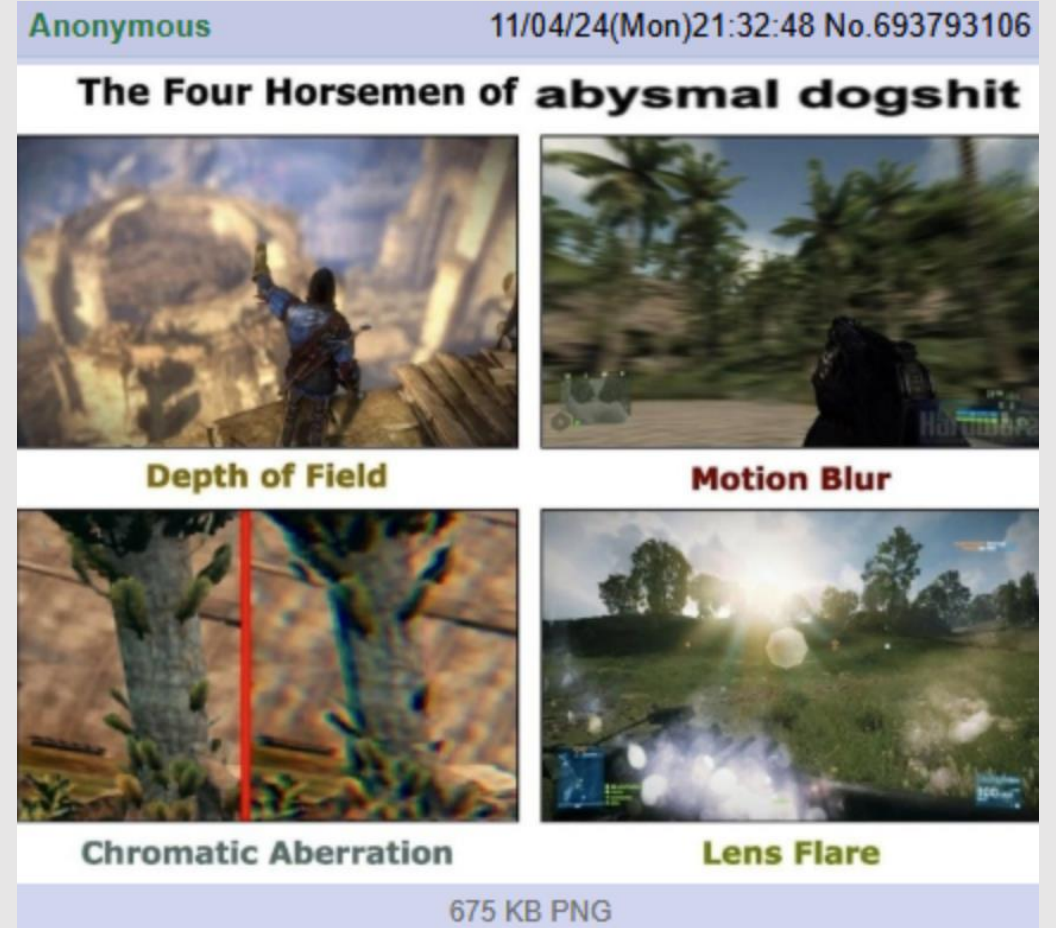


Special Topics in A3: Non-Photorealistic Rendering

- **NPR Introduction**
- NPR Features

Non-Photorealistic Rendering

- Focuses on creativity/expressiveness in rendering
 - Not concerned with making **physically-accurate results**
 - Other names:
 - Toon-shading
 - Cel-shading
 - Stylized Rendering
- Famous for using 3D graphics to create 2D stylings
 - Paint-like
 - Sketch-like
 - Comic-like
 - Cartoon-like
- **Idea:** change the way light interacts with geometry
 - NPR BRDFs



NPR In Media



NPR In Games



Legend of Genshin or something, idk I don't play video games (2017) Nintendo

Unpacking The Spot and Hobie's Disruptive Styles in 'Spider-Man: Across the Spider-Verse'

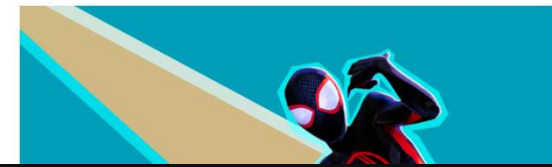
Production designer Patrick O'Keefe dives deep into two of the hit film's most underrated characters, including one who is more 'unnatural disaster' than 'villain' and one based on 'continuous noise' and 1970s London punk rock.

