

Uncharted 2: HDR Lighting

John Hable
Naughty Dog



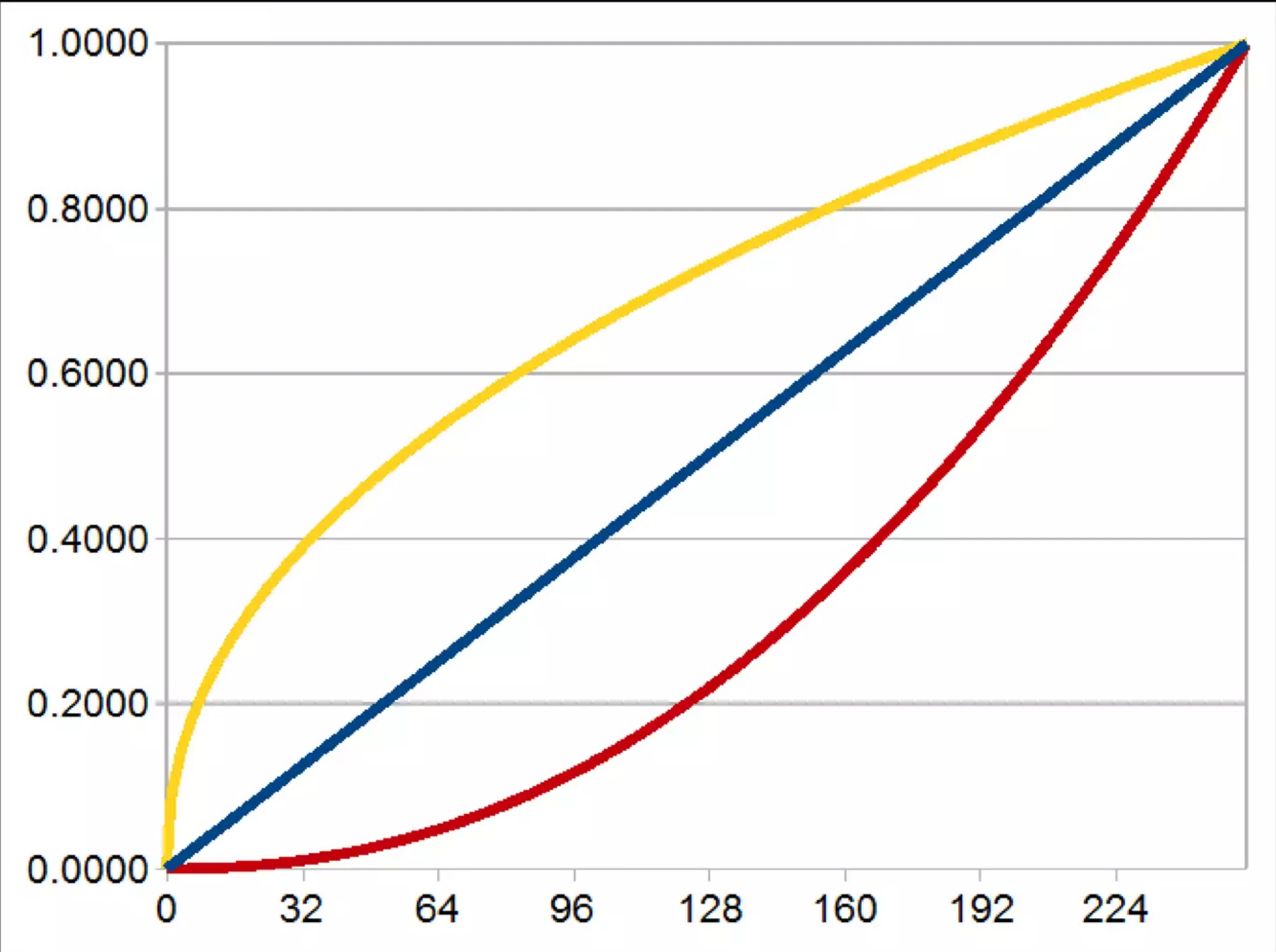
Agenda

1. Gamma/Linear-Space Lighting
2. Filmic Tonemapping
3. SSAO
4. Rendering Architecture/How it all fits together.

Skeletons in the Closet

- Used to work for EA Black Box (Vancouver)
 - Ucap Project
 - I.e. Tiger Woods's Face
- Also used to work for EA Los Angeles
 - LMNO (Spielberg Project)
 - Not PQRS (Boom Blox)
- Now at Naughty Dog
 - Uncharted 2

Part 1: Gamma!

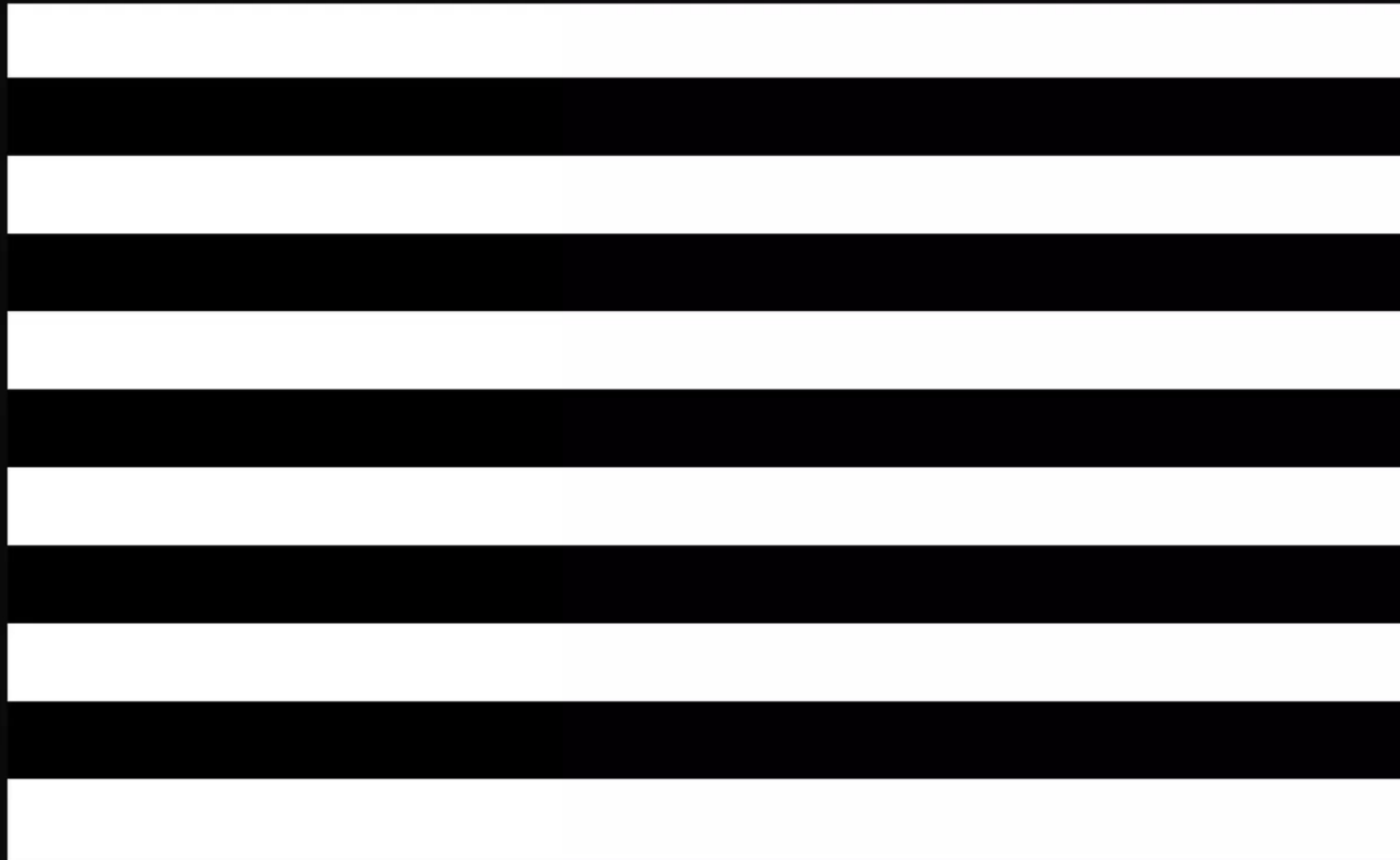


Gamma

- Mostly solved in Film Industry after lots of kicking and screaming
- Never heard about it in college
- George Borshukov taught it to me back at EA
 - Matrix Sequels
- Issue is getting more traction now
 - Eugene d'Eon's chapter in GPU Gems 3

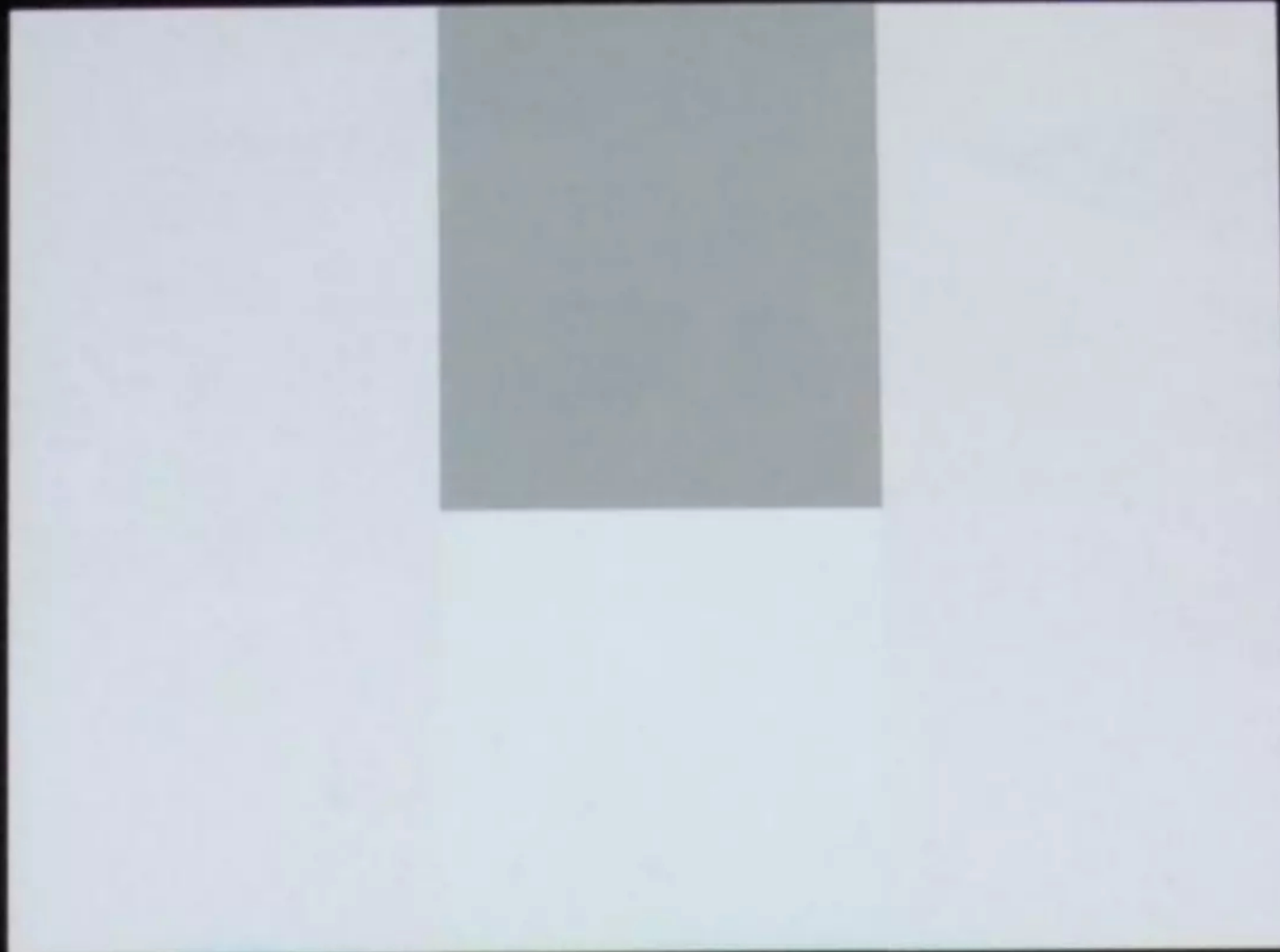
Demo

- What is halfway between white and black
- Suppose we show alternating light/dark lines.
- If we squint, we get half the linear intensity.



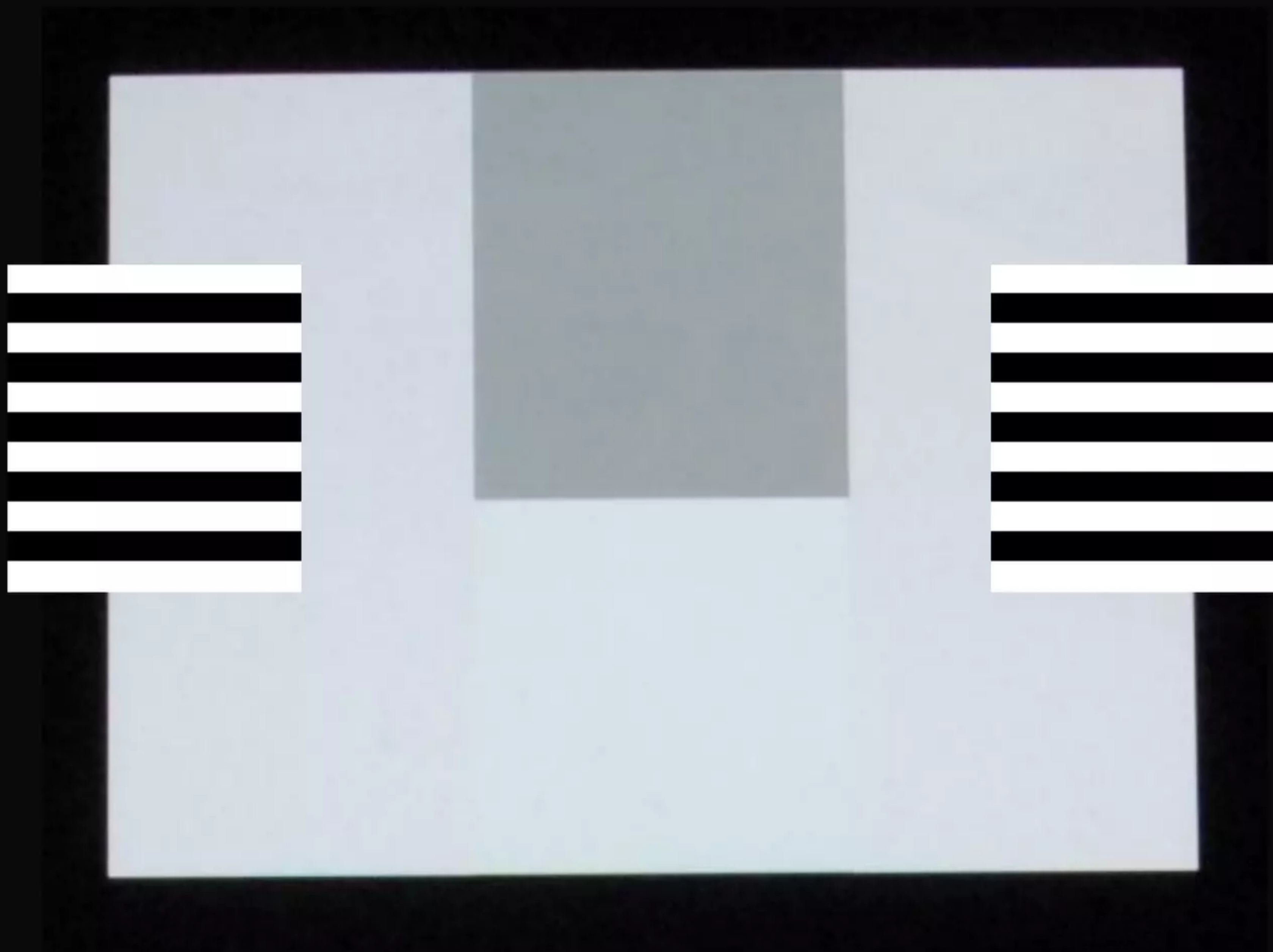
Demo

- Test image with 4 rectangles.
- Real image of a computer screen shot from my camera.



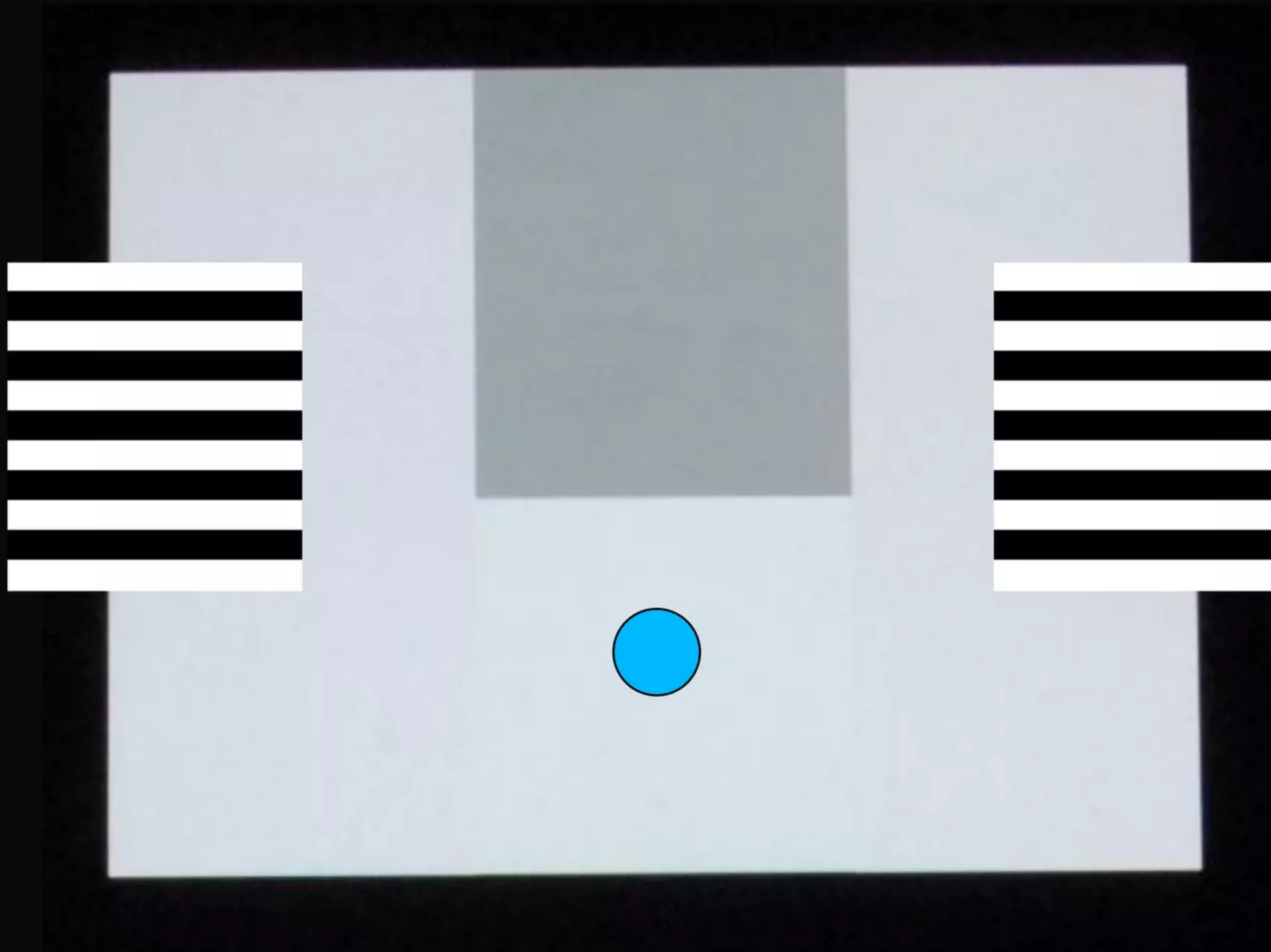
Demo

- Alternating lines of black and white (0 and 255).



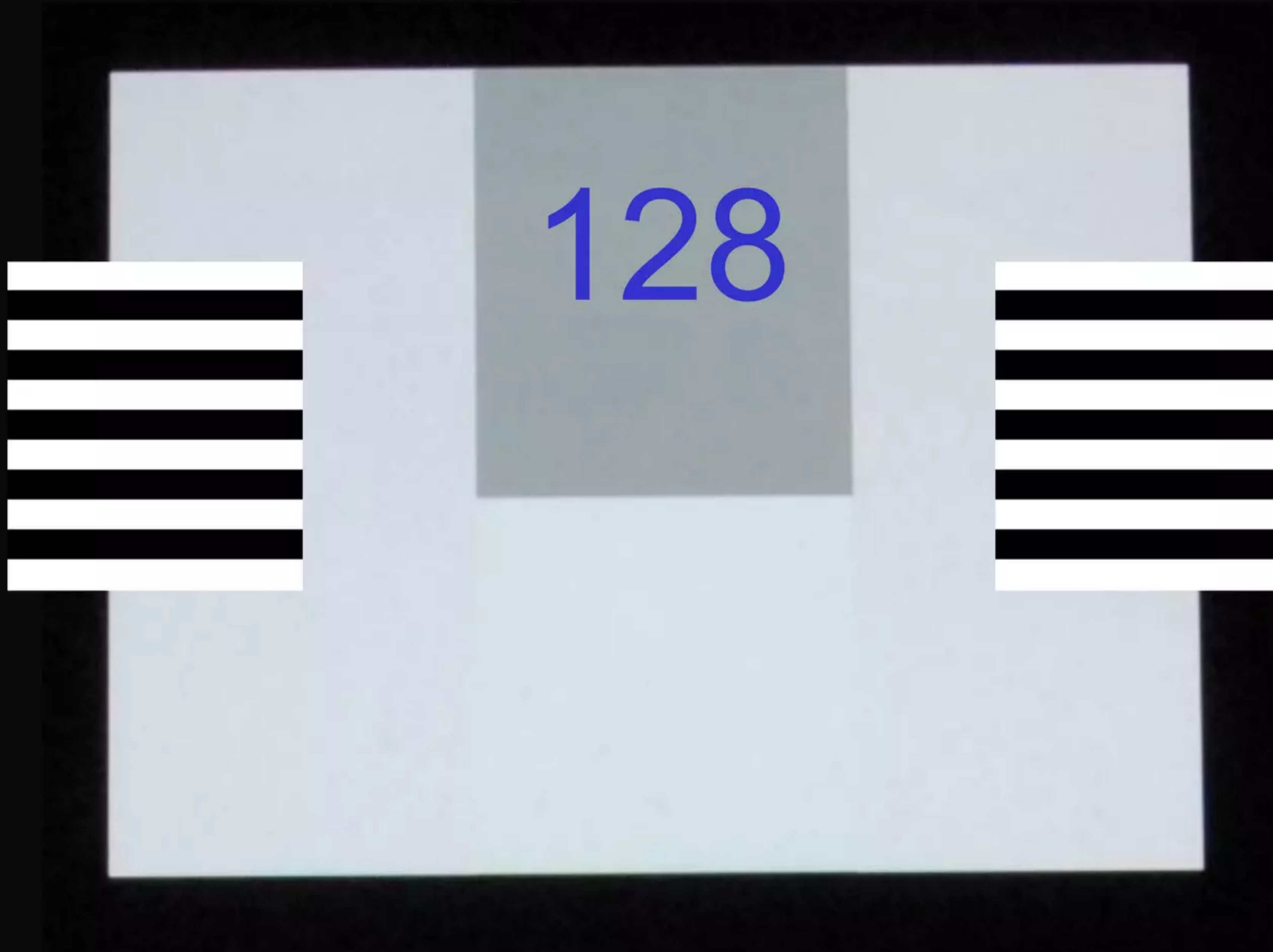
Demo

- So if the left and right are alternating lines of 0 and 255, then what color is the rectangle with the blue dot?



Demo

- Common wrong answer: 127/128.
- That's the box on the top.



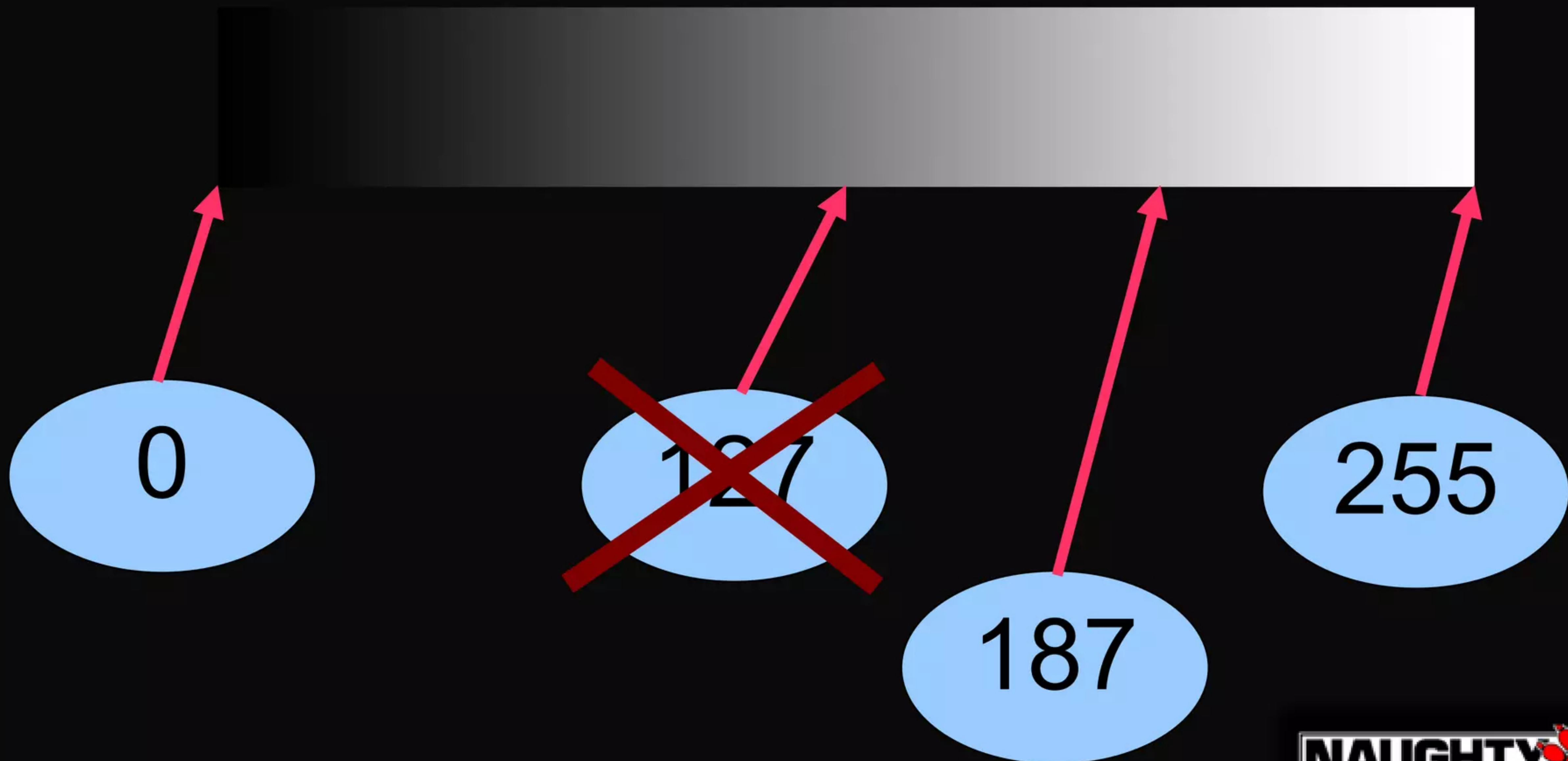
Demo

- Correct answer is 187.
- WTF?



