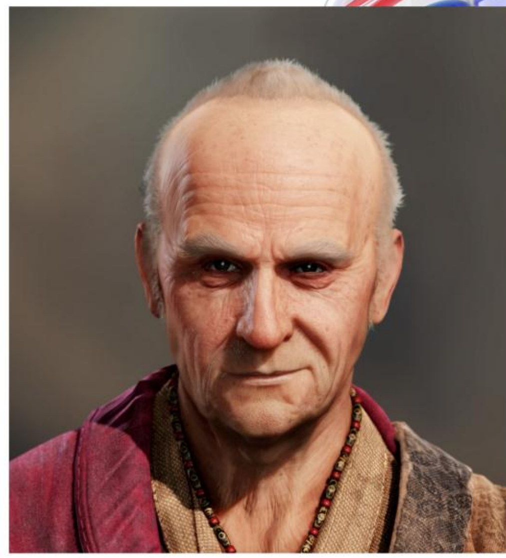
    ClothMultiplier = Rim + Inner + Lambert;
    FinalDiffuseLight *= ClothMultiplier;
}
```

Cloth

- Not based on light direction
- Looks better than nothing
- Hanno: “Doesn’t look that great, but it’s hard to screw up.”

Conclusions

- Do something, anything



5 Secrets

Secret #1

- Avoid the hacks as long as possible

The left shot is one of the first released screenshots before a lot of the tech got in. The one on the right is what we shipped. The one on the left has lots of hacks that we eventually took out, such as that orange glow around Drake’s skin.

Hacks Don't Work!

- Hacks look great in still images.
- Don't work when you move the light/camera.
- Photoshop tricks only work in stills

Secret #2

- Avoid Wraparound Lighting Models
- A few exceptions (I.e. Hair)
- diff=.5+.5*dot(N,L)
  - As opposed to: diff=saturate(dot(N,L))
- VFX/Photography: Ignore this point

Secret #2

- Lambert.
- Looks too crunchy.

Secret #2

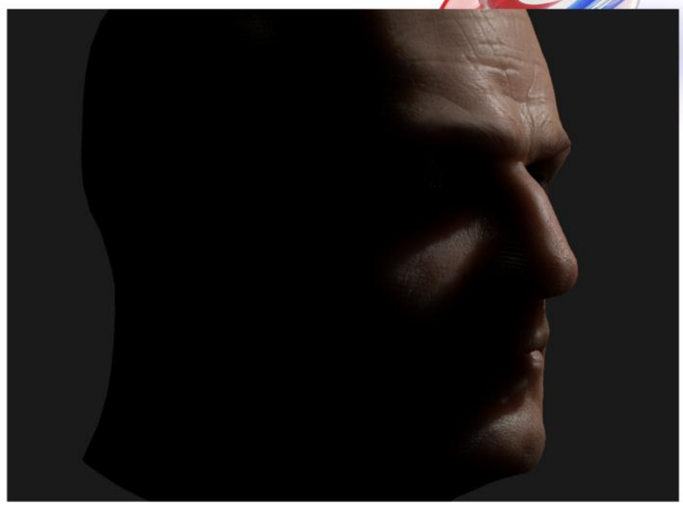
- Wraparound
- Do you want your key light to look like this?
- Looks ok for ambient.

Secret #2

- You want this.

Secret #2

- With SSS
- Looks fine.
- Disclaimer for Film / Photography



Harsh Falloff

- Harsh Falloff is your friend
  - If you use it right
- Don’t wrap light to make skin softer
- Instead change your shading model
- Doesn’t apply to VFX and Photography

NVIDIA Demo

Notice that the NVIDIA demo has a harsh falloff. It looks great if you do everything else right, which is why that demo is the gold standard for skin in realtime.