By Victoria Davis | Wednesday, July 12, 2023 at 1:19pm
In 2D, 3D, Art, CG, Films, People, Visual Effects | ANIMATIONWorld | Geographic Region: All



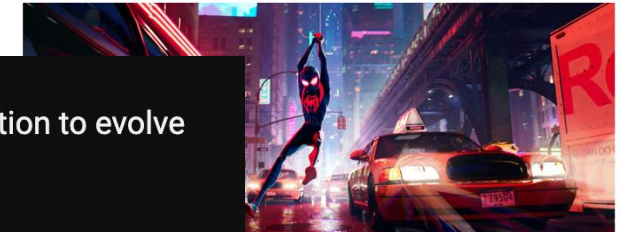
NPR In Movies

'Spider-Man: Across the Spider-Verse' and the Hollywood animation



How the 'Spider-Verse' Animators Created That Trippy Look

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VULTURE

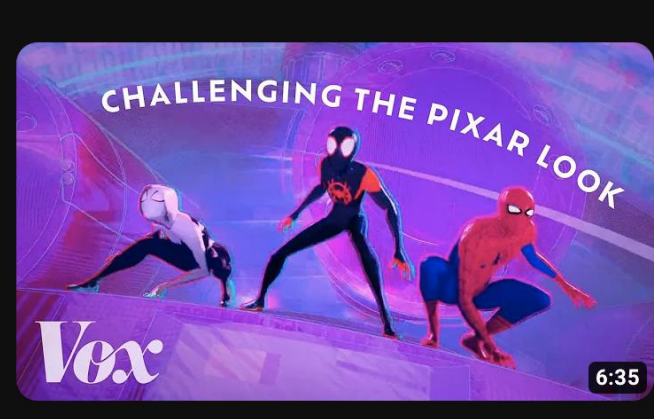
How Spider-Man: Into the Spider-Verse Animation Game

By Charles Bramesco, a freelance film and TV critic



Photo: Sony Pictures Animation

Spider-Man, Spider-Man, he does whatever a spider can — but with the web-slinger's latest feature outing, *Spider-Man: Into the Spider-Verse*, an elite creative team set out to redefine just what a spider could do.



How "Spider-Verse" forced animation to evolve

3.3M views • 1 year ago



Non-photorealistic rendering has opened up an alternative to the ubiquitous

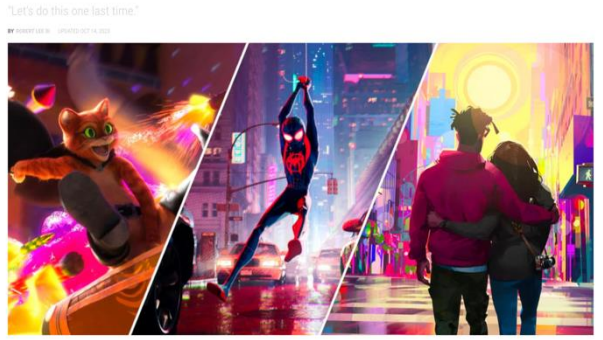


How 'Spider-Man: Across the Spider-Verse' Directors Crafted That Signature Spidey Animation Style

By Murtada Elfadl



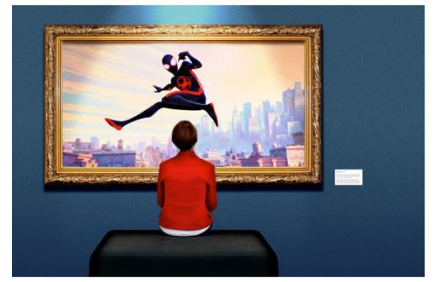
14 Stylized Animated Movies to Watch If You Love 'Spider-Man: Across the Spider-Verse'



"Spider-Man: Across the Spider-Verse" defies boundaries of animation

Jun 1, 2023 - World

Martha E. Franco (Noticias Telemundo for Axios)