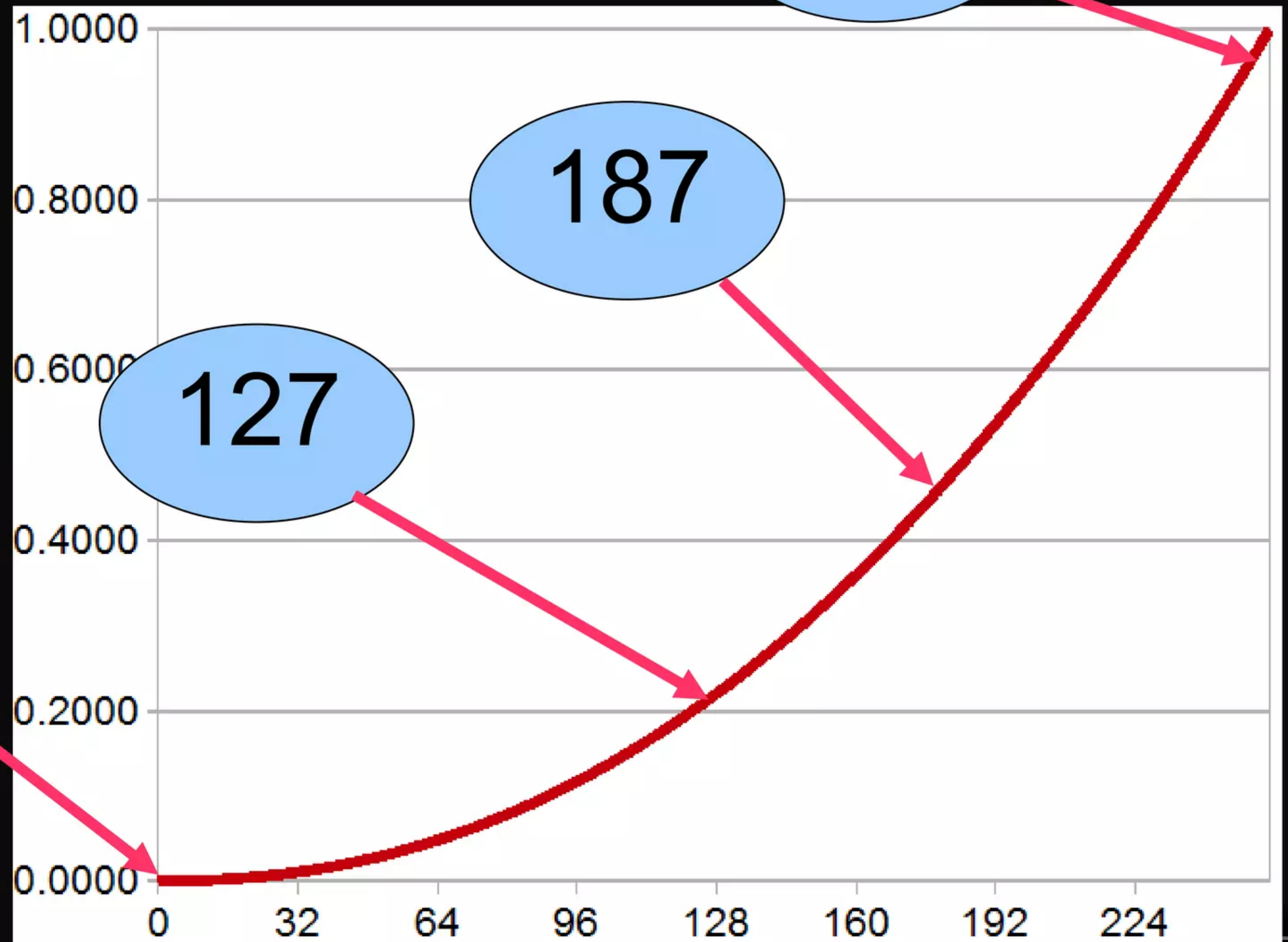
Color Ramp

- You have seen this before.



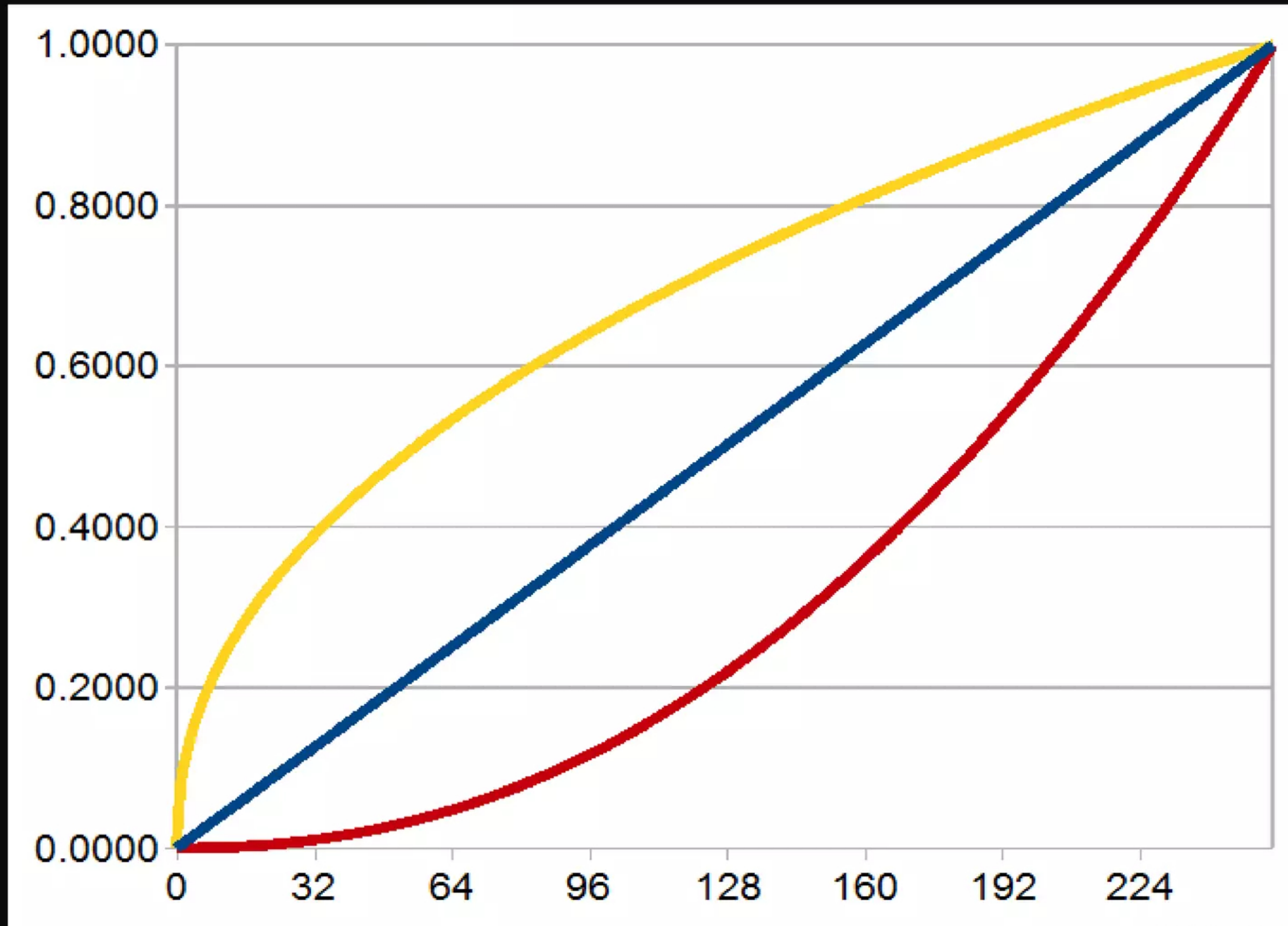
Gamma Lines

- $F(x) = \text{pow}(x, 2.2)$



What is Gamma

- Gamma of 0.45, 1, 2.2
- Our monitors are the red one



We all love mink...

- $F(x) = x$



We all love mink...

- $F(x) = \text{pow}(x, 0.45)$ note: $.45 \approx 1/2.2$



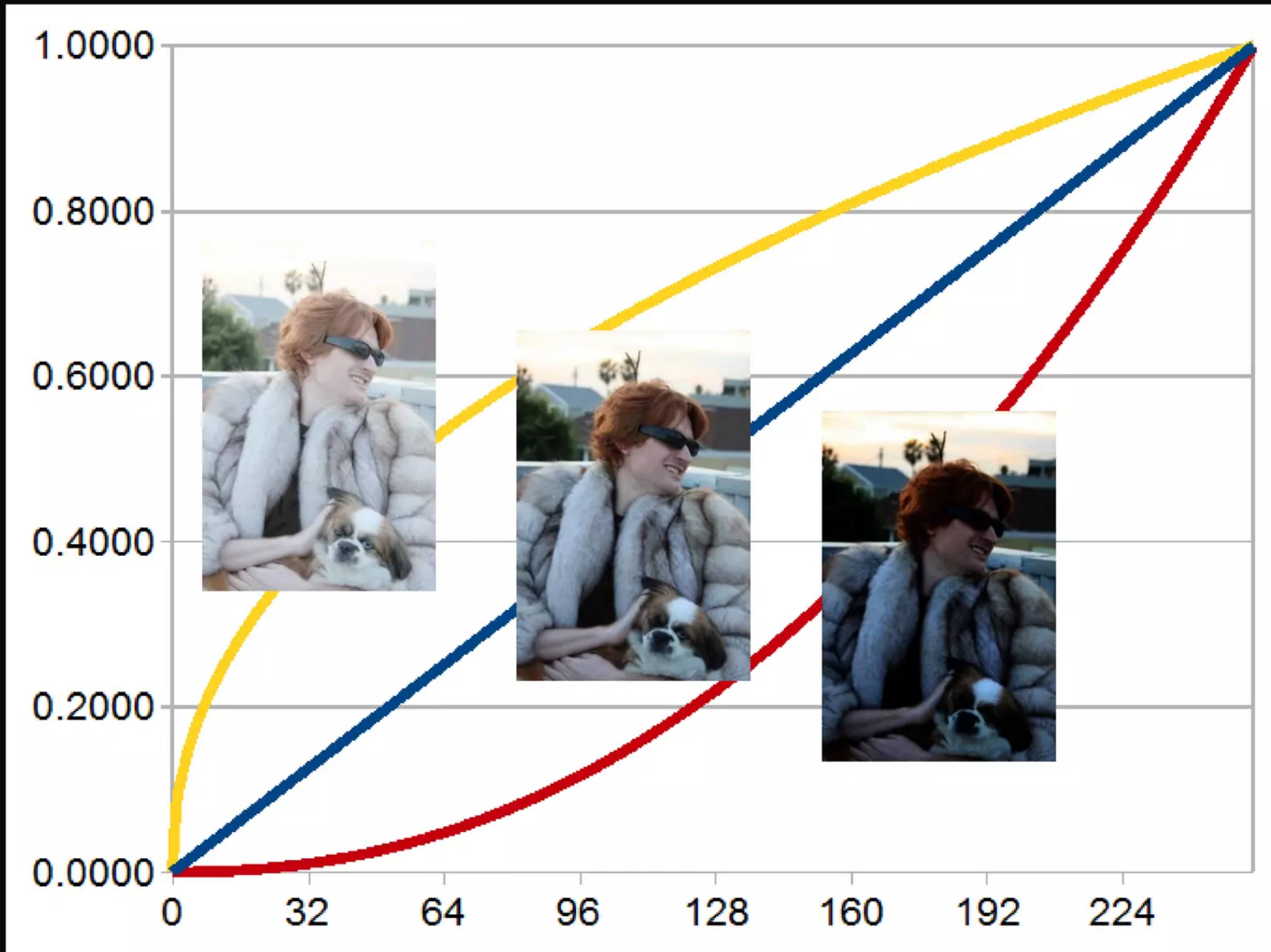
We all love mink...

- $F(x) = \text{pow}(x, 2.2)$



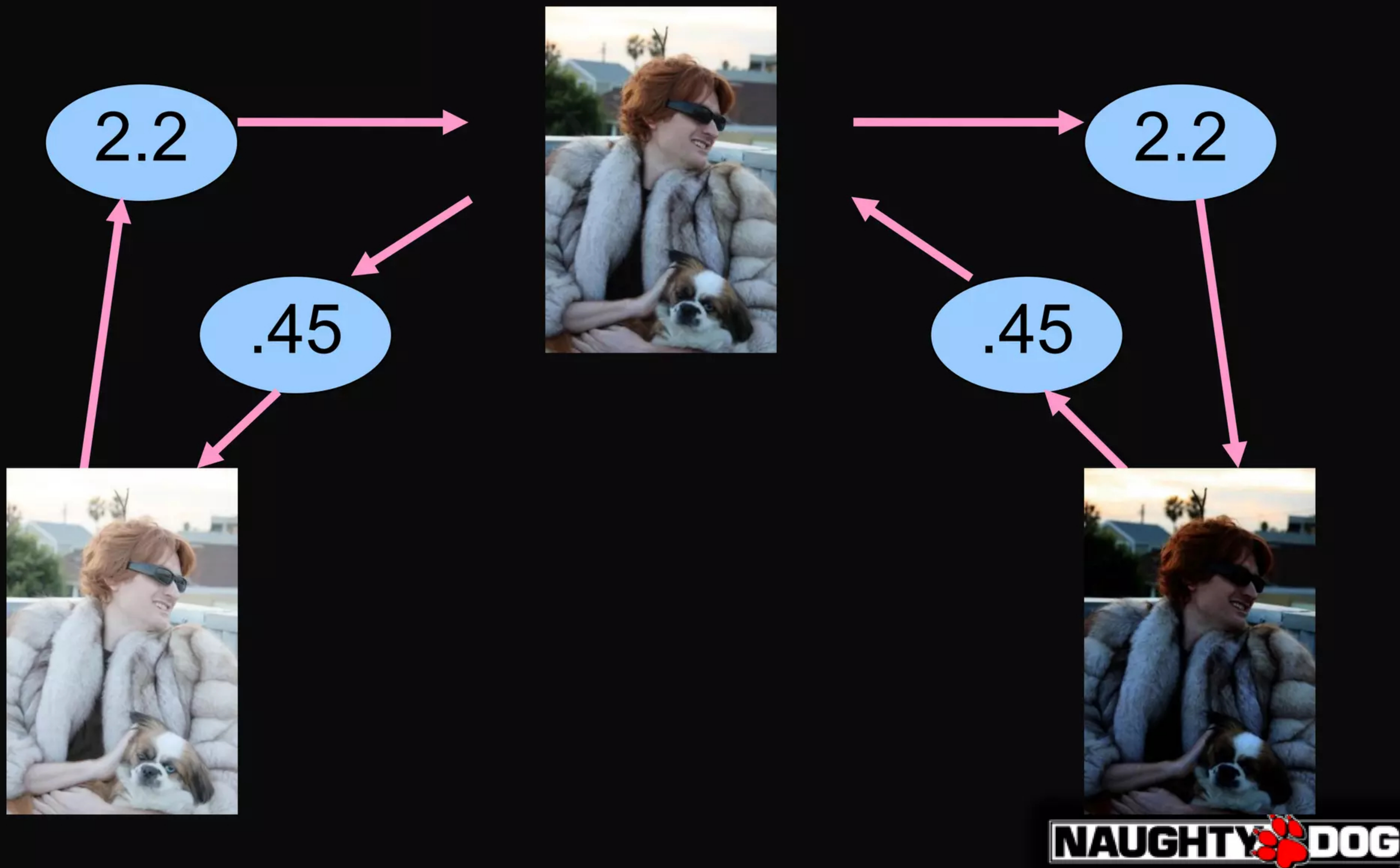
What is Gamma

- Get to know these curves...



What is Gamma

- Back and forth between curves.



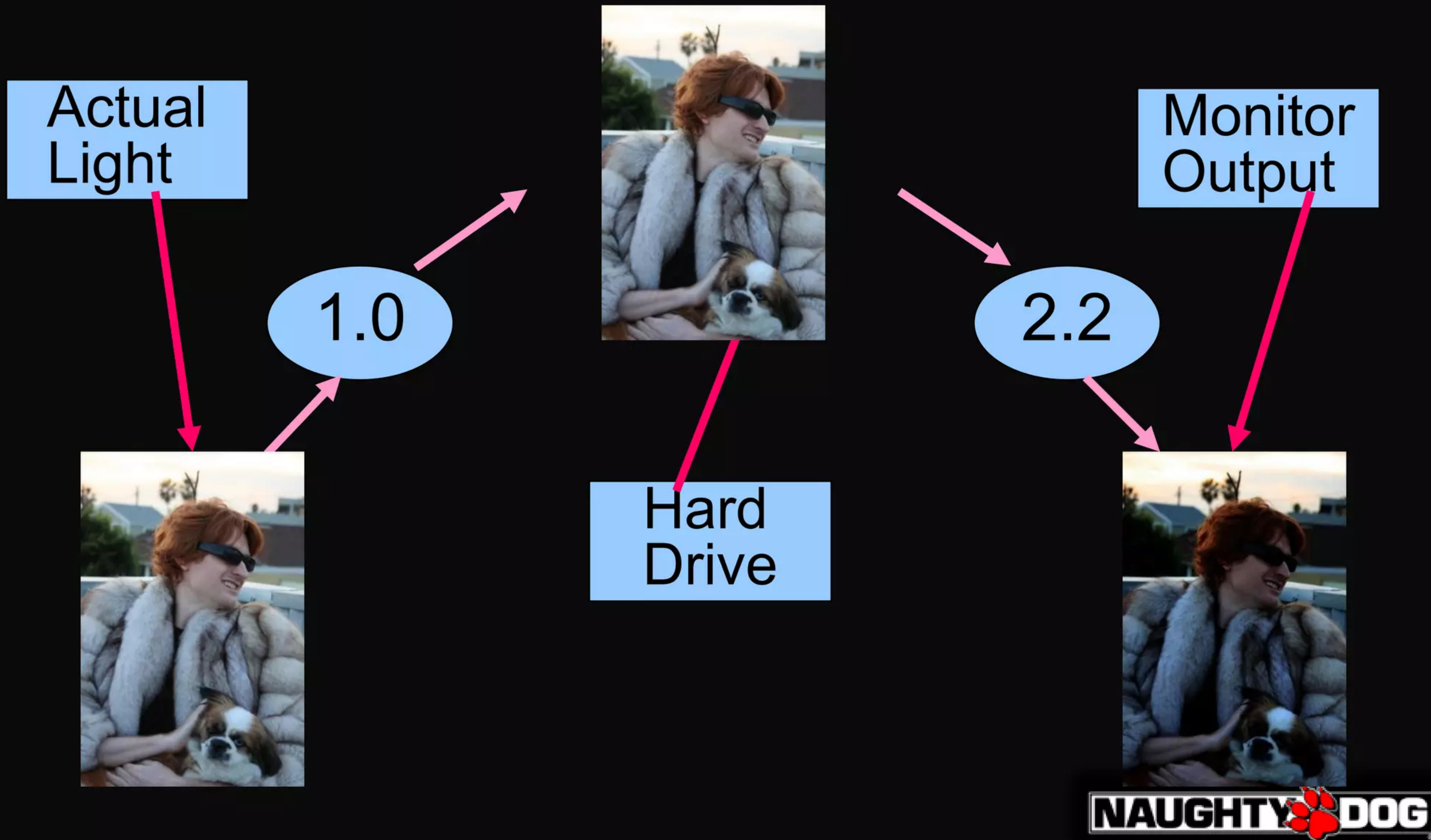
How bad is it?

- Your monitor has a gamma of about 2.2
- So if you output the left image to the framebuffer, it will actually look like the one right.



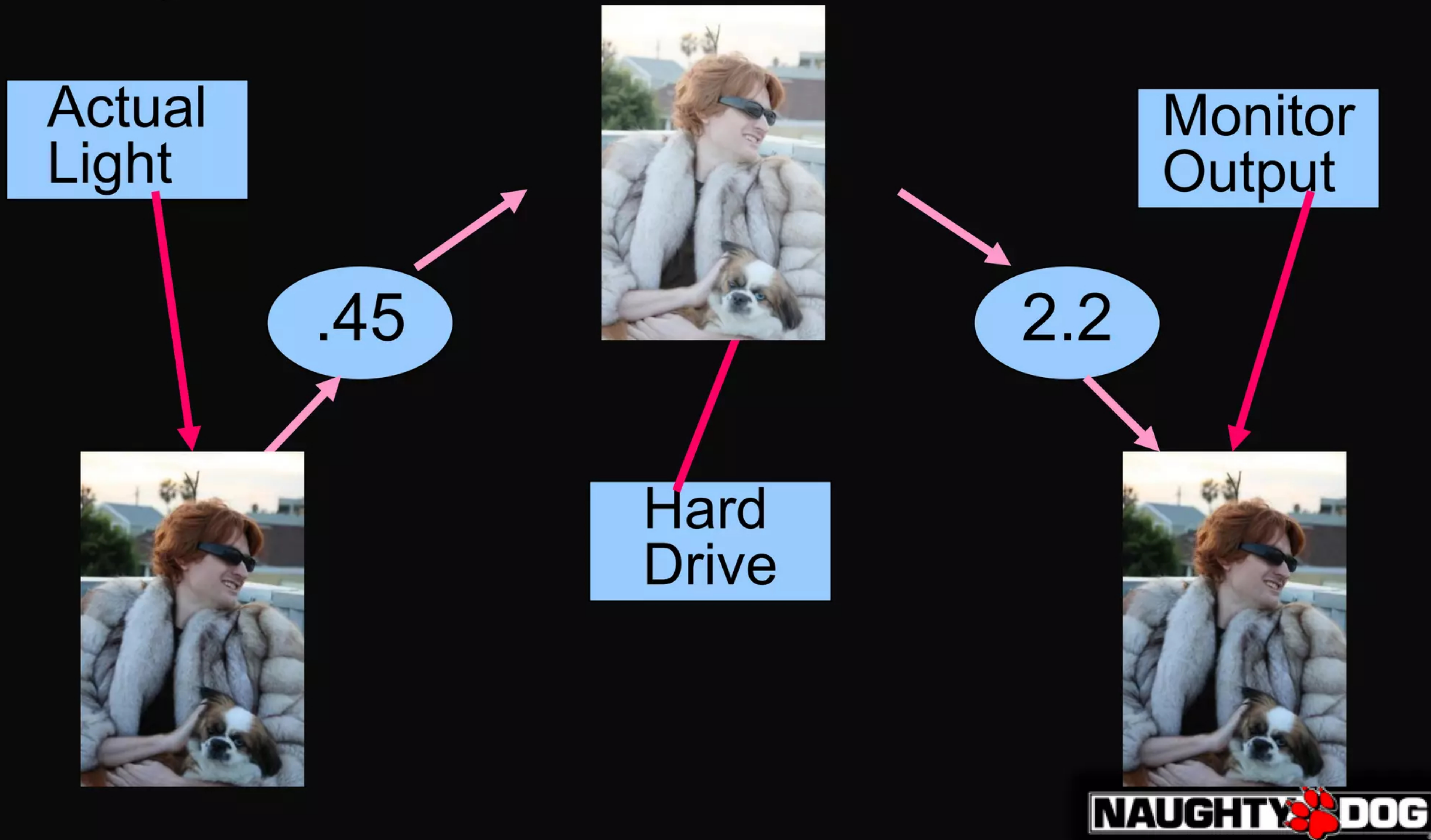
Let's build a Camera...

- A linear camera.



Let's build a Camera...

- Any consumer camera.



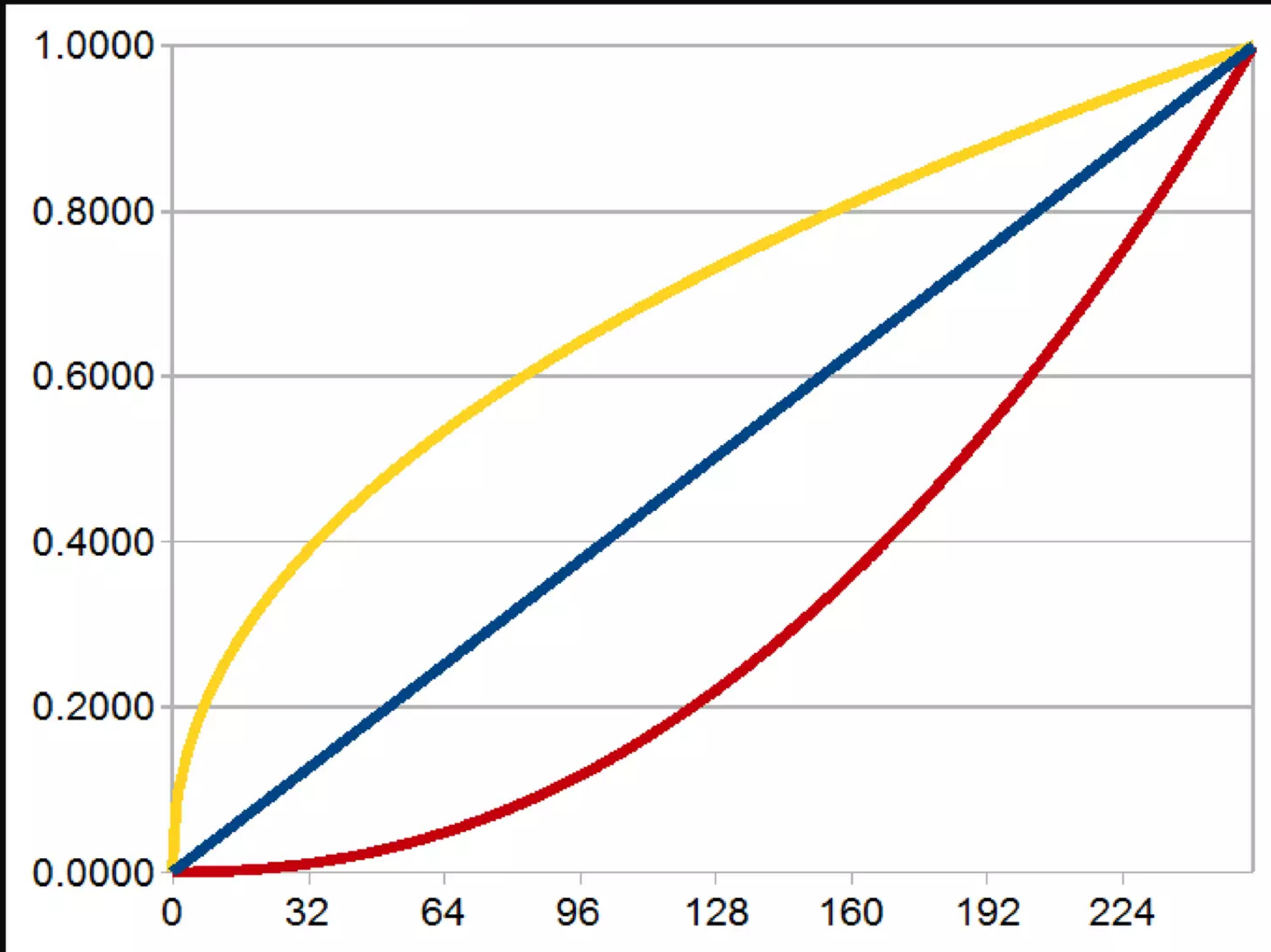
How to fix this?