Secret #3

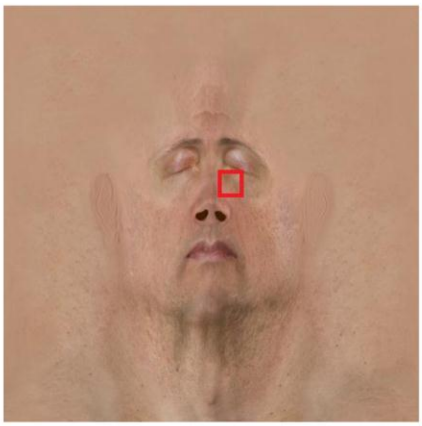
- Avoid Blurry Maps on Faces
- Have detail in Diffuse Map
- Have crazy detail in Normal Map
- It should look terrible in Maya

NVIDIA Demo

Since he looks fleshy, you would think that he has blurry maps.

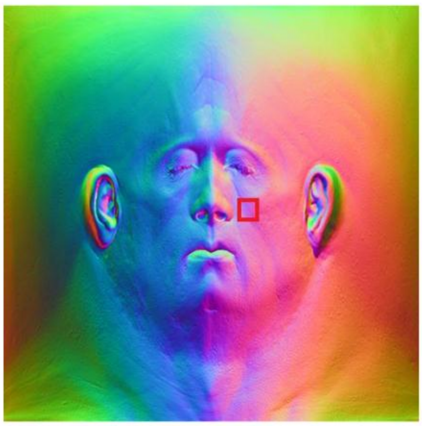
NVIDIA Human Head Maps

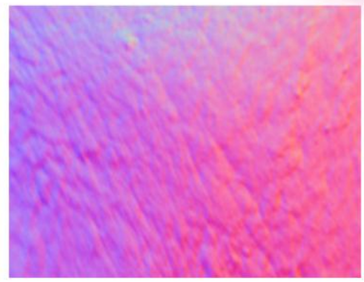
- Diffuse Maps



NVIDIA Human Head Maps

- Normal Maps (world space?)





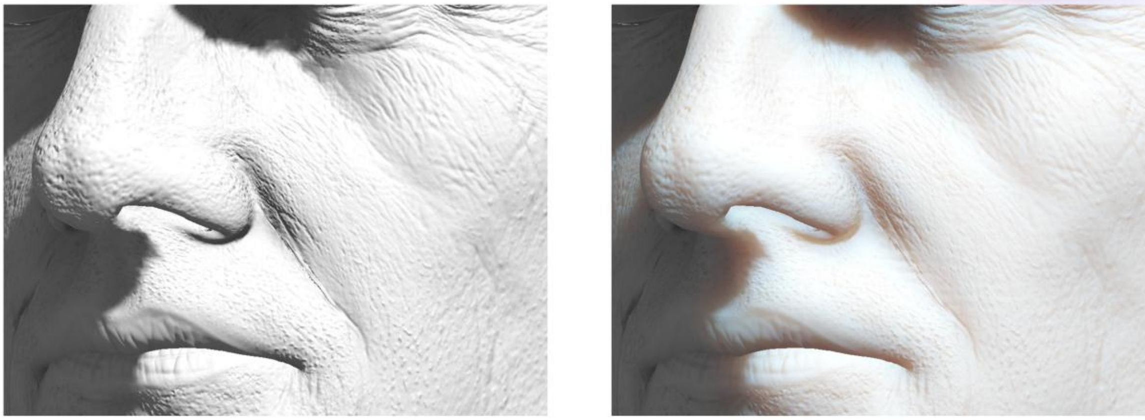
NVIDIA Human Head Maps

- Don’t paint soft maps
- Paint very crunchy detailed maps
- Let lighting model soften it

In the demo, they have extremely detailed maps and they use the lighting model to soften it.

Heads

- Softening via lighting model.



IMO what makes skin look right is how light bleeds around the normals. If you paint soft maps with no detail in the normals, it just looks flat.

Maps

- Crank the detail!

Notice that there is more detail in the shot on the right. For U2, we really cranked the detail in the maps and the strength of the normals and then let the lighting model soften it.