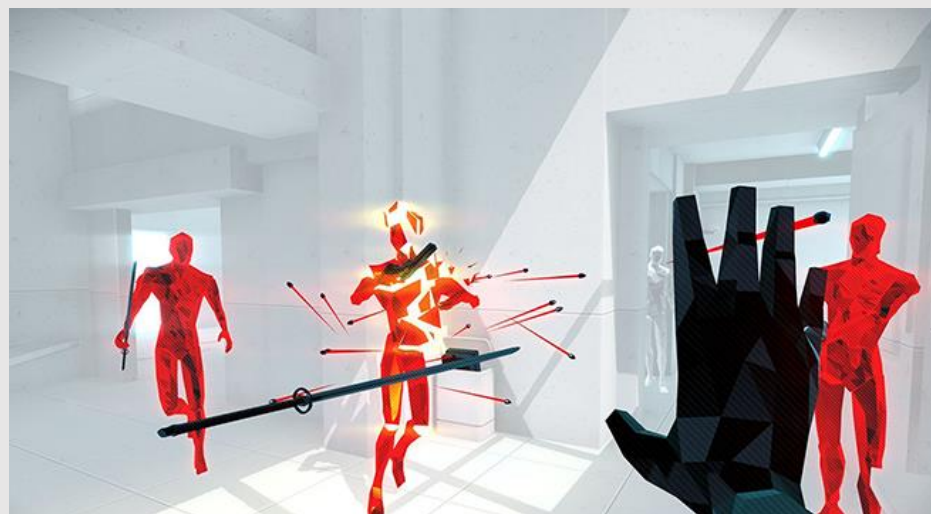


Across the Spider-Verse — one of the most anticipated movies of the summer — is redefining the boundaries of animation.