- Your screen displays a gamma of 2.2
- This is stored on your hard drive.
 - You never see this image, but it's on your hard drive.



What is Gamma

- Curves again.



What is Gamma

Q) Why not just store as linear?

A) Our eyes perceive more data in the blacks.



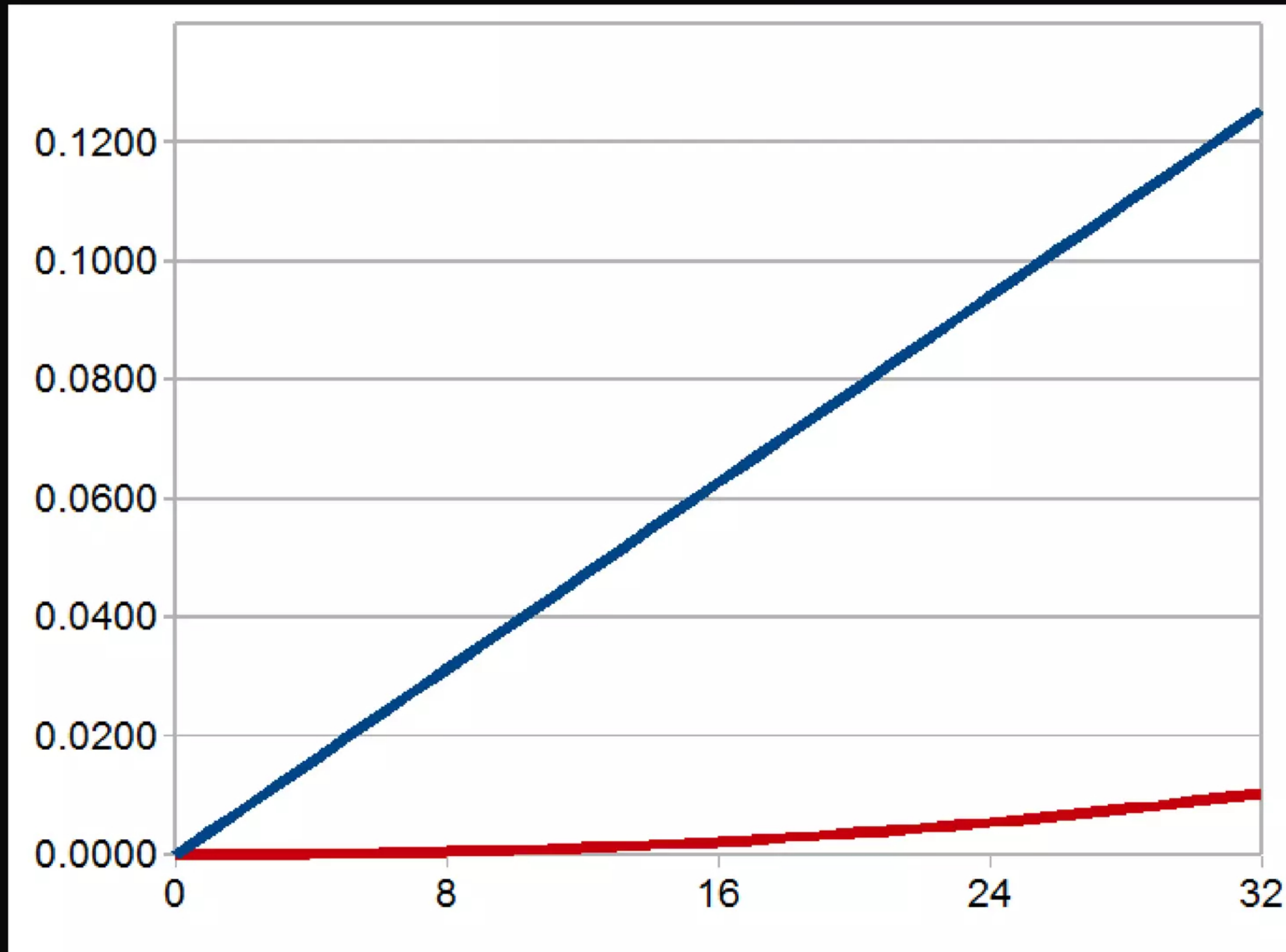
How bad is it?

- Suppose we look at the 0-63 range.
- What if displays were linear?



Gamma

- Gamma of 2.2 gives us more dark colors.



How bad is it?

- If displays were linear:
 - On a scale from 0-255
 - 0 would equal 0
 - 1 would equal our current value of 20
 - 2 would equal our current value of 28
 - 3 would equal our current value of 33
- Darkest Values:



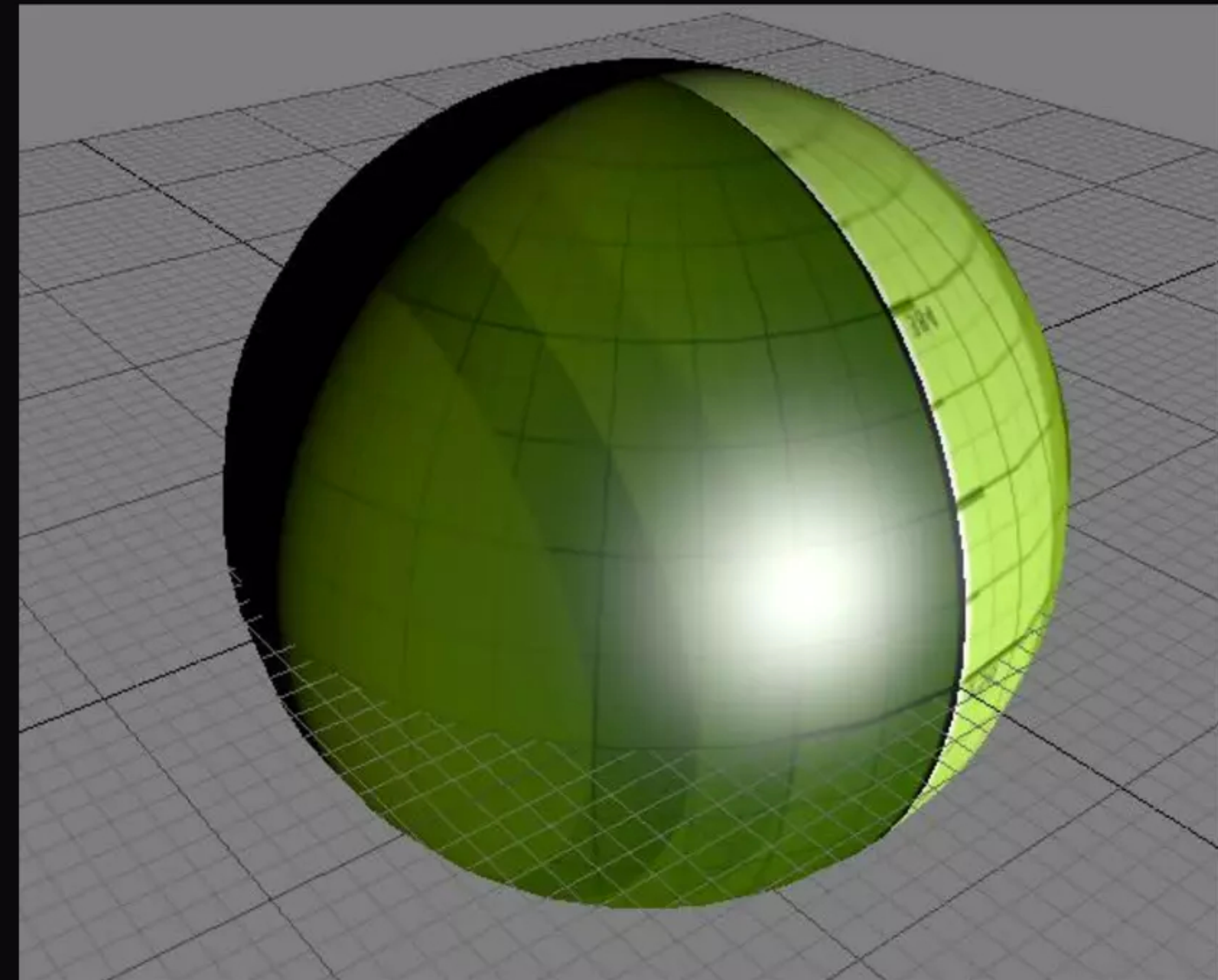
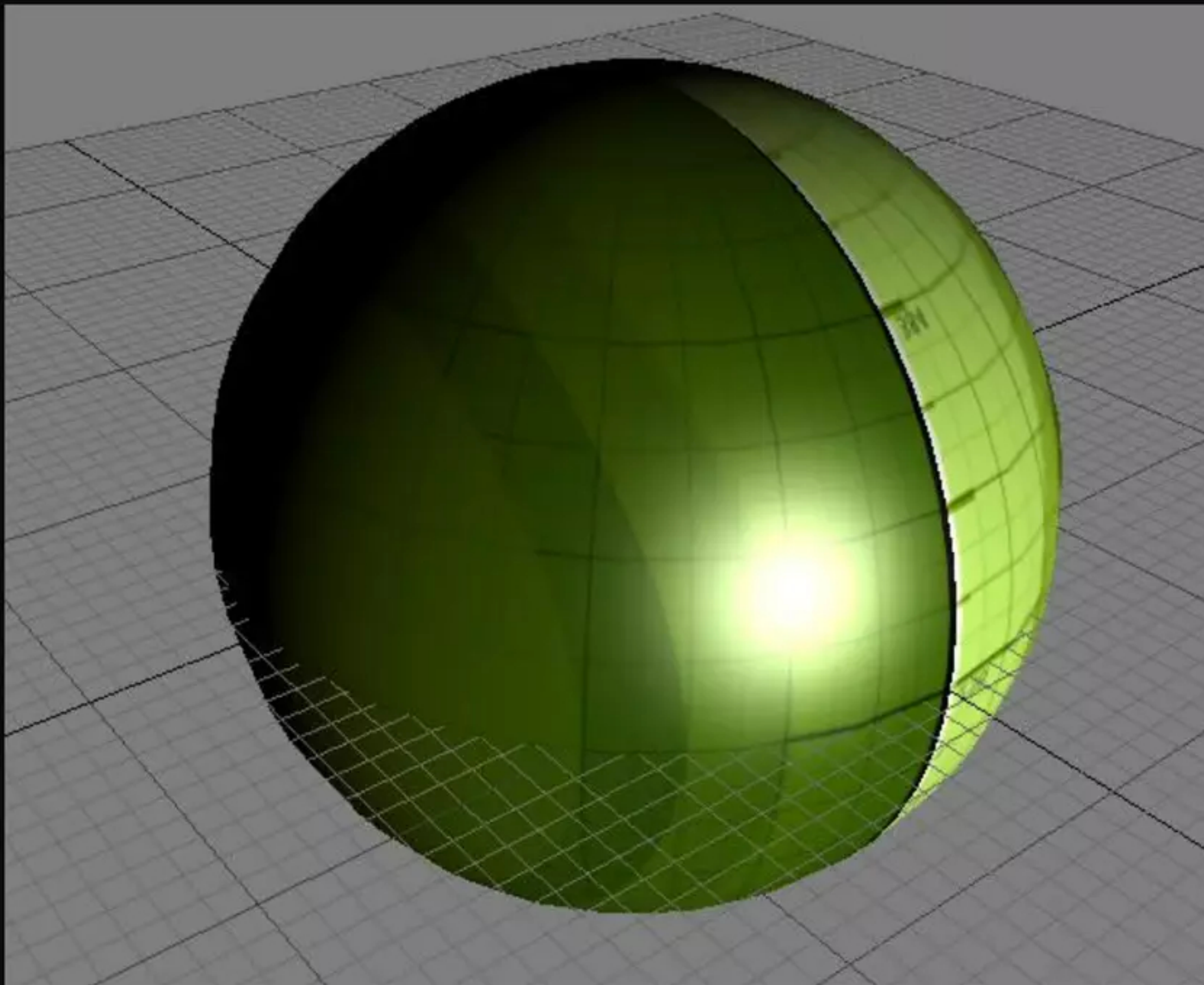
Ramp Again

- See any banding in the whites?



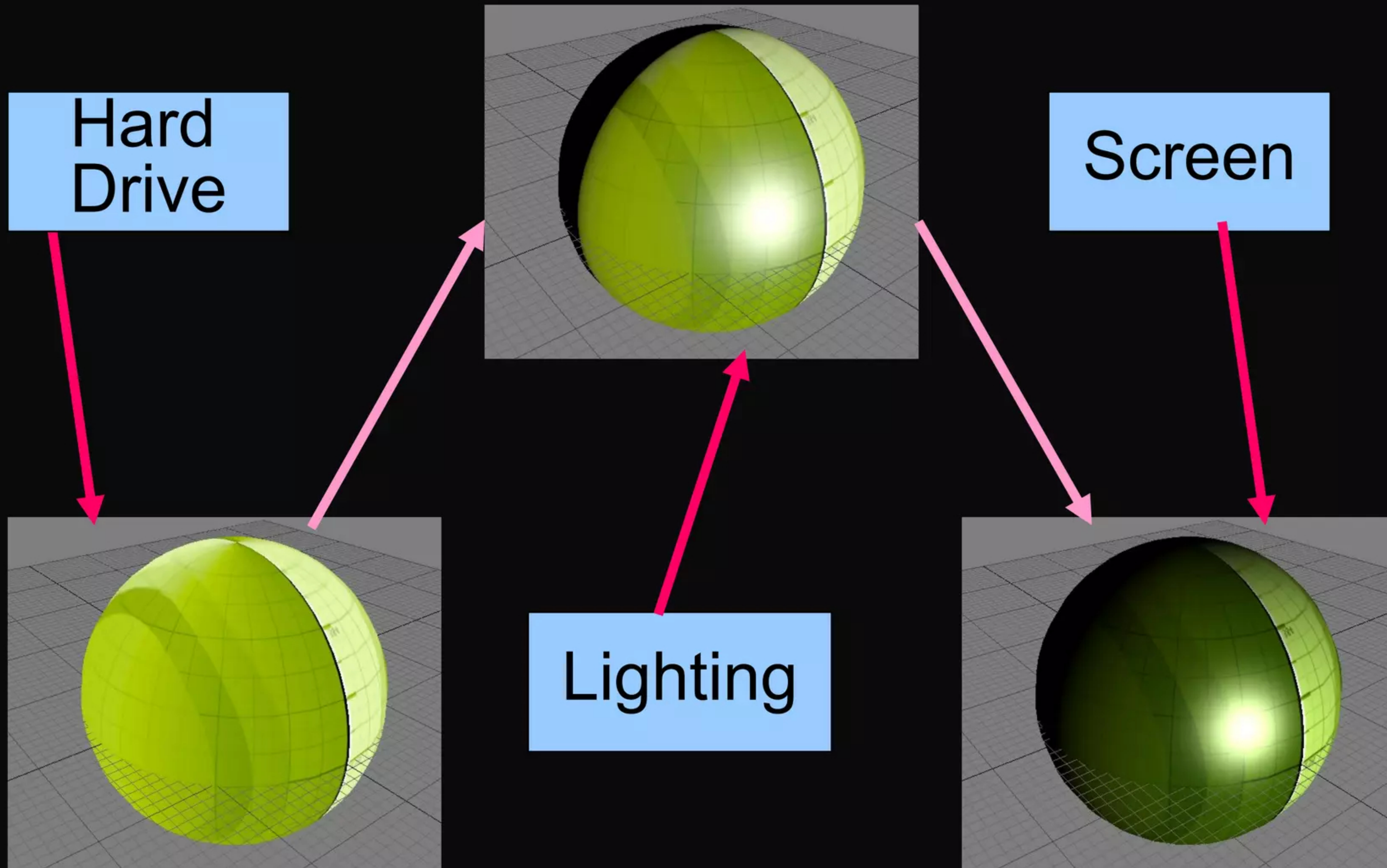
3D Graphics

- If your game is not gamma correct, it looks like the image on the left..
- Note: we're talking about "correct", not "good"



3D Graphics

- Here's what is going on.

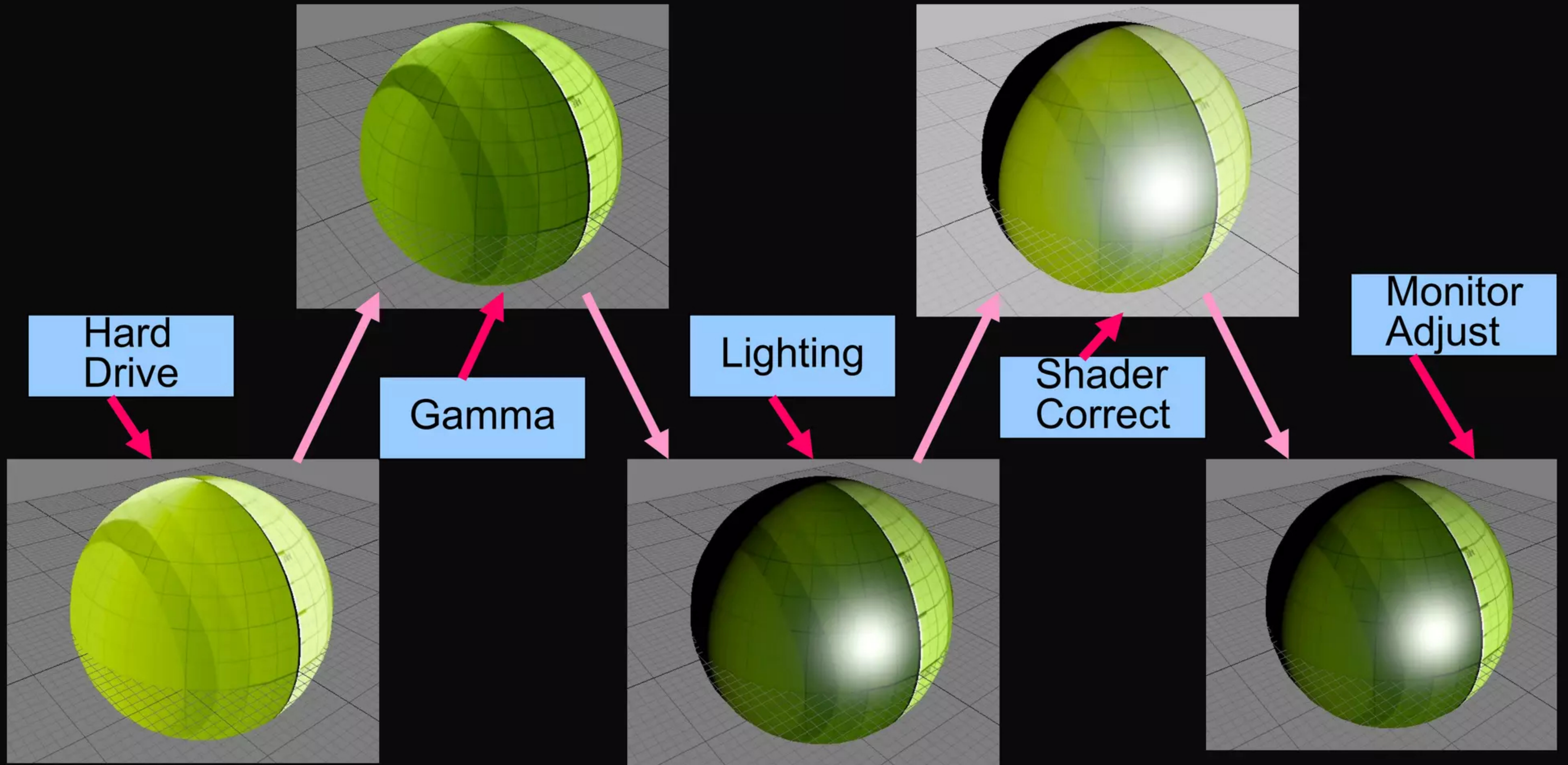


3D Graphics

- Account for gamma when reading textures
 - $\text{color} = \text{pow}(\text{tex2D}(\text{Sampler}, \text{Uv}), 2.2)$
- Do your lighting calculations
- Account for gamma on color output
 - $\text{finalcolor} = \text{pow}(\text{color}, 1/2.2)$

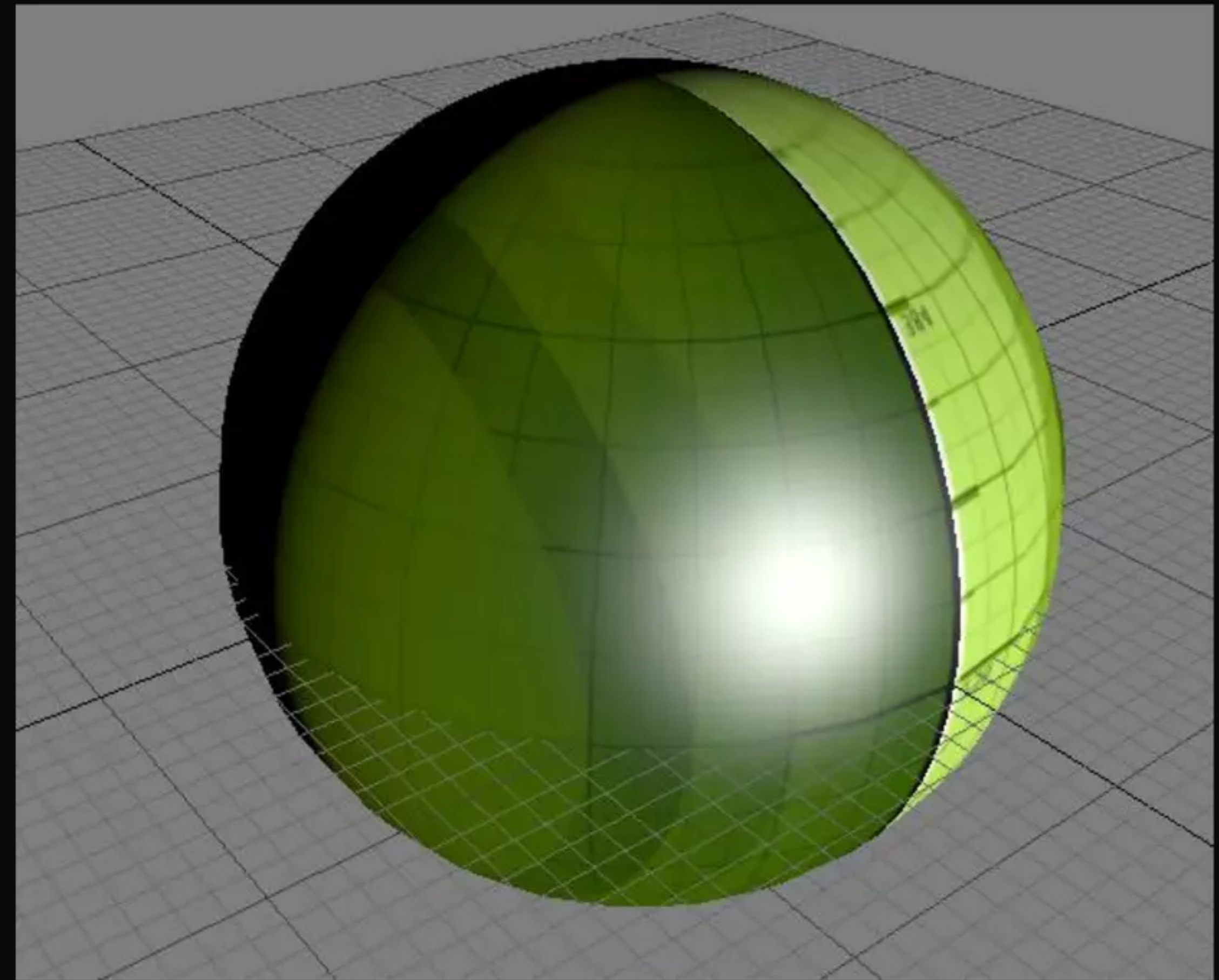
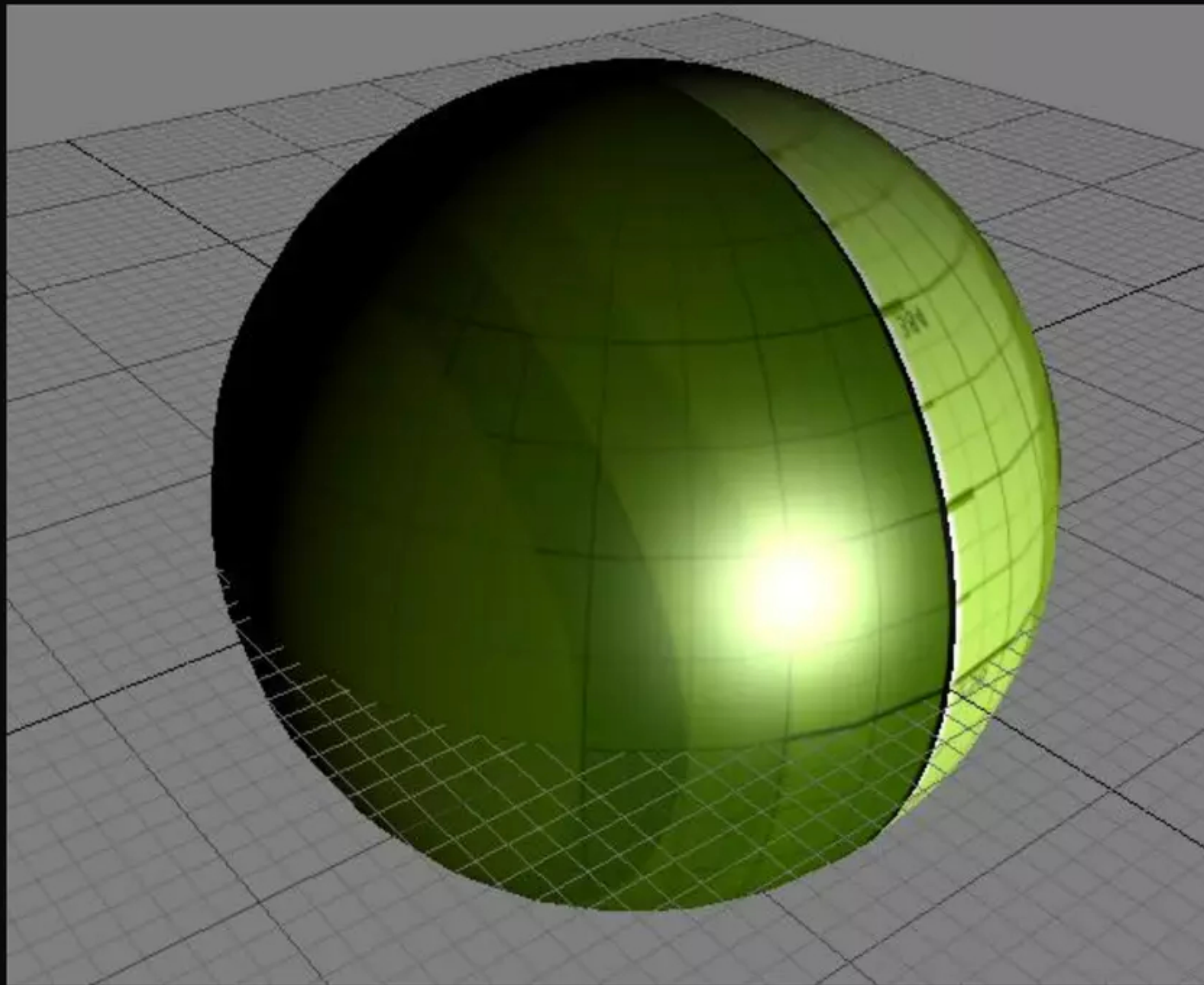
3D Graphics

- Here's what is going on.