Secret #4

- Don’t bake too much lighting into diffuse maps
- Especially AO
- Becomes Unlightable

Drake’s Shirt

- Looks fine in Sunlight
- Very boring in Shadows

Drake’s Shirt

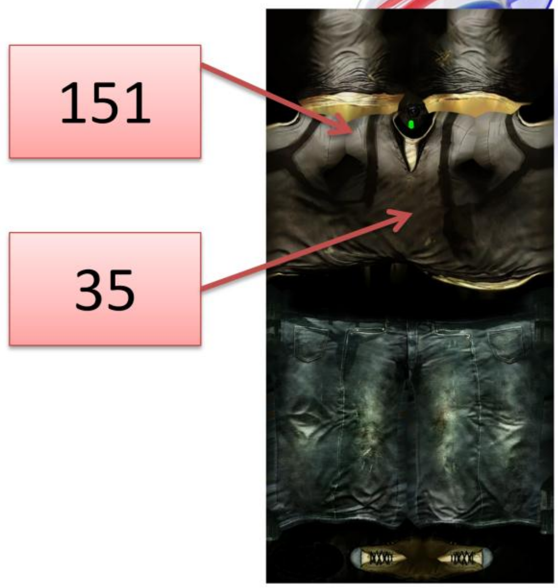
- Create Light Rig
- Ambient Light

AO into Diffuse

- Apply to Diffuse
- Better Ambient
- The Catch?

The Unlightables

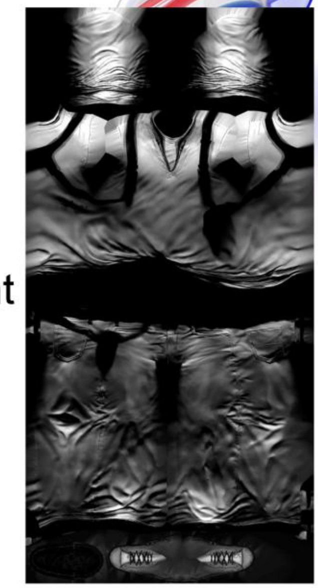
- (151/255)^2.2=0.315
- (35/255)^2.2=0.0126
- 25x!!!
- Full histogram in ambient



Don’t bake too much AO into your diffuse maps.

Solution

- Leave AO map separate
- Can be lower-res
- direct=diffuseMap*diffuseLight
- ambient=diffuseMap*aoMap*ambientLight
- diffuseColor=direct+ambient



The Unlightables

- Contrast between Sun and Shadow
- Doesn't happen if your diffuse maps have too much black
- Tech isn't enough for HDR Lighting
- HDR vs. Flat and Contrasty

You get HDR lighting from having high dynamic range in your ***LIGHTING***. I see a lot of games that have all the tech for HDR lighting, but it still looks flat. The reason 99% of the time is that they have too much black in their textures. For an example of a game doing a really good job of managing their textures, check out Mirror's Edge.

Secret #5

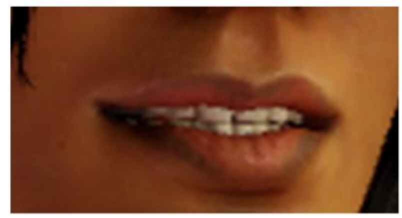
- Make sure your AO and Diffuse match
- We screwed this up
- Don't play telephone

Chloe-Intro

- White Direct
- Yellow-ish Ambient

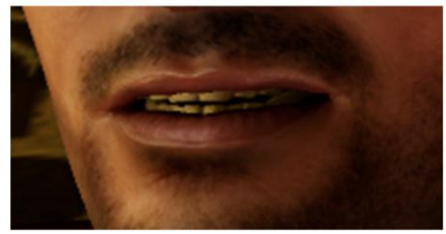
Chloe

- Direct Too High (White)
- Ambient Too Low (Yellow)



Drake

- Direct Too Low (White)
- Ambient Too High (Yellow)



Where's his tongue?

Go through the cutscenes again and look for Drake's tongue. You'll see what I mean.

Conclusions

- Custom Shading Models
- If you tried these things in the past
  - Take a second look if your lighting has improved
- Linear-Space Lighting

I’m a big fan of custom lighting models (i.e. beyond Blinn-Phong). Btw, doing proper Linear-Space Lighting is more important than everything in this presentation combined.

References

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  - http://www.shaderwrangler.com/publications/
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  - http://http.developer.nvidia.com/GPUGems3/gpugems3_ch14.html
- Fast Skin Shading, John Hable, George Borshukov, and Jim Hejl, ShaderX7, 2008
  - http://www.shaderx7.com/TOC.html

Done!