NPR Styles: Low Poly



Lonely Mountains Downhill (2019) Megagon Industries



SuperHot (2016) SuperHot Team



What The Golf (2019) Triband

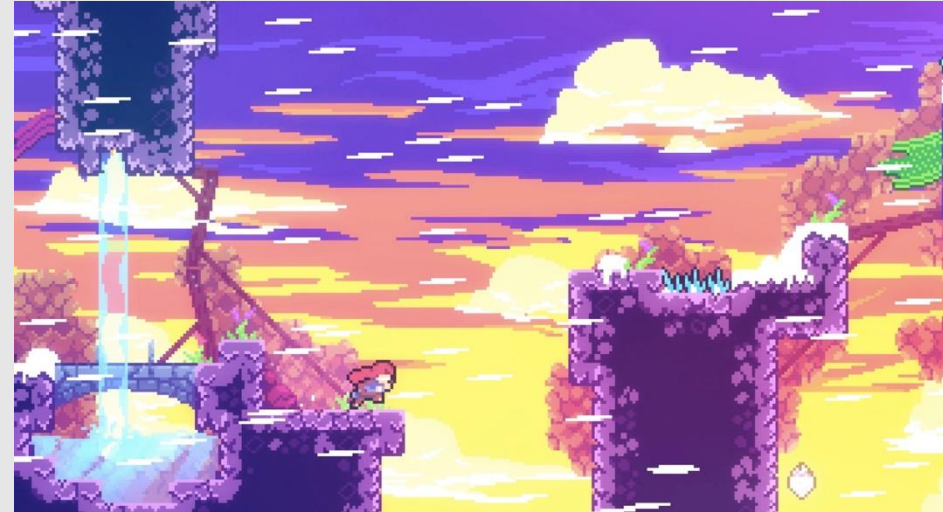


Minecraft (2011) Mojang

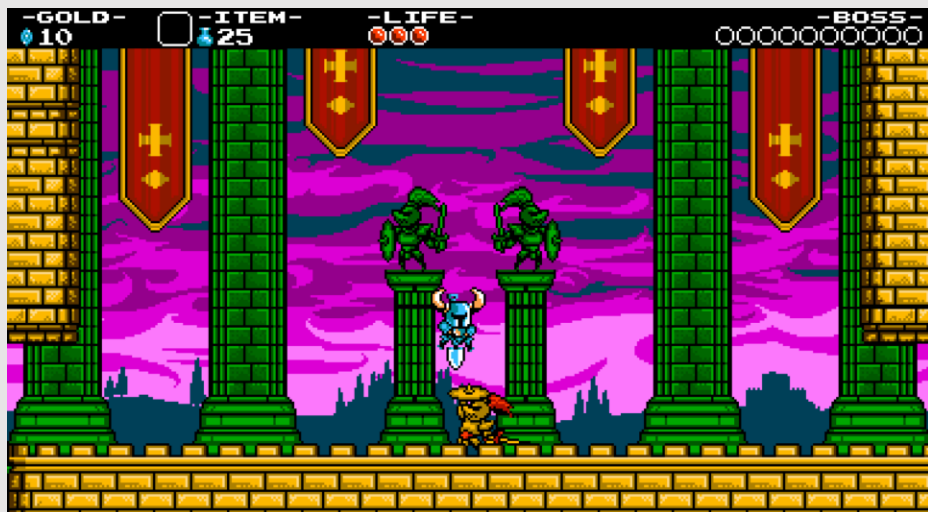
NPR Styles: Pixel Art



Enter the Gungeon (2016) Devolver Digital



Celeste (2018) Maddy Makes Games



Shovel Knight (2014) Yacht Club Games



Stardew Valley (2016) Eric Barone

NPR Styles: 2D Animation



Snow White (1937) Walt Disney Animation Studio



Klaus (2019) SPA Studios



Moana (2016) Walt Disney Animation Studio



The Bad Guys (2022) Dreamworks

NPR Styles: Ghibli Animation



My Neighbor Totoro (1988) Studio Ghibli



Ponyo (2009) Studio Ghibli



Spirited Away (2001) Studio Ghibli



Earwig And The Witch (2020) Studio Ghibli

NPR Styles: Comic Book



Spiderman vs Superman



Peanuts



One Piece Netflix Adaptation



Lore Olympus

Halftone Printing

- Also referred to as **stippling**
- Printing used to require carving out blocks and dipping them in ink to press onto sheets of paper
 - Printing many small dots was an easier way to print images
 - Can create gradients with varying dot sizes
- Subtractive color scheme: print colors on top of each other on white paper to produce darker colors
 - Example: CMYK
- Printing many small CMKY dots produced color prints
 - The alignment offset caused by printing error became known as the 'comic book' style



- ~~NPR Introduction~~

- **NPR Features**

Non-Photorealistic Rendering

- NPR rendering is heavily based off of 2D art
 - What are the components of 2D art?
 - Solid color
 - Hard shadows
 - Outlines
- **Goal:** achieve these components in our renderer
 - We want our 3D graphics to look like 2D graphics



Wish (2023) Walt Disney Pictures

Solid Colors

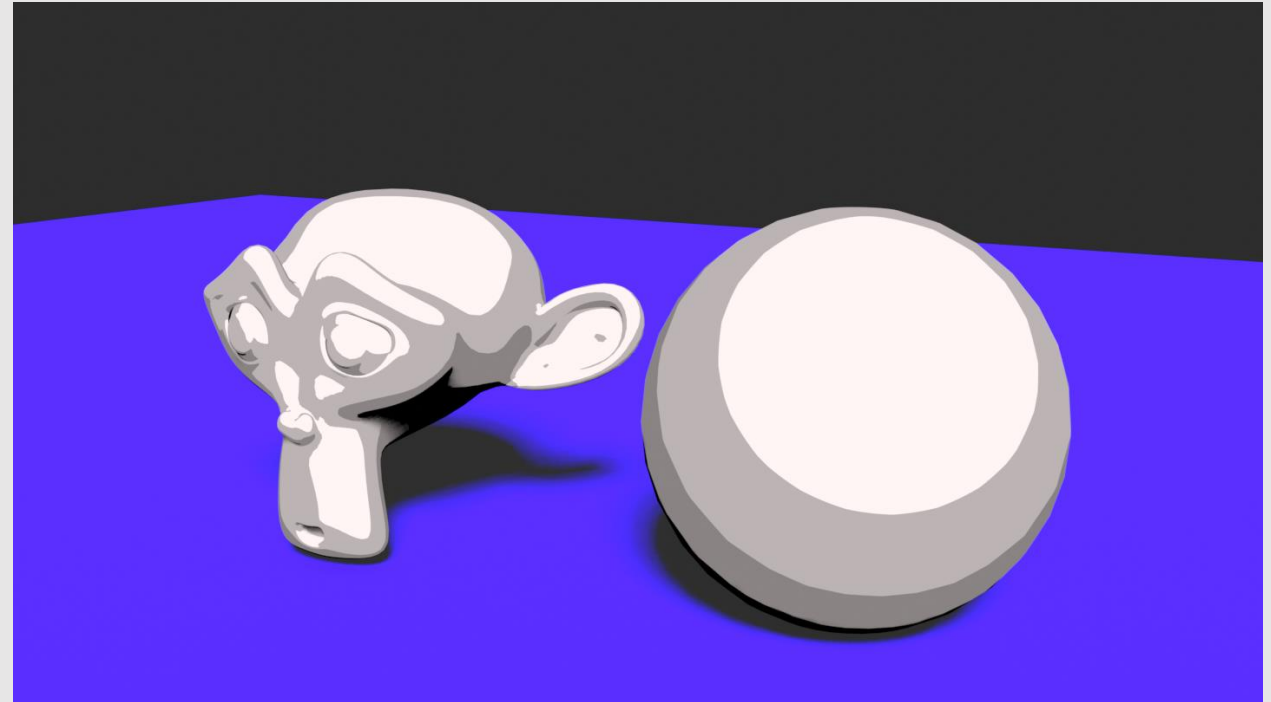
- The foundation of NPR is **solid colors**
 - Rather than interpolating colors at vertices, set solid colors for entire regions
- Emphasize bold, contrasting colors
 - Want to be able to tell apart different elements from their colors
 - Some shadows are baked in
 - Ex: hair
- Can add hard shadows for volumetric effect



The Legend of Zelda: The Wind Waker (2002) Nintendo

Hard Shadows