3D Graphics

- Comparison again...



3D Graphics

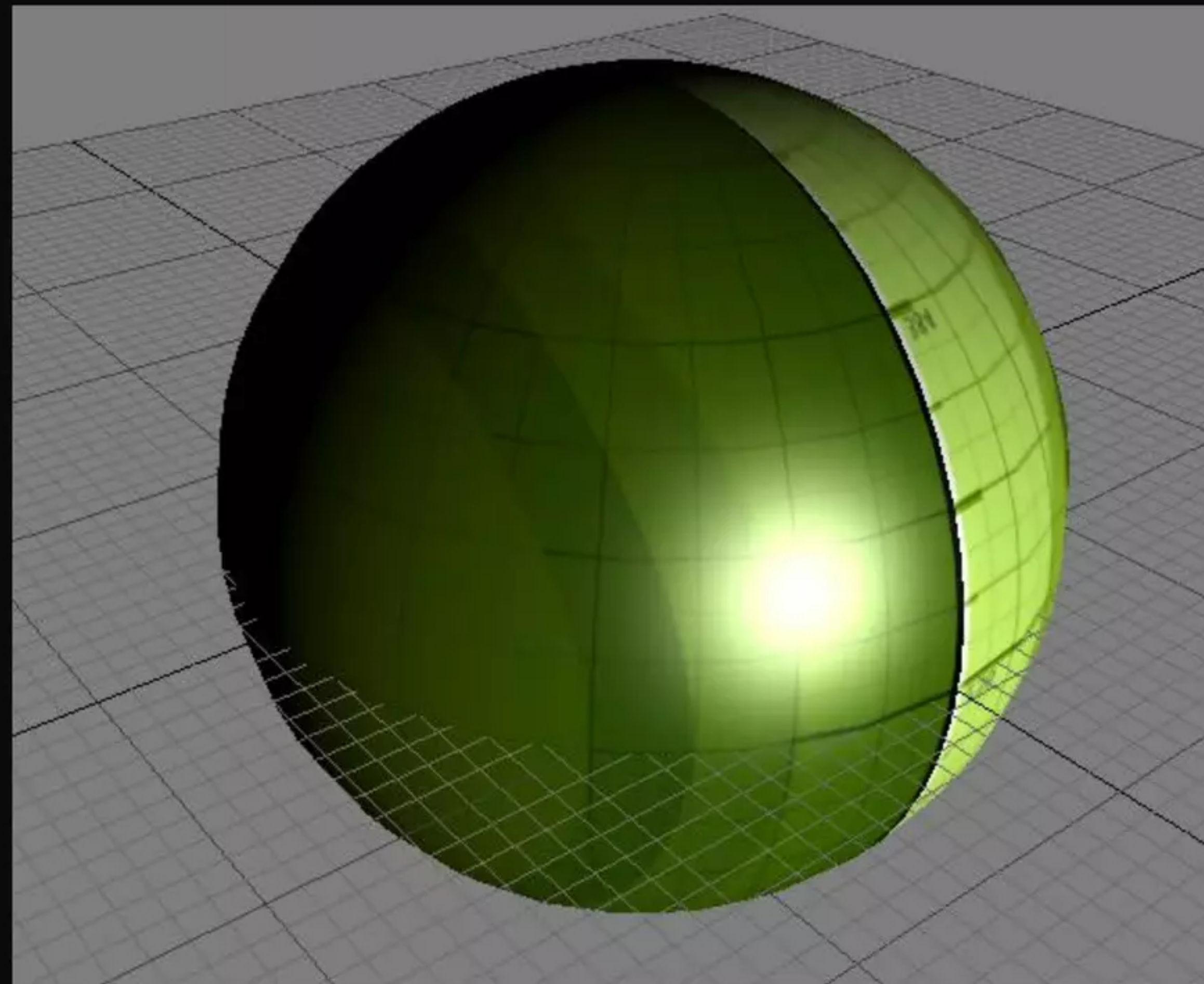
- The Wrong Shader?

```
Spec = CalSpec();
```

```
Diff = tex2D( Sampler, UV );
```

```
Color = Diff * max( 0, dot( N, L ) ) + Spec;
```

```
return Color;
```



3D Graphics

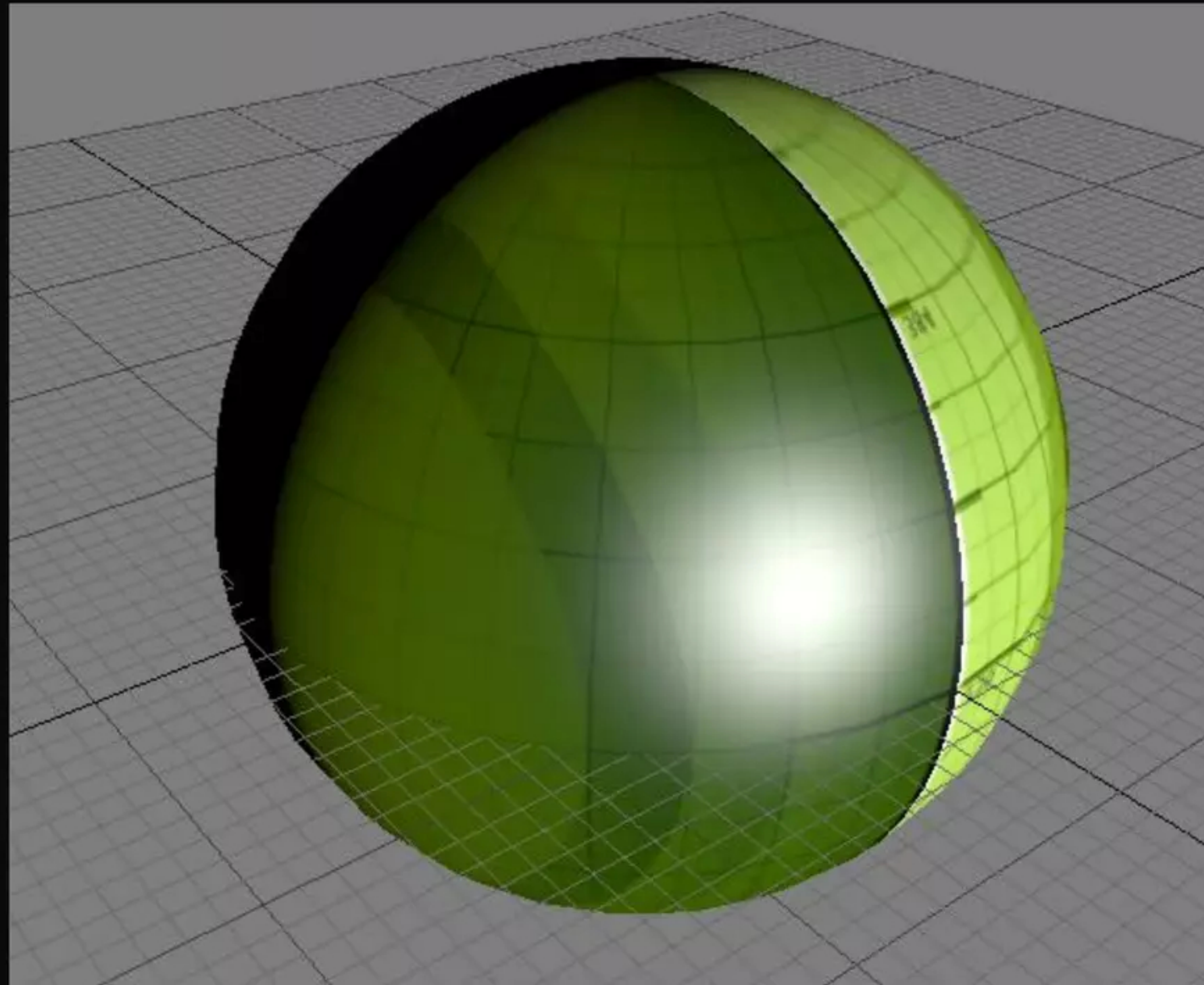
- The Right Shader?

```
Spec = CalSpec();
```

```
Diff = pow( tex2D( Sampler, UV ), 2.2 );
```

```
Color = Diff * max( 0, dot( N, L ) ) + Spec;
```

```
return pow( Color, 1/2.2);
```

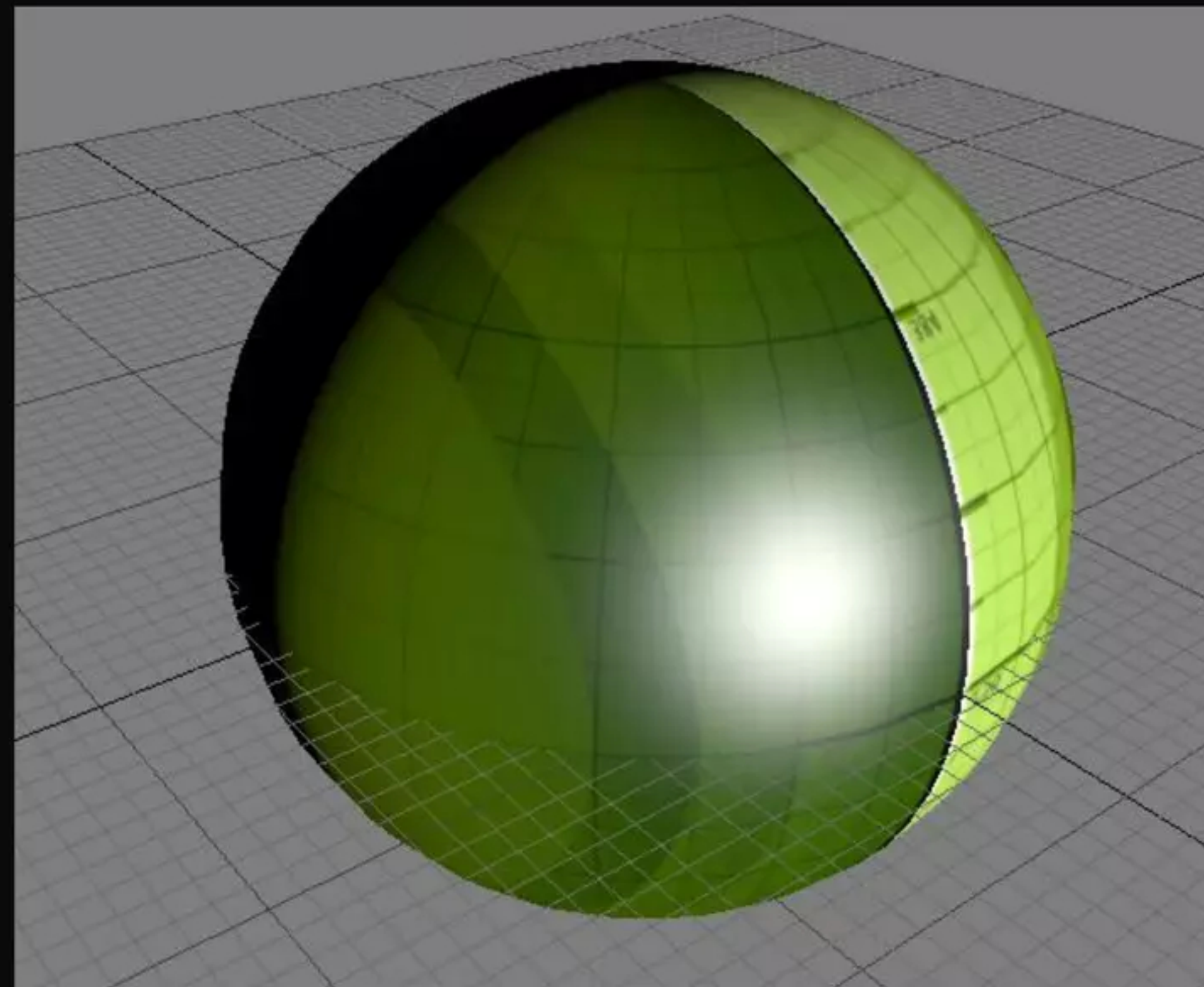


3D Graphics

- But, there is hardware to do this for us.
 - Hardware does sampling for free
 - For Texture read:
 - D3DSAMP_SRGBTEXTURE
 - For RenderTarget write:
 - D3DRS_SRGBWRITEENABLE

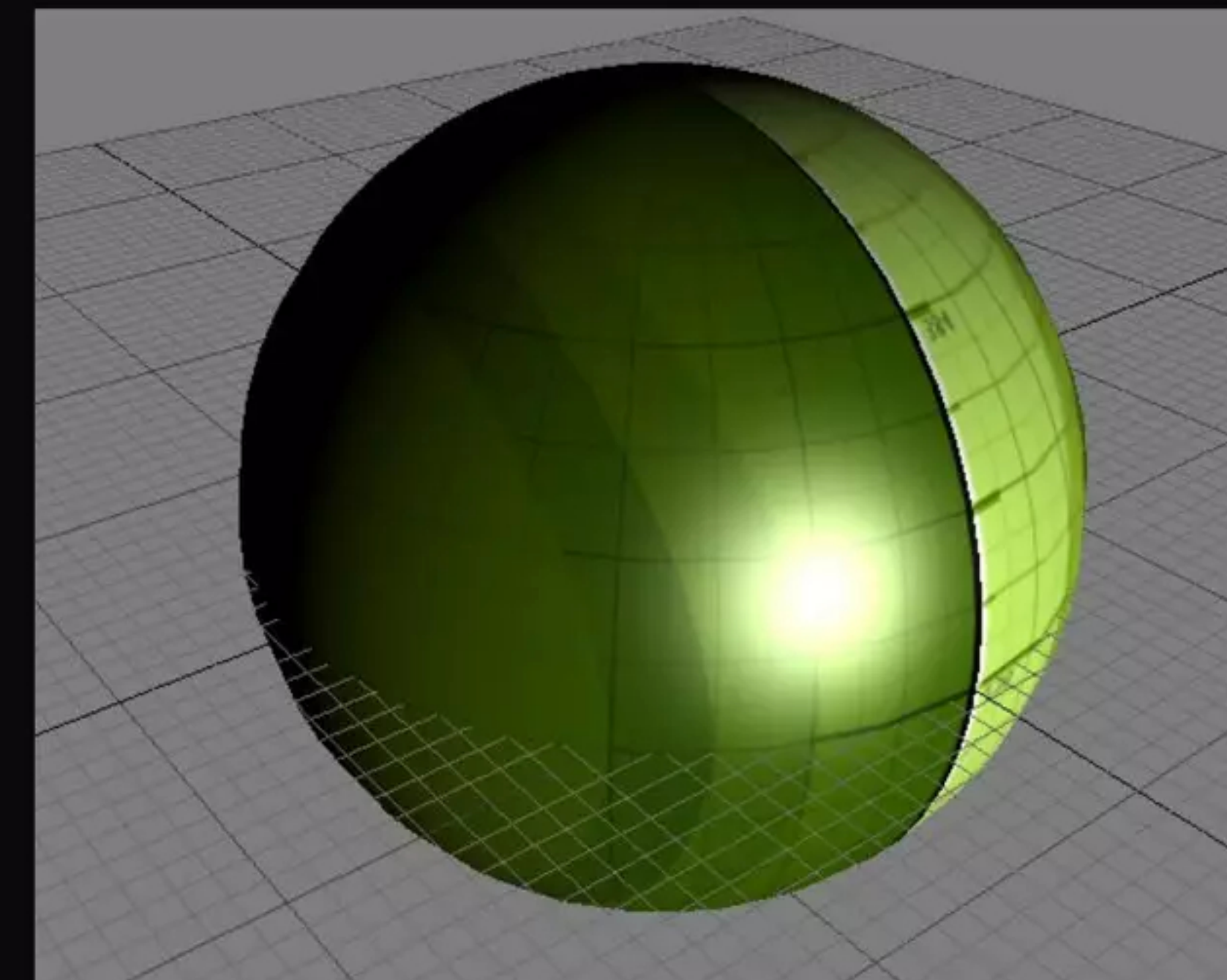
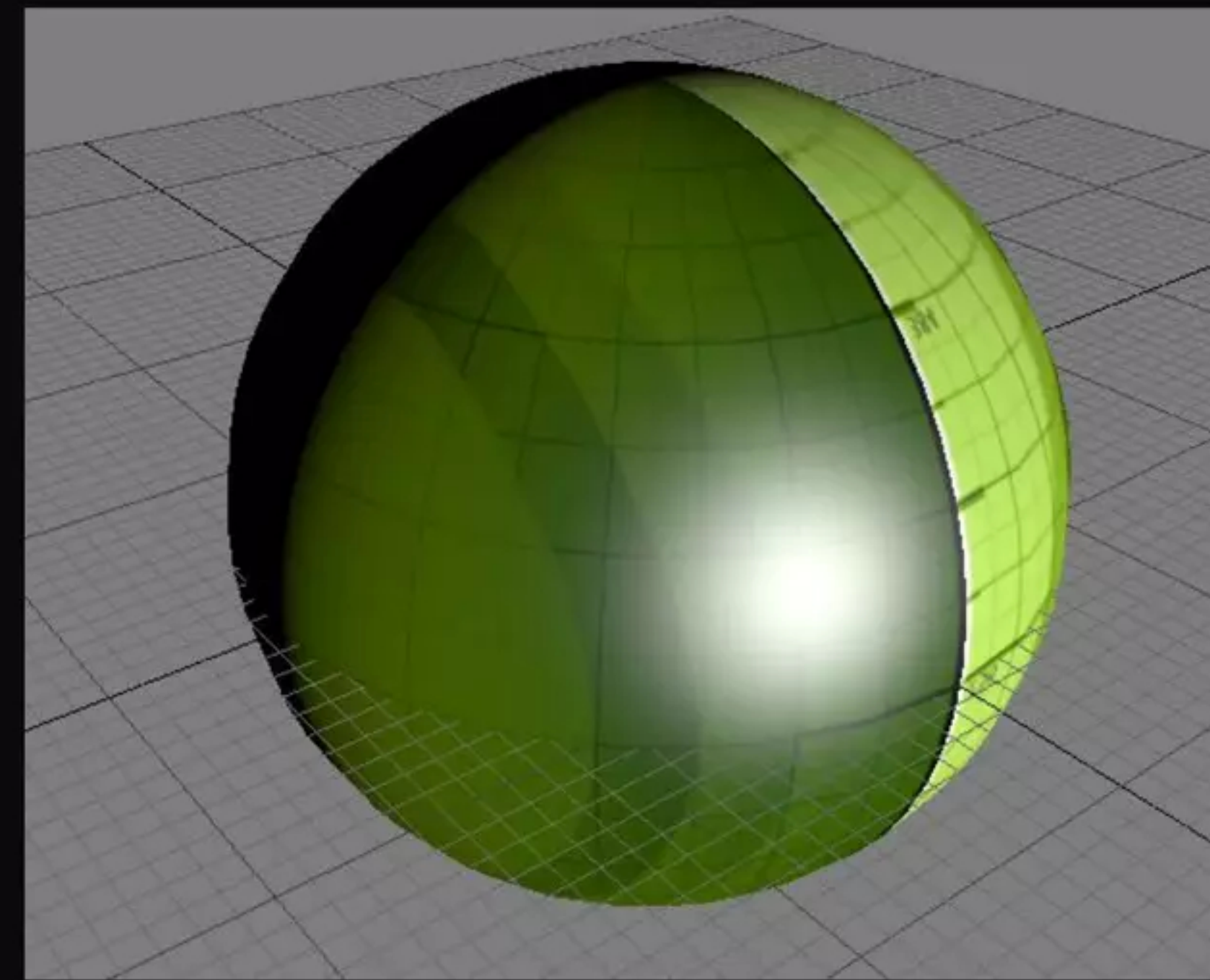
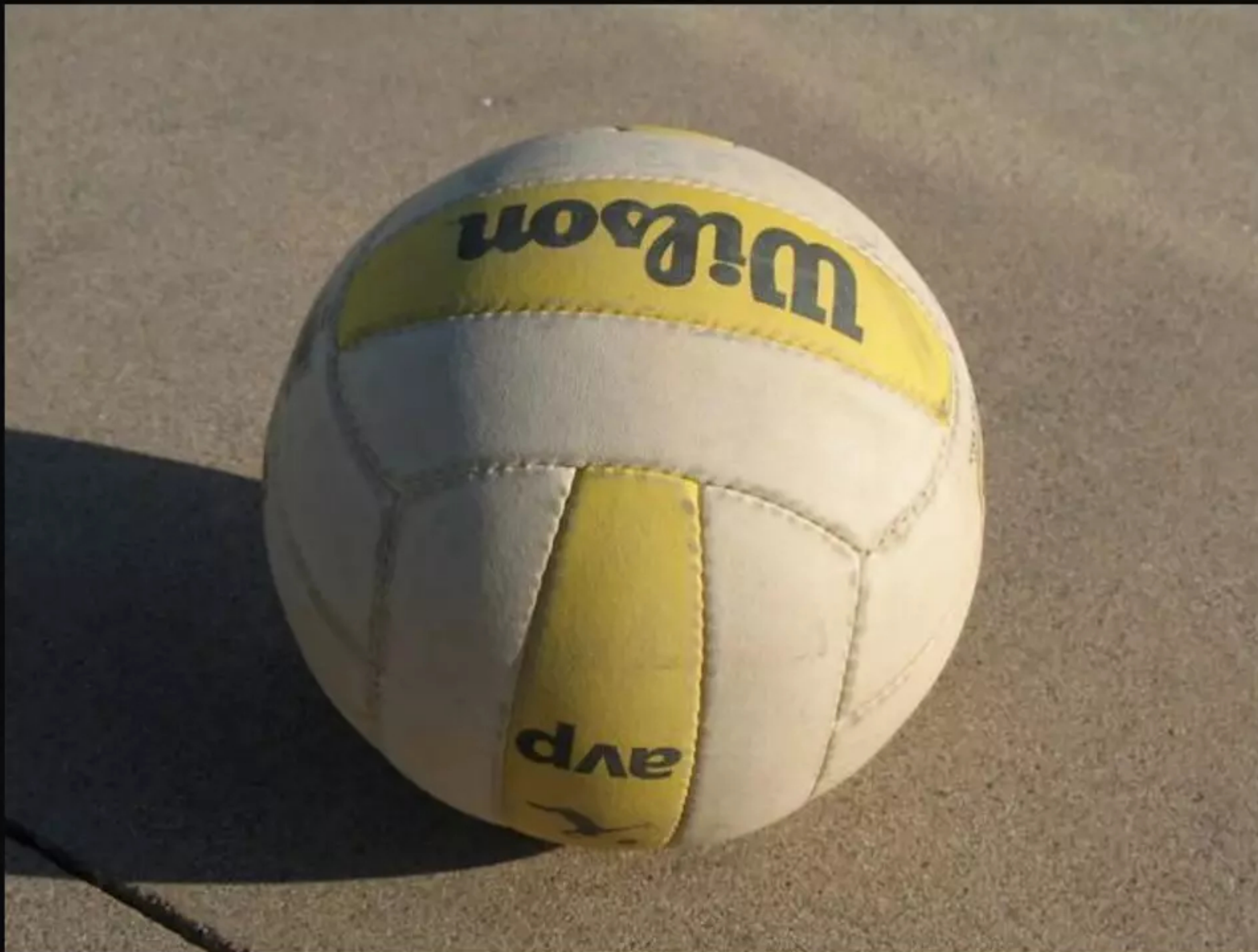
3D Graphics

- With those states we can remove the pow functions.
Spec = CalSpec();
Diff = tex2D(Sampler, UV);
Color = Diff * max(0, dot(N, L)) + Spec;
return Color;



3D Graphics

- What does the real world look like?
 - Notice the harsh line.



3D Graphics

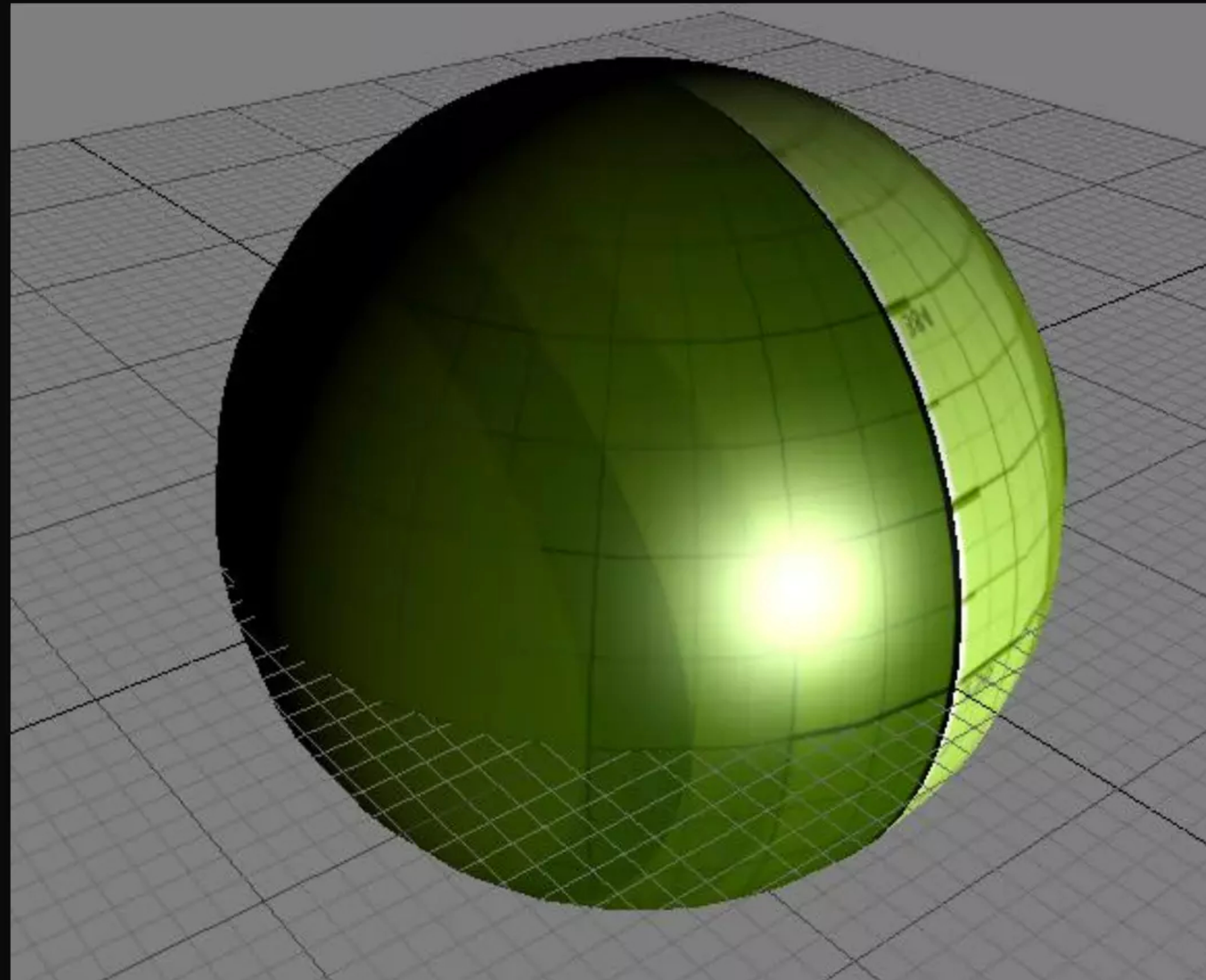
- Another Example



FAQs

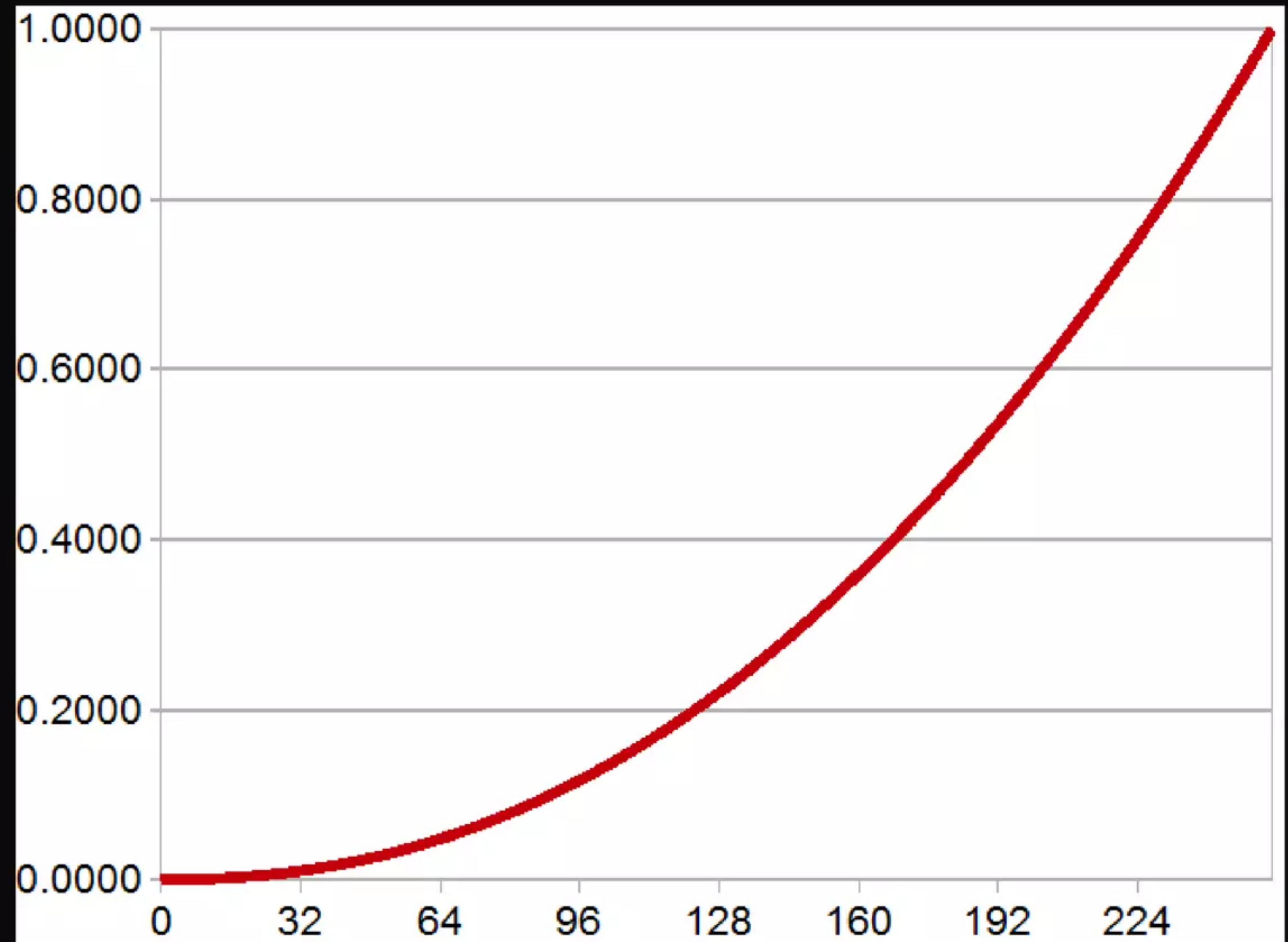
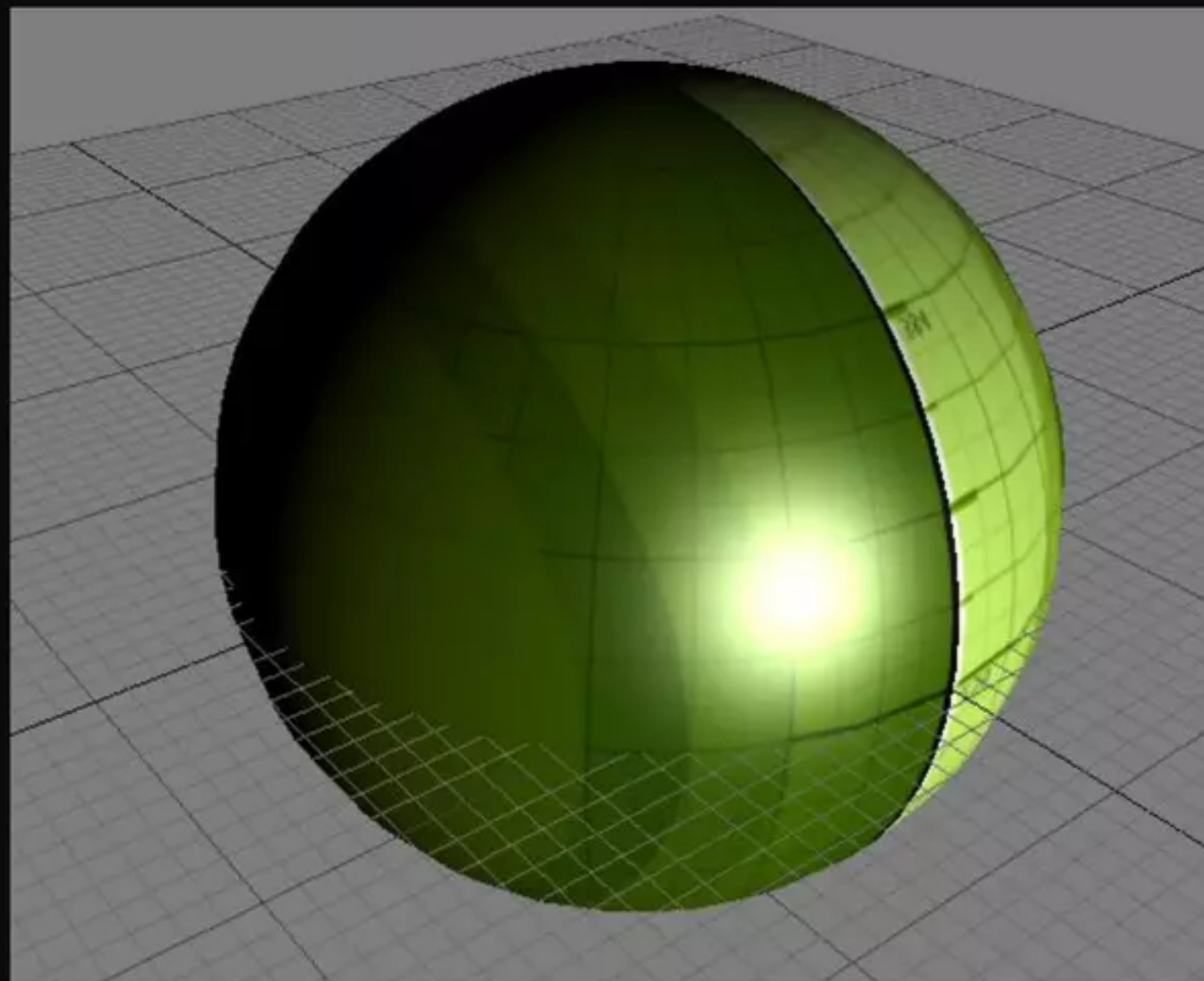
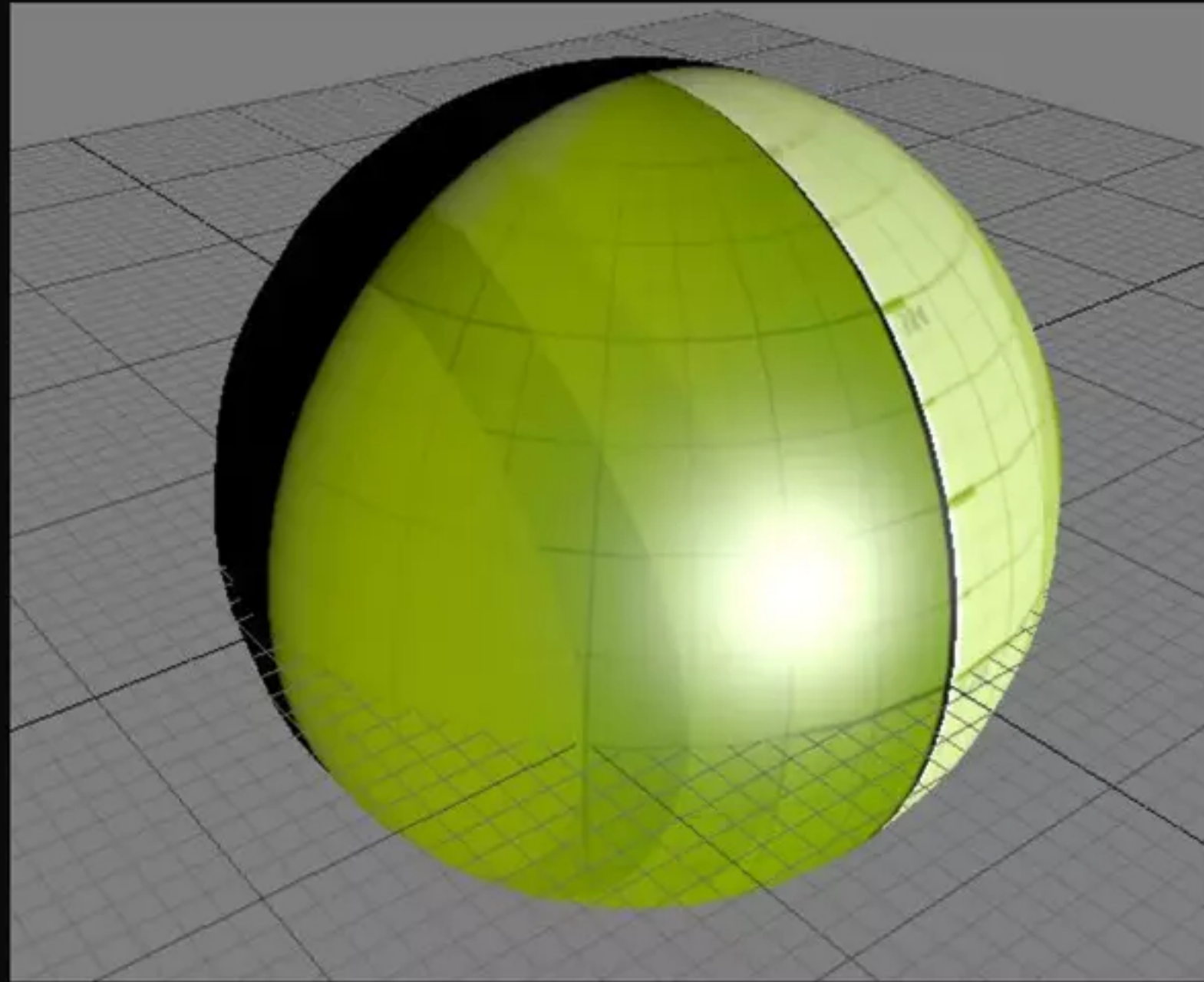
Q1) But I like the soft falloff!

A1) Don't be so sure.



FAQs

- It looks like the one on top before the monitor's 2.2



Harsh Falloff

- Devastating.



Harsh Falloff

- Devastating.



Harsh Falloff

- Devastating.



Which Maps?

- Which maps should be Linear-Space vs Gamma-Space?
 - Gamma-Space
 - Use sRGB hardware or $\text{pow}(2.2)$ on read
 - $128 \approx 0.2$
 - Linear-Space
 - Don't use sRGB or $\text{pow}(2.2)$ on read
 - $128 = 0.5$

Which Maps?

- Diffuse Map
 - Definitely Gamma
- Normal Map
 - Definitely Linear

Which Maps?

- Specular?
 - Uncharted 2 had them as Linear
 - Artists have trouble tweaking them to look right
 - Probably should be in Gamma

Which Maps?

- Ambient Occlusion
 - Technically, it's a mathematical value like a normal map.
 - But artists tweak them a lot and bake extra lighting into them.
 - Uncharted 2 had them as Linear
 - Probably should be Gamma

Exercise for the Reader

- Gamma 2.2 \neq sRGB \neq Xenon PWL
- sRGB: PC and PS3 gamma
- Xenon PWL: Piecewise linear gamma

Xenon Gotchas

- Xbox 360 Gamma Curve is wonky
 - Way too bright at the low end.
 - *HDR the Bungie Way*, Chris Tchou
 - *Post Processing in The Orange Box*, Alex Vlachos
 - Output curve is extra contrasty
 - Henry LaBounta was going to talk about it.
 - Try hooking up your Xenon to a waveform monitor and display a test pattern. Prepare to be mortified.
- Both factors counteract each other

Linear-Space Lighting: Conclusion

“Drake! You must *believe* in linear-space lighting!”



Part 2: Filmic Tonemapping

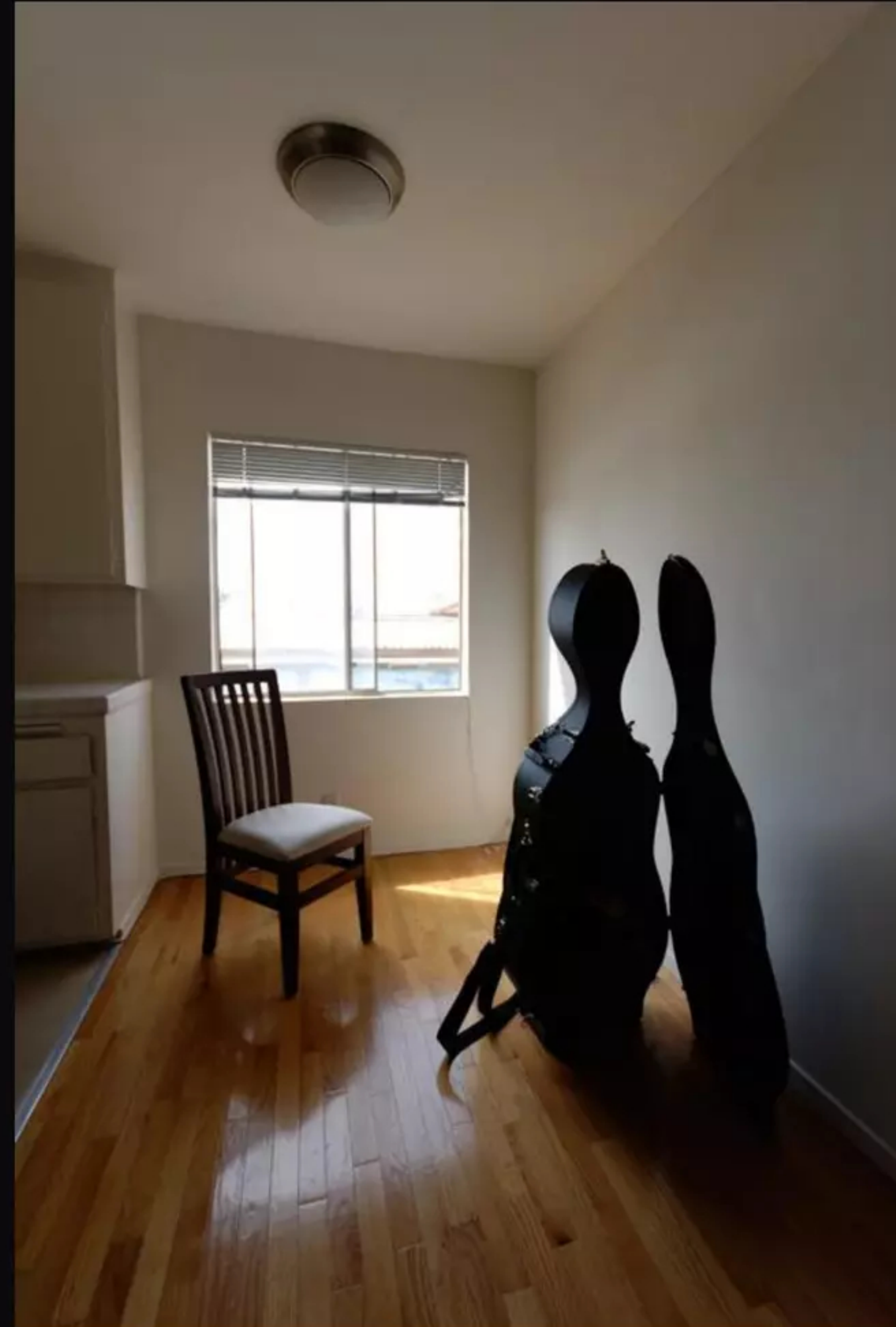


Filmic Tonemapping

- Let's talk about the magic of the human eye.

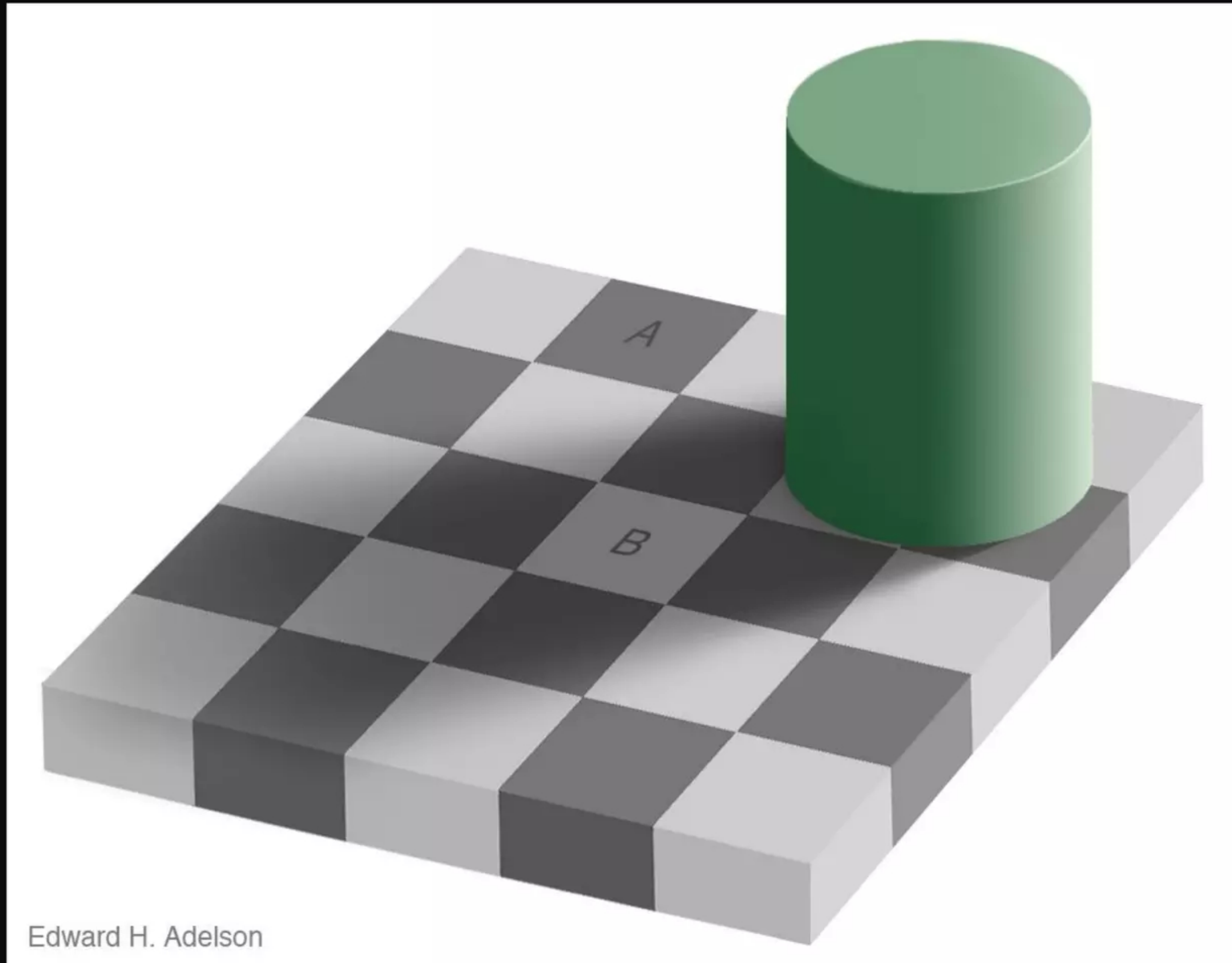
Filmic Tonemapping

- Real example from my apartment.
- Full Auto settings.
- Outside blown out.
- Cello case looks empty.
- My eye somehow adjusts...



Filmic Tonemapping

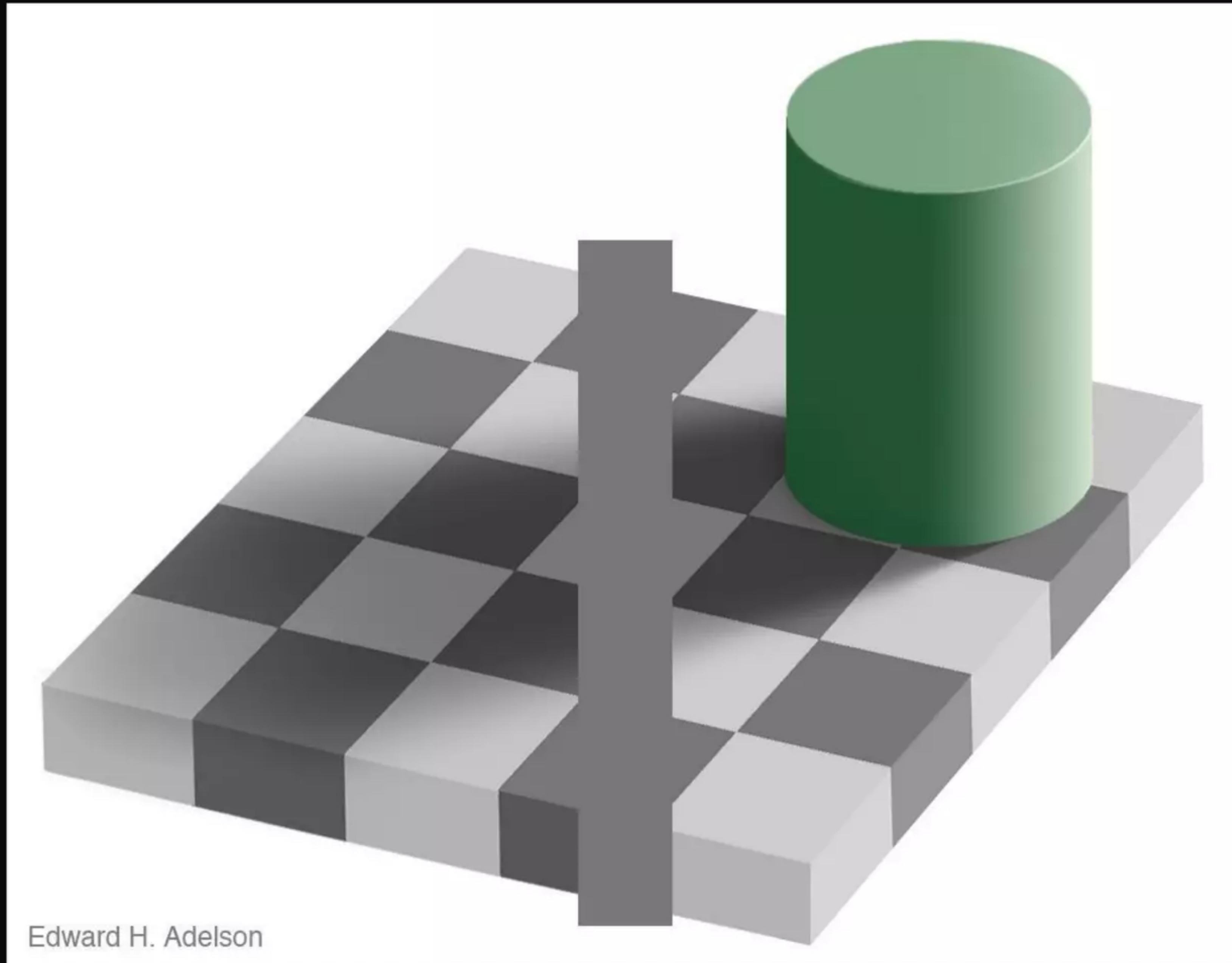
- Adaptiveness of human eye.



Edward H. Adelson

Filmic Tonemapping

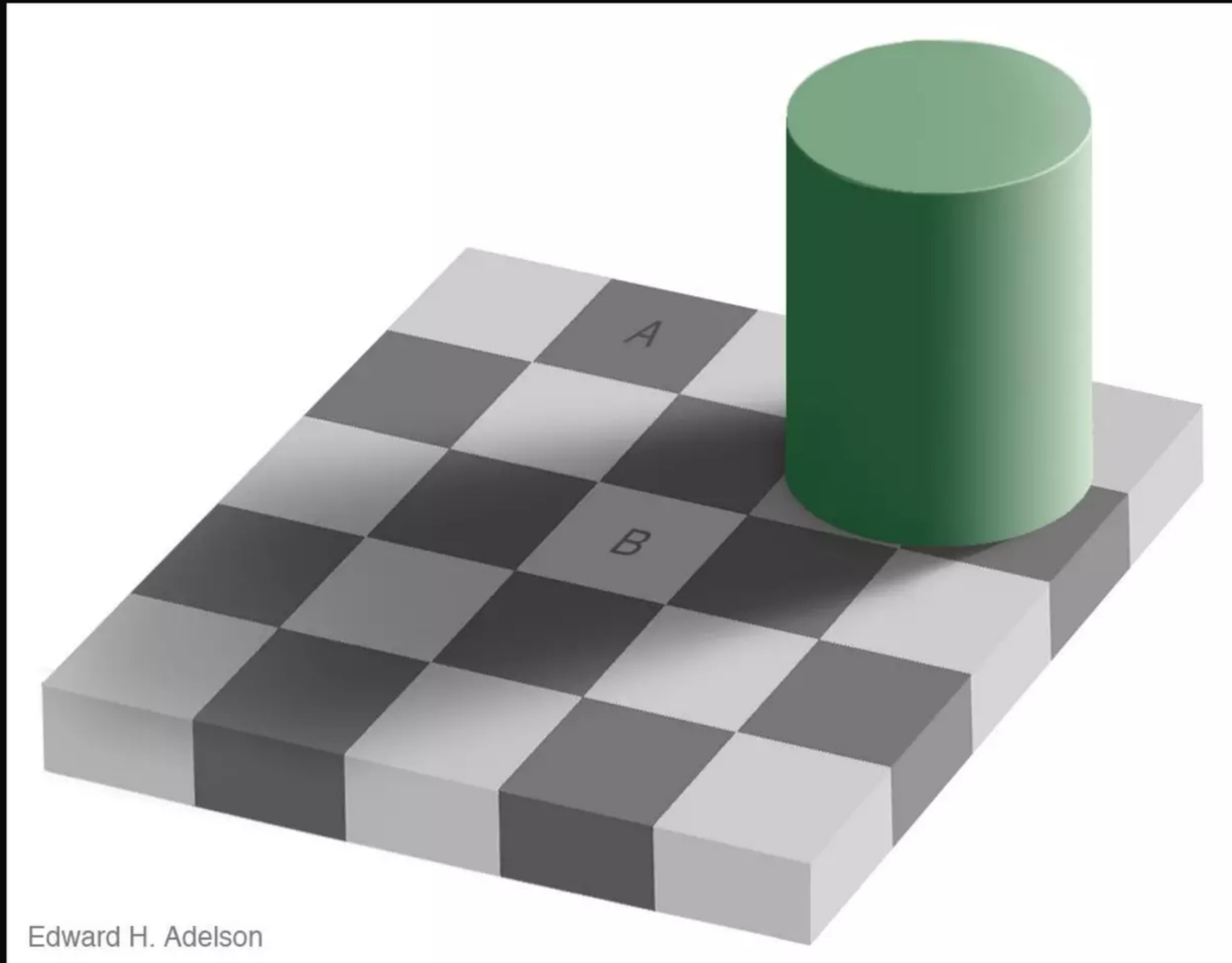
- Adaptiveness of human eye.



Edward H. Adelson

Filmic Tonemapping

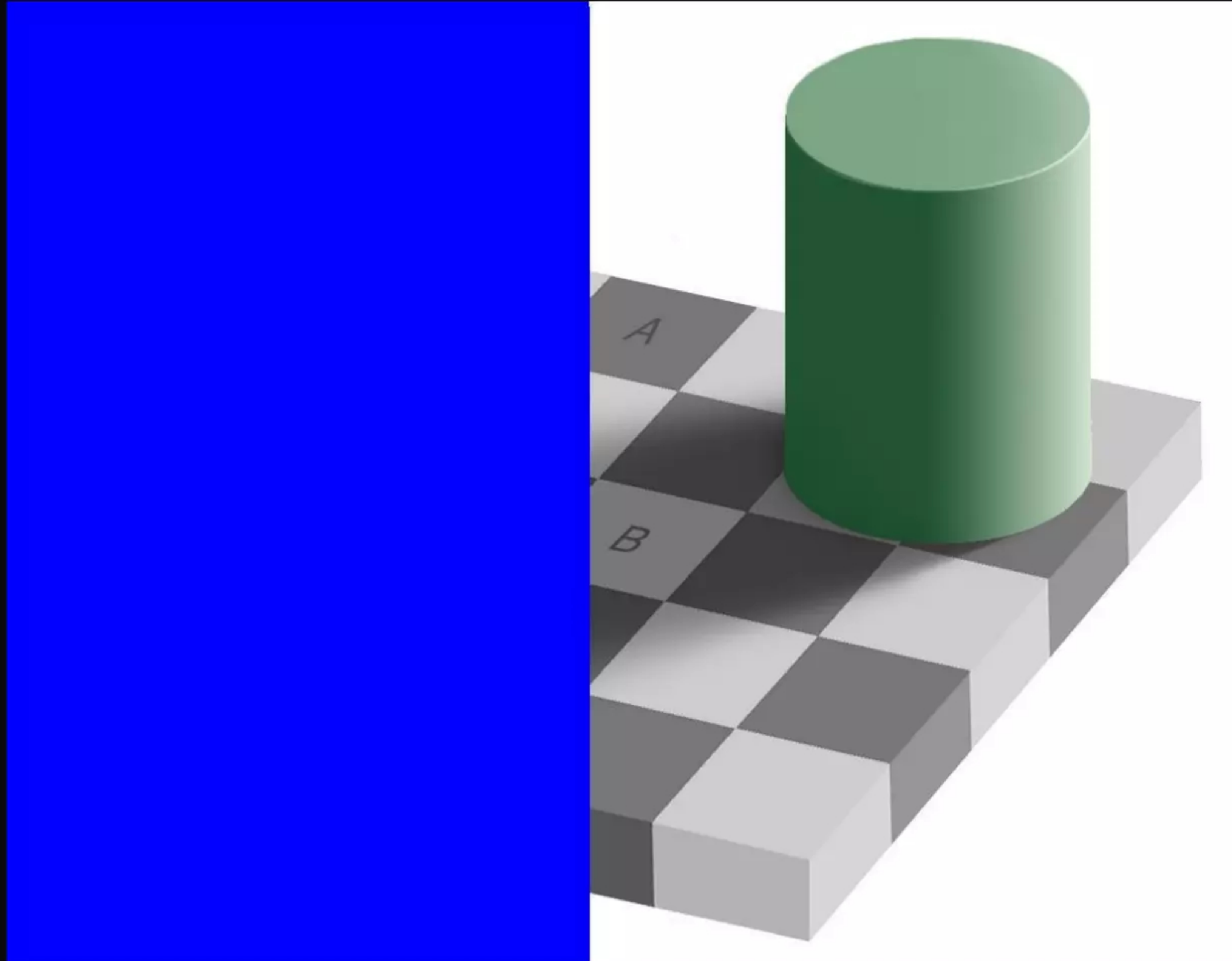
- Adaptiveness of human eye.



Edward H. Adelson

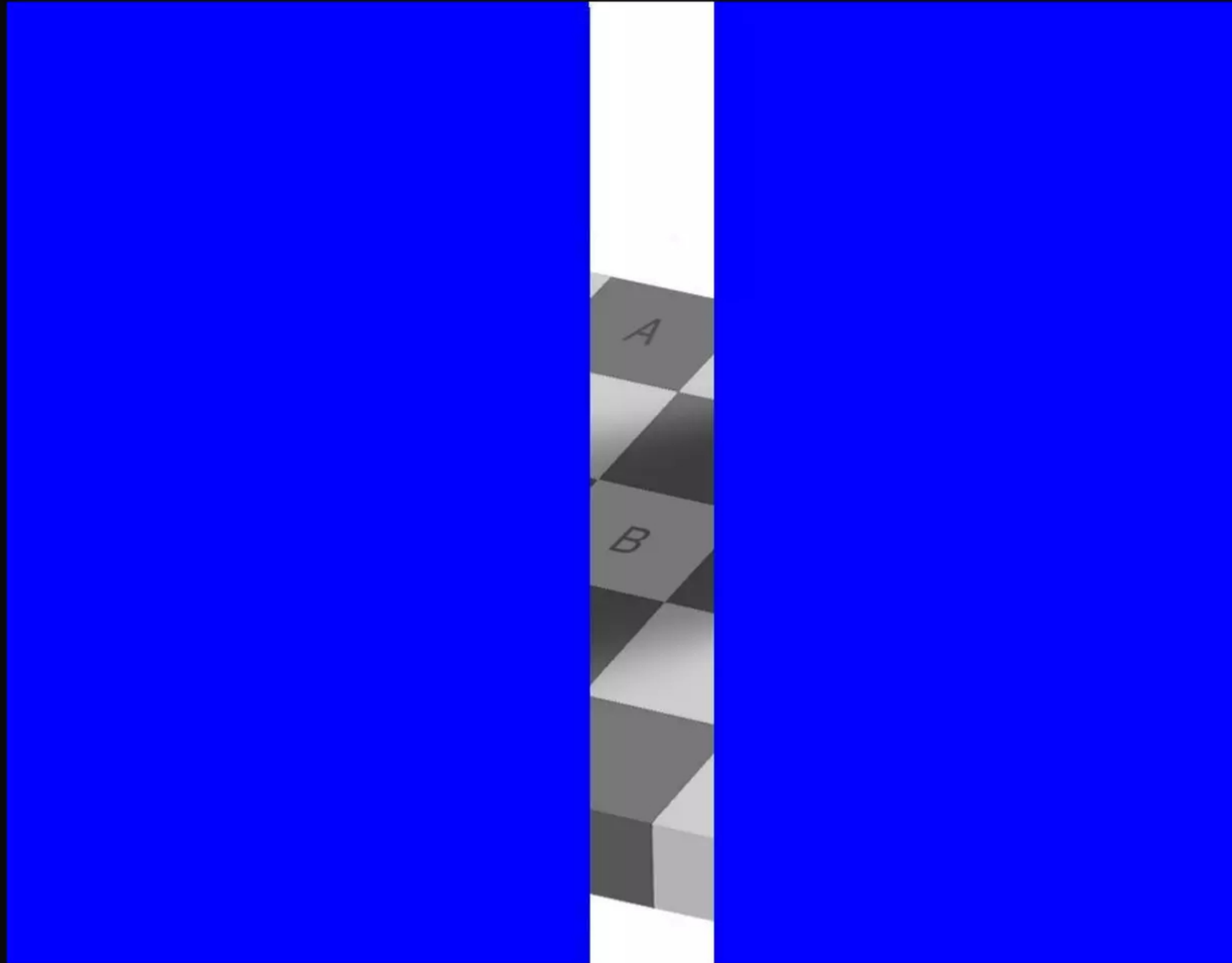
Filmic Tonemapping

- Adaptiveness of human eye.



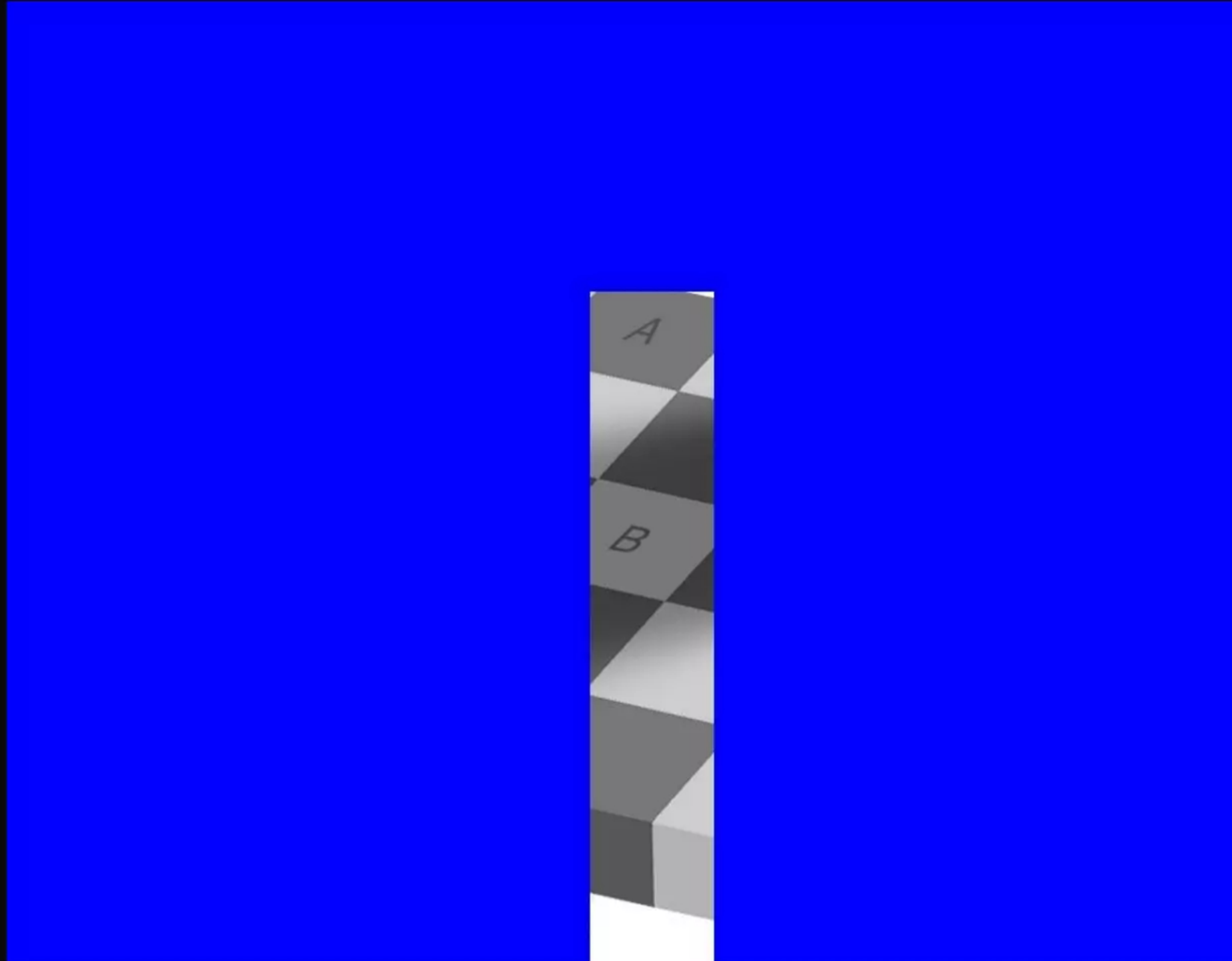
Filmic Tonemapping

- Adaptiveness of human eye.



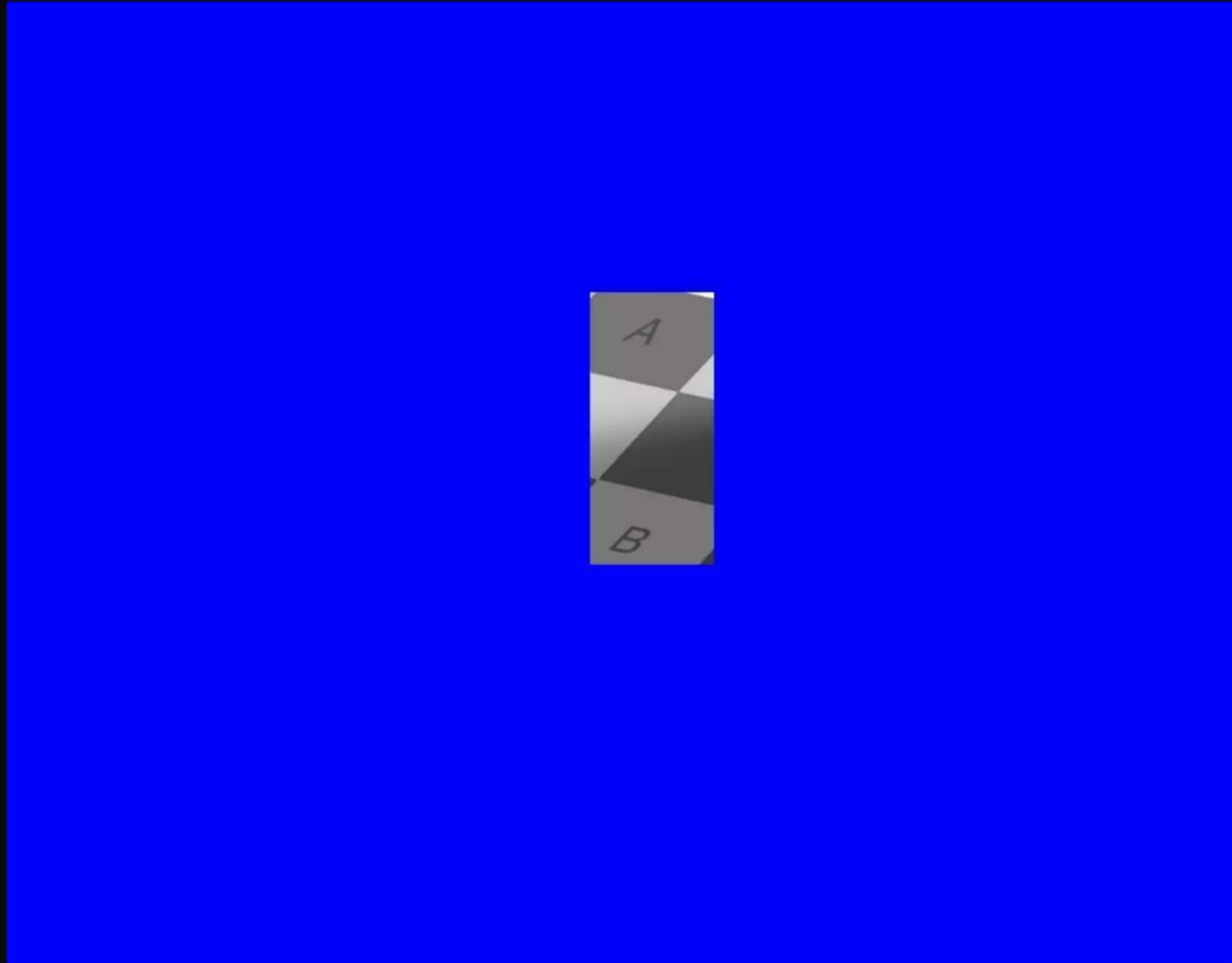
Filmic Tonemapping

- Adaptiveness of human eye.



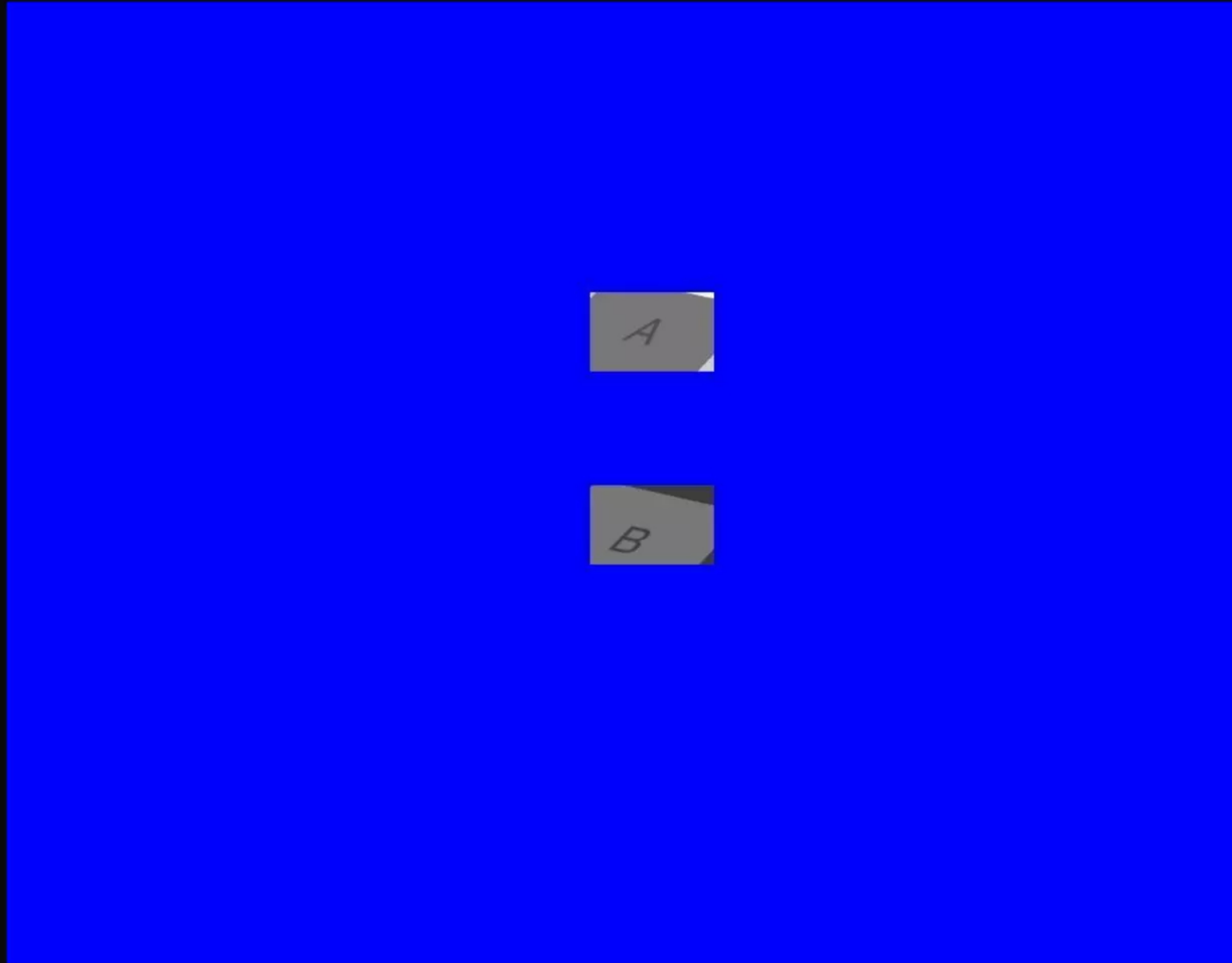
Filmic Tonemapping

- Adaptiveness of human eye.



Filmic Tonemapping

- Adaptiveness of human eye.



Filmic Tonemapping

- One more



Filmic Tonemapping

- One more



Gamma

- Let's take an HDR image
 - Note: 1 F-Stop is a power of two
 - So 4 F-stops is $2^4=16x$ difference in intensity

Gamma

- Exposure: -4



Gamma

- Exposure: -2



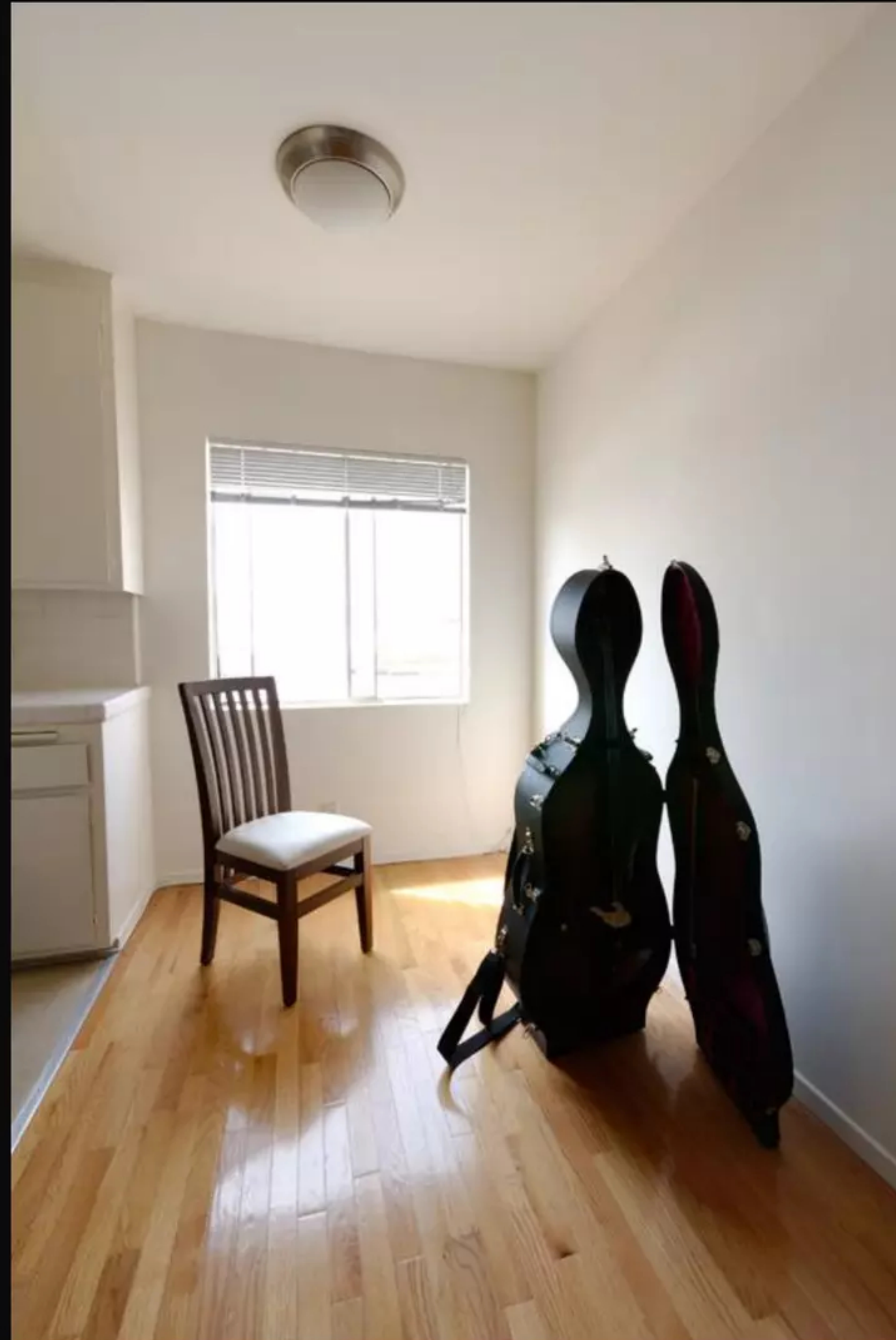
Gamma

- Exposure: 0



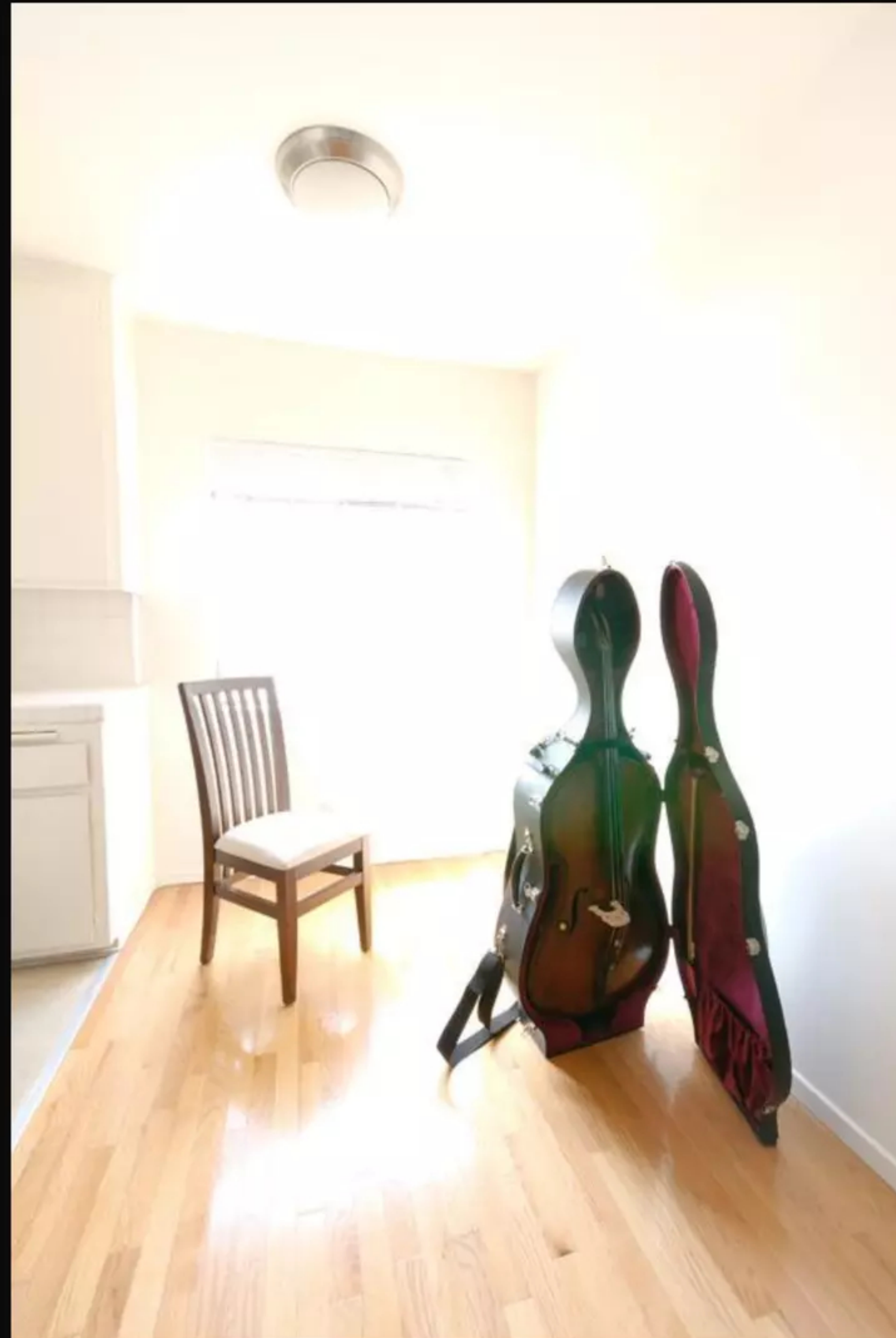
Gamma

- Exposure: 2



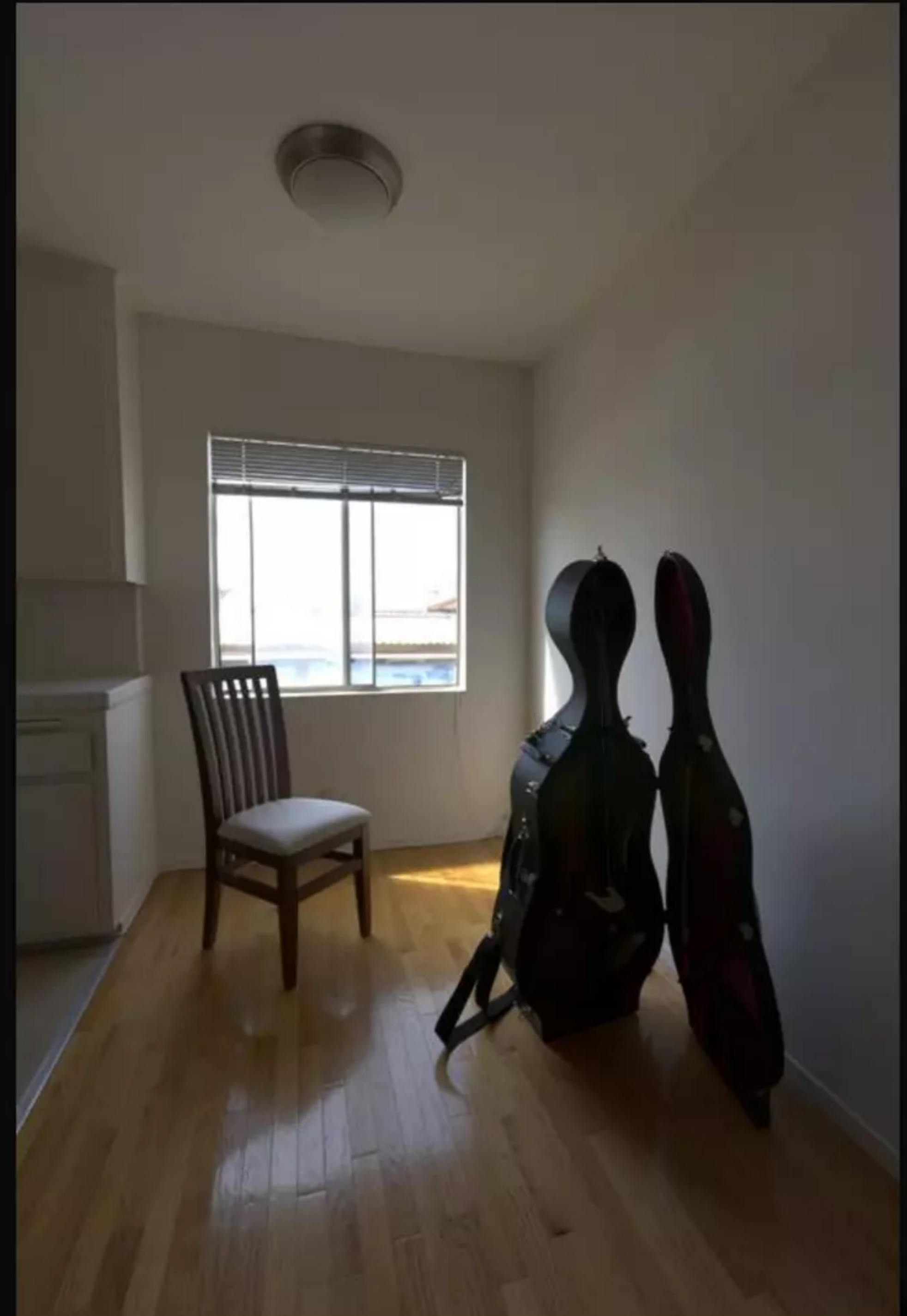
Gamma

- Exposure: 4



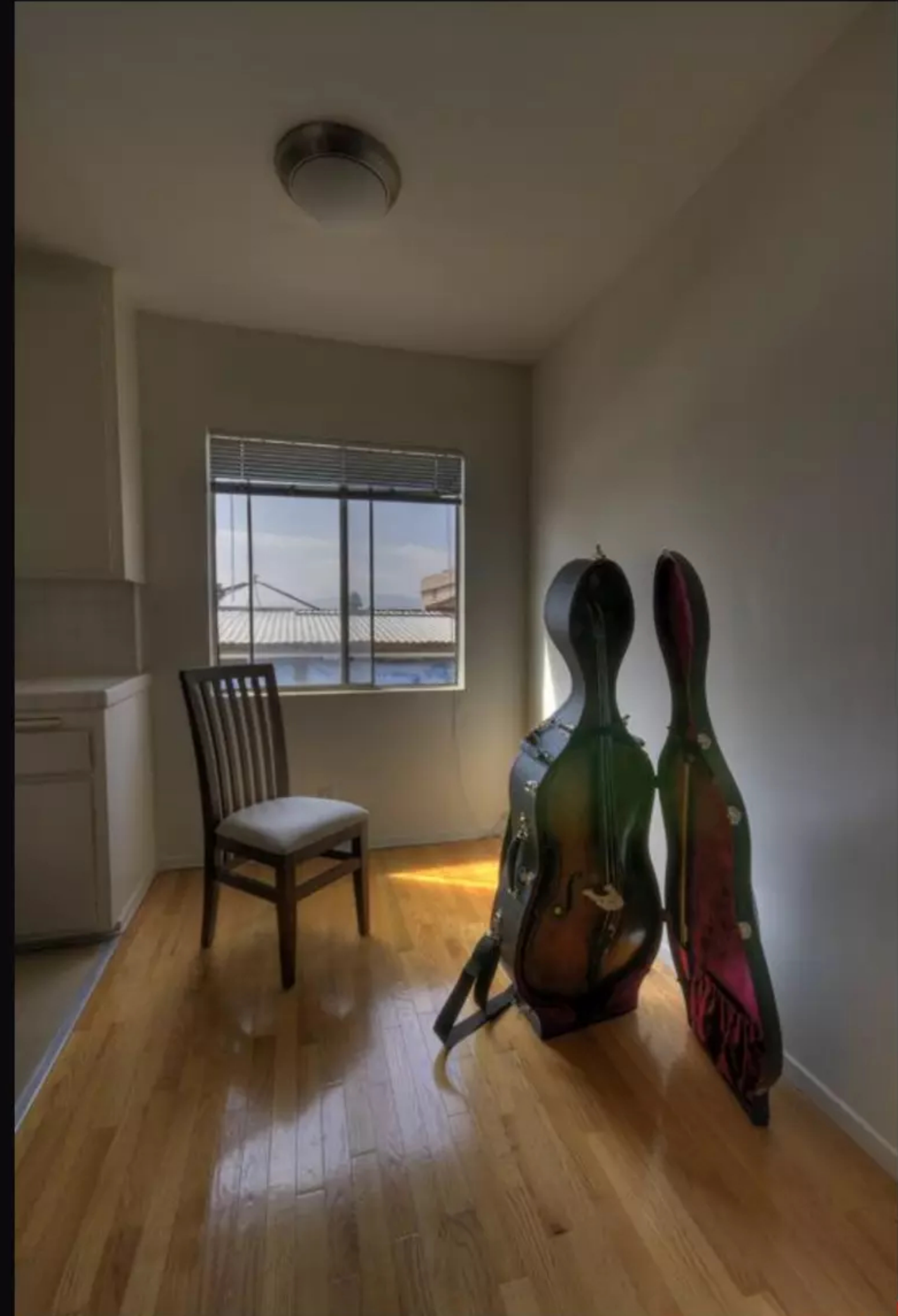
Now what?

- We actually need 8 stops
- Good News: HDR Image
- Bad News: Now what?
- Re-tweaking exposure won't help



Gamma

- This is what Photography people call tonemapping.
 - Photomatix
 - This one is local
 - The one we'll use is global



Point of Confusion

- Two problems to solve.
 - Simulate the Iris
 - Dynamic Range in different shots
 - Tunnel vs. Daylight
 - Simulate the Retina
 - Different Range within a shot
 - Inside looking outside

Terminology

- Photography/Film
 - Within a Shot – HDR Tonemapping
 - Different Shots – Choosing the correct exposure?
- Video Games
 - Within a Shot – HDR Tonemapping
 - Different Shots – HDR Tonemapping?

Terminology

- For this presentation
 - Within a Shot – HDR Tonemapping
 - Different Shots
 - Automatic Exposure Adjustment
 - Dynamic Iris

Linear Curve

- Apartment of Habib Zargarpour
- Creative Director, Microsoft Game Studios
- Used to be Art Director on LMNO at EA



Linear Curve

- $\text{OutColor} = \text{pow}(x, 1/2.2)$



Reinhard

- Most common tonemapping operator is Reinhard
- Simplest version is:
 - $F(x) = x/(x+1)$
 - Yes, I'm oversimplifying for time.



Fade!

- Let's fade from linear to Reinhard.



Fade!

- Let's fade from linear to Reinhard.



Fade!

- Let's fade from linear to Reinhard.



Fade!

- Let's fade from linear to Reinhard.



Fade!

- Let's fade from linear to Reinhard.



Fade!

- Let's fade from linear to Reinhard.



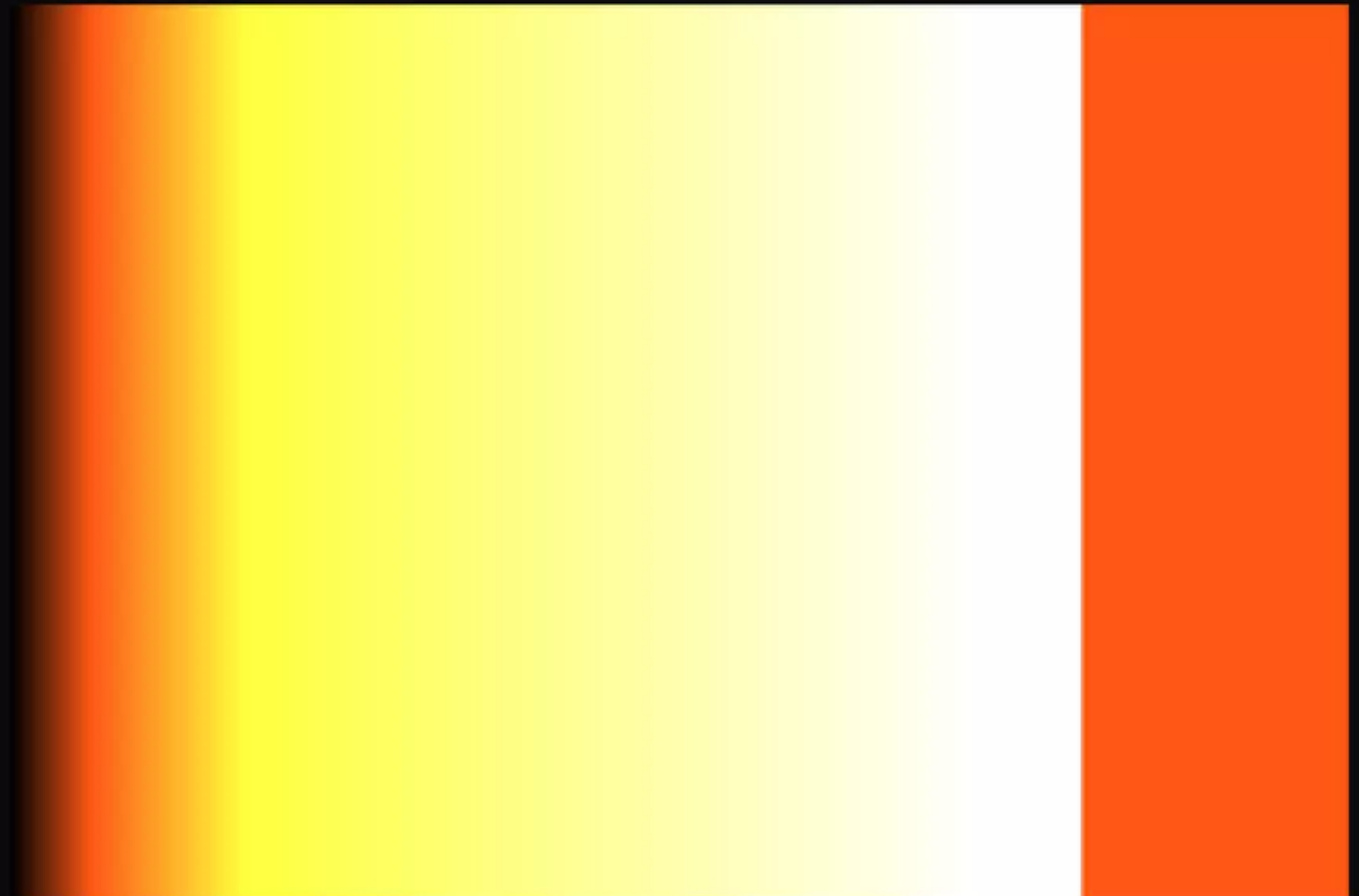
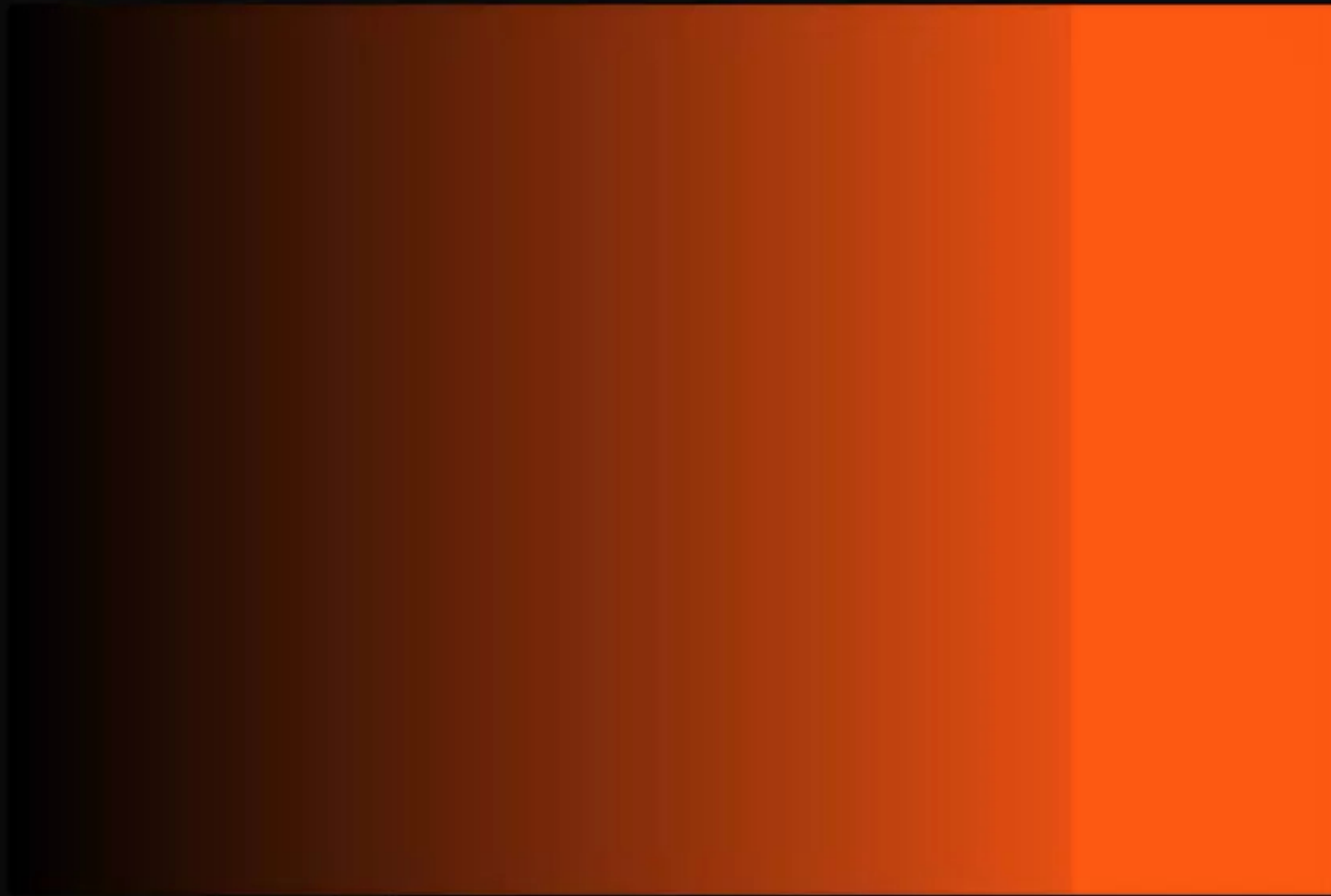
Why Does this happen

- Start with orange (255,88,21)



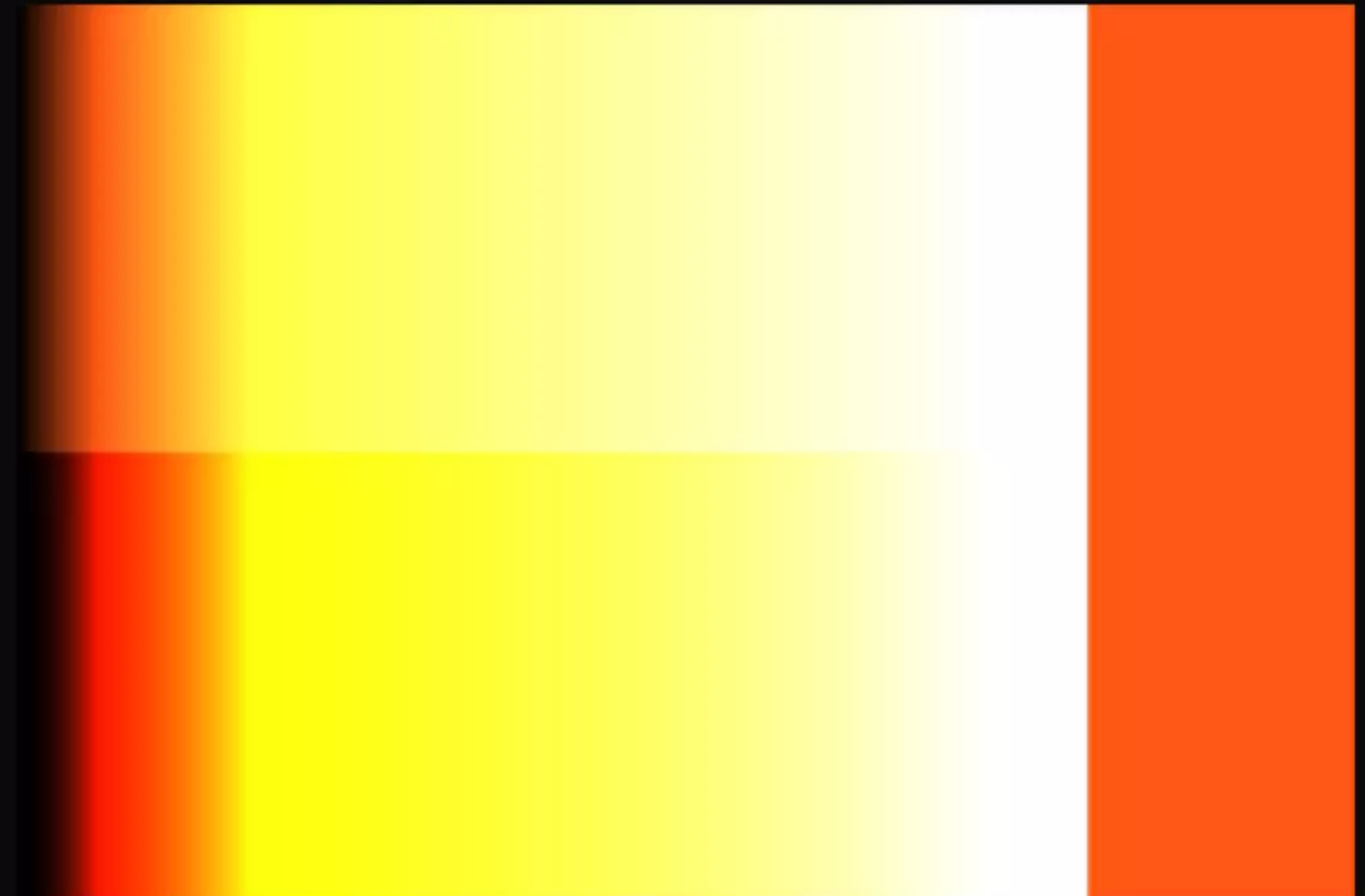
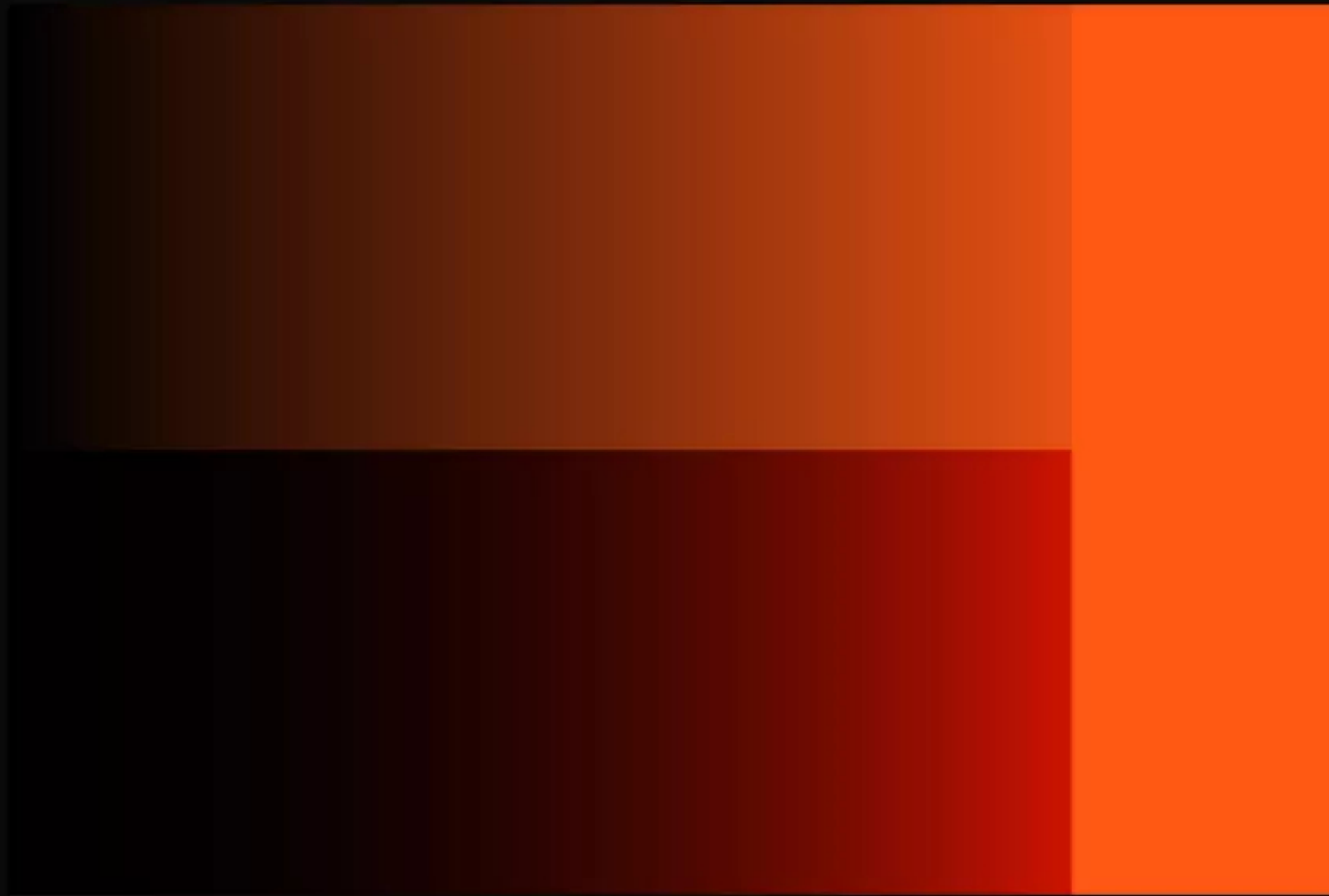
Linear Curve

- Linear curve at the low end and high end



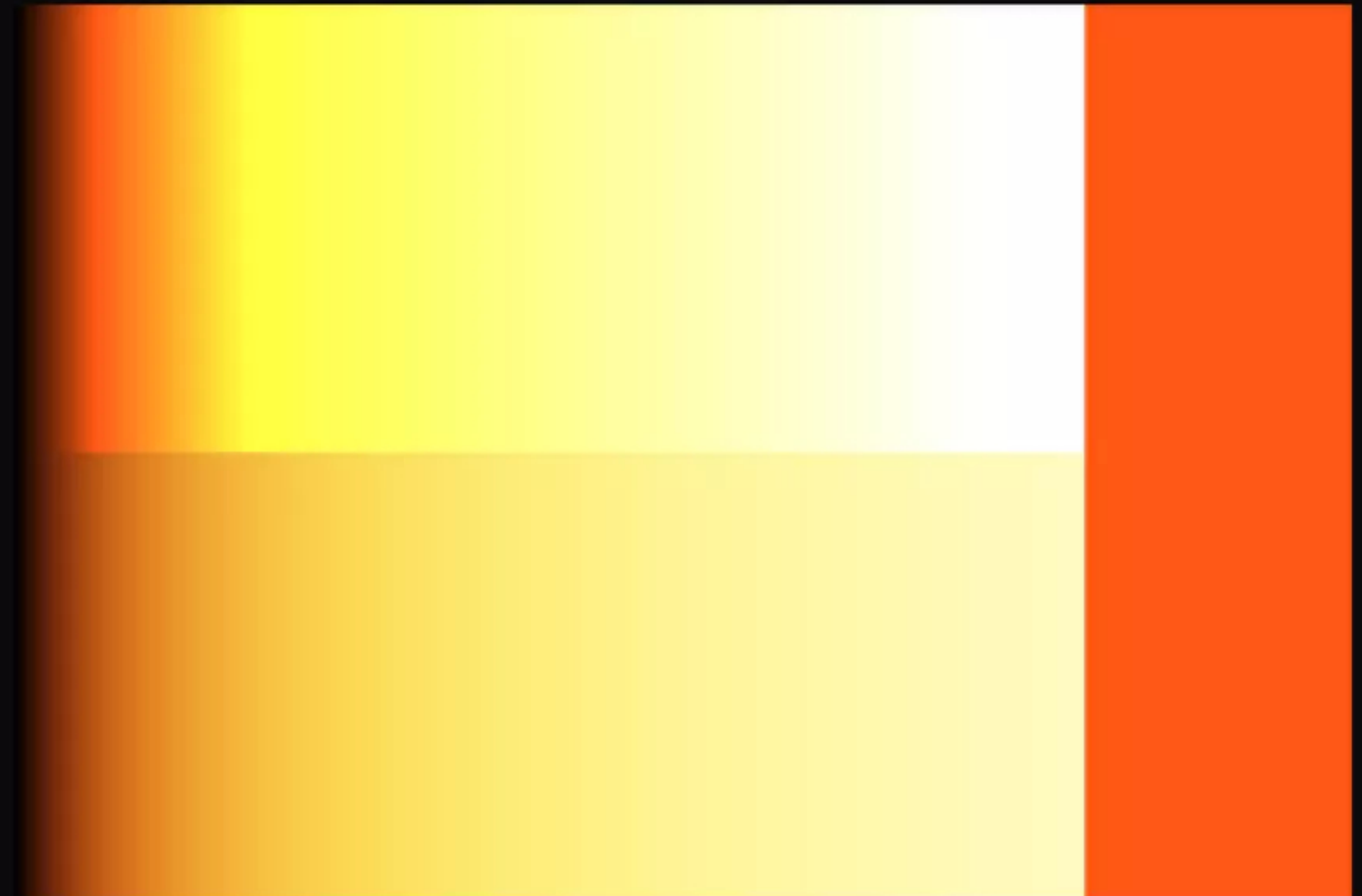
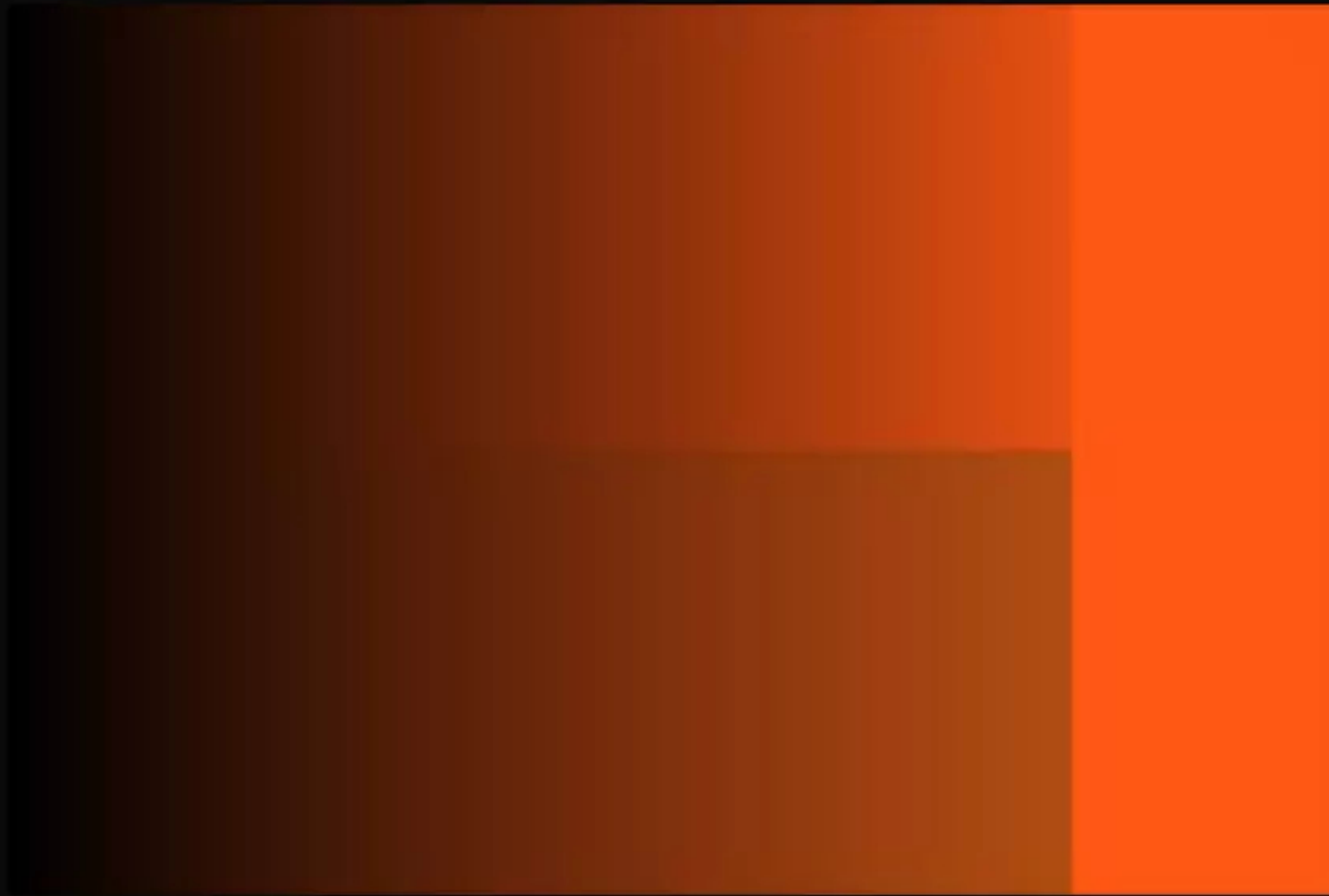
Bad Gamma

- Better blacks actually, but wrong color at the bottom and horrible hue-shifting.



Reinhard

- Desaturated blacks, but nice top end.



Color Changes

- Gee...if only we could get:
 - The crisper, more saturated blacks of improper gamma.
 - The nice soft highlights of Reinhard
 - And get the input colors to actually match like pure linear.

Voila!

- Guess what? There is a solution!

Voila!

- Solution by Haarm-Peter Duiker
- CG Supervisor at Digital Domain
- Used to be a CG Supervisor on LMNO at EA

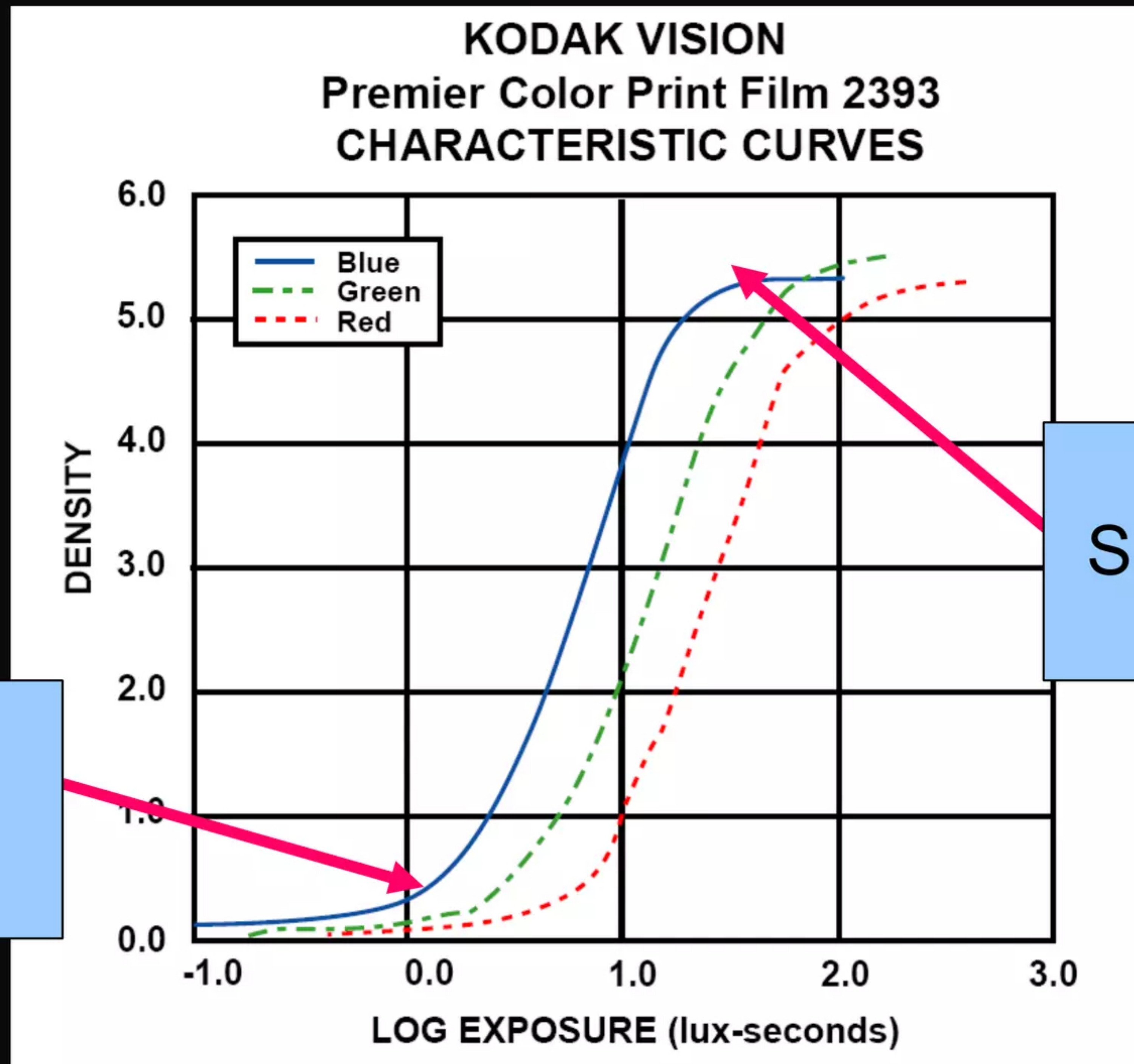
Film

Q) Why do they still use film in movies?

A) The look.

Film

- Kodak film examples.



Toe

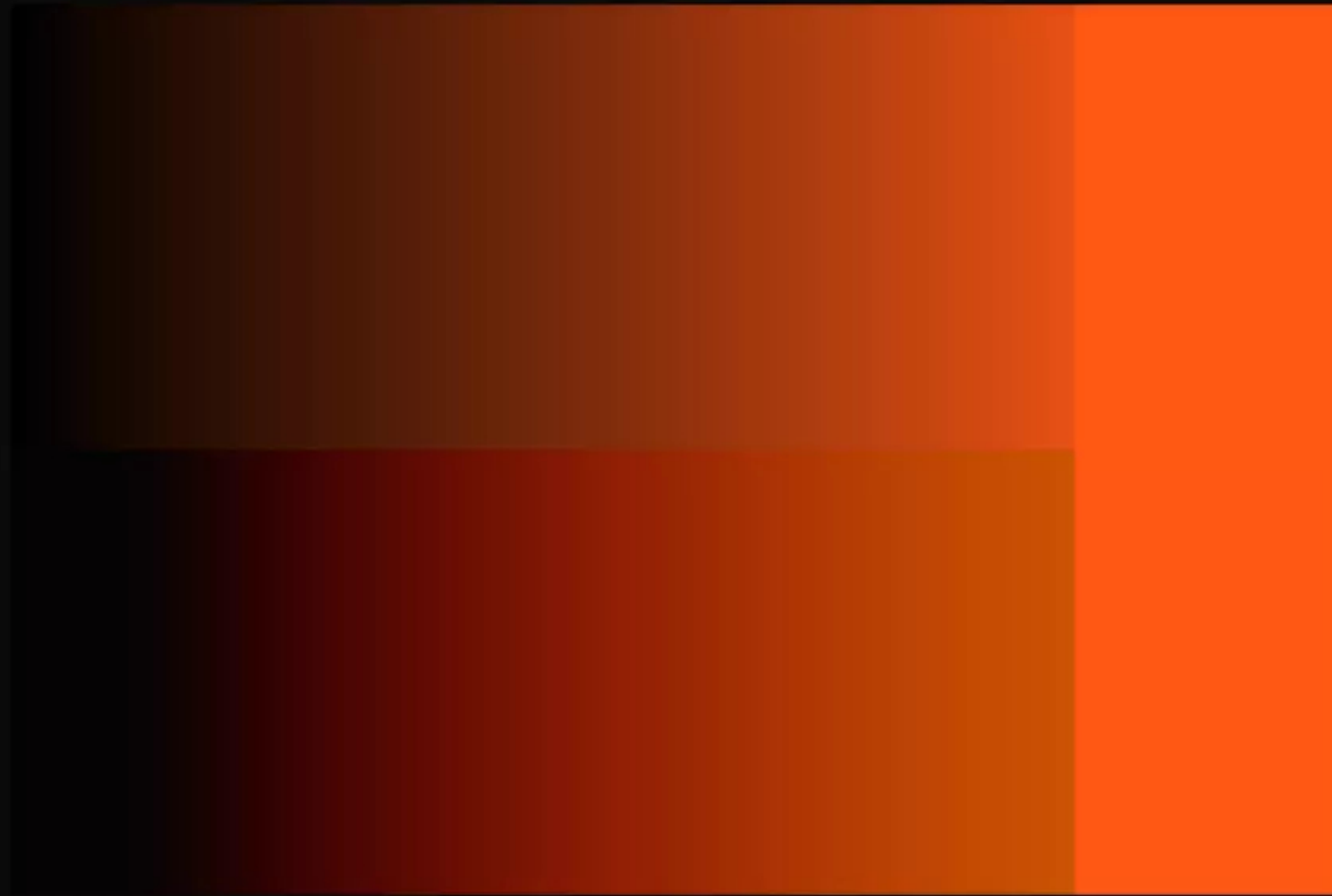
Shoulder

Film

- Using a film curve solves tons of problems.
- Film vs. Digital purists.
- Who would've thought: Kodak knows how to make good film.

Filmic Curve

- Crisp blacks, saturated dark end, and nice highlights.



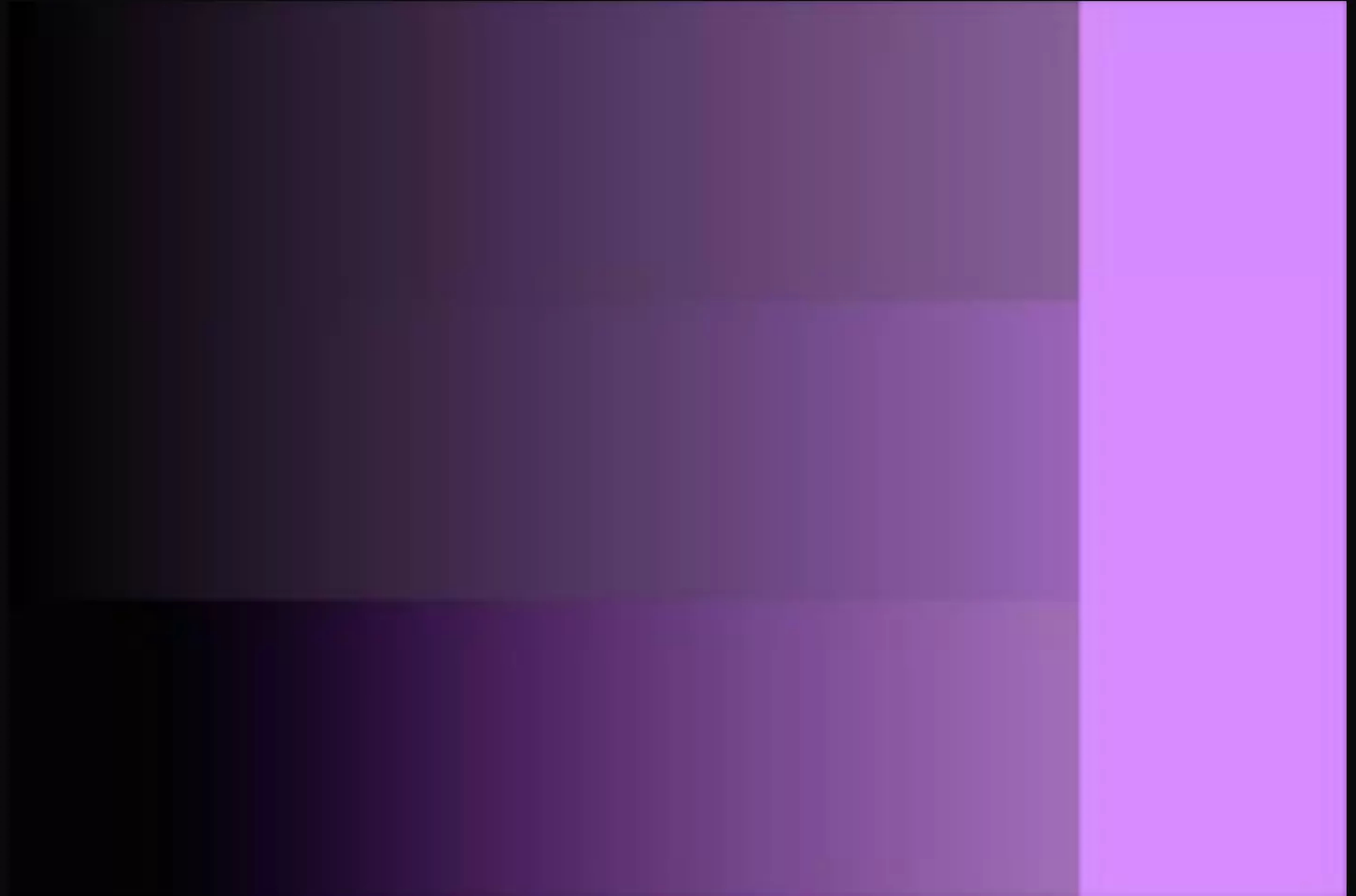
Filmic Tonemapping

- This technique works with any color.

Reinhard

Linear

Filmic



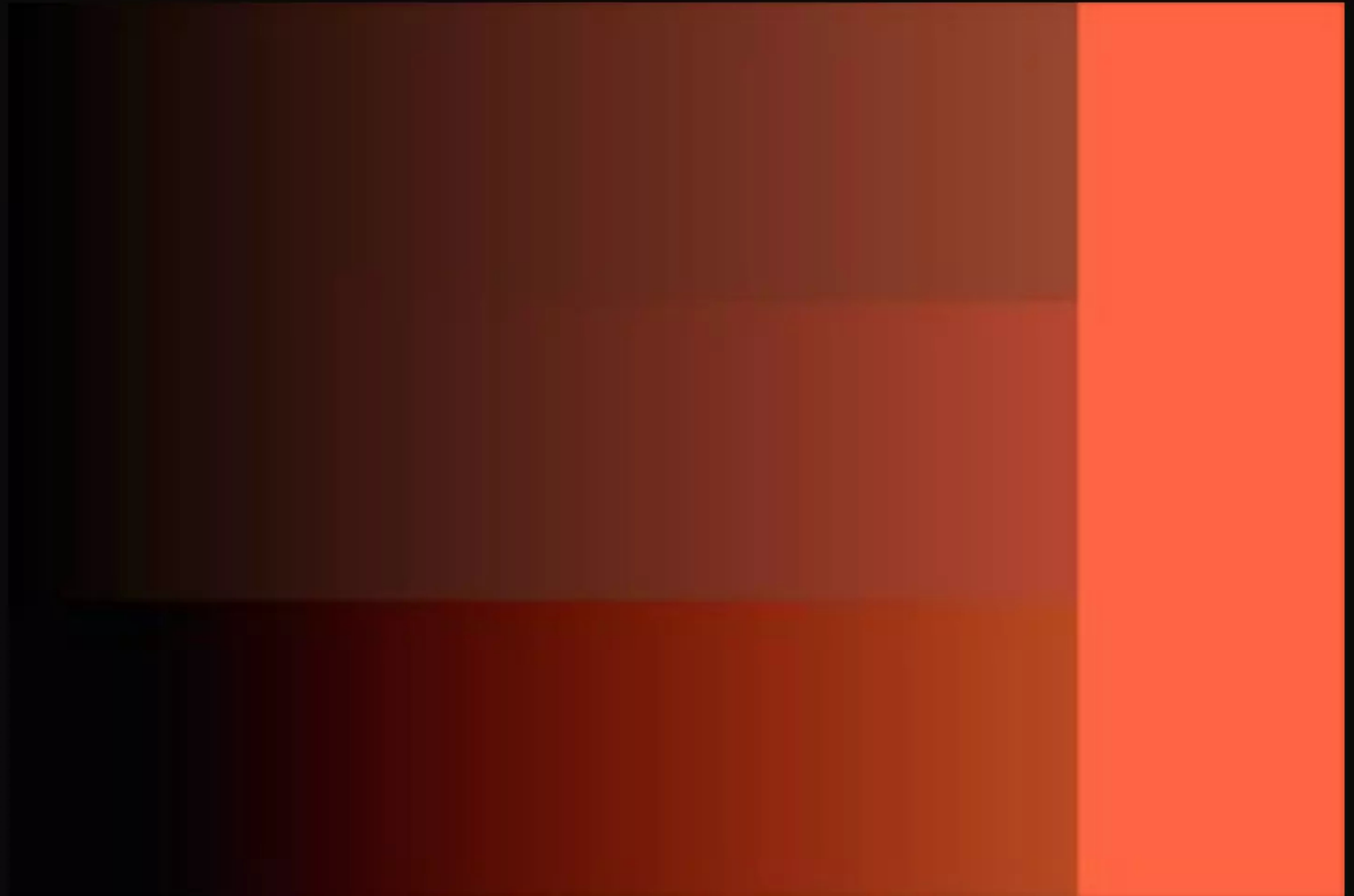
Filmic Tonemapping

- This technique works with any color.

Reinhard

Linear

Filmic



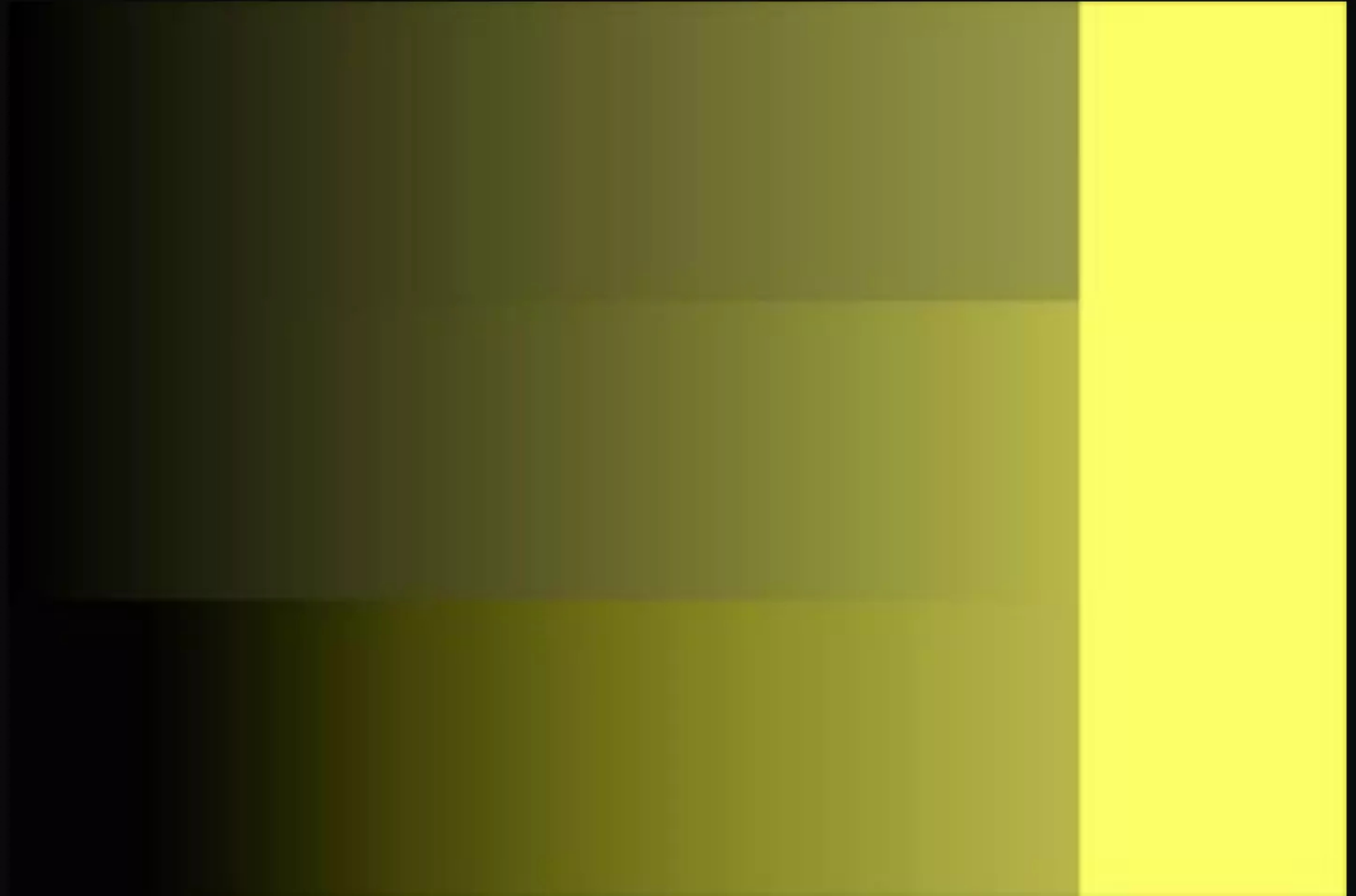
Filmic Tonemapping

- This technique works with any color.

Reinhard

Linear

Filmic



Filmic Tonemapping

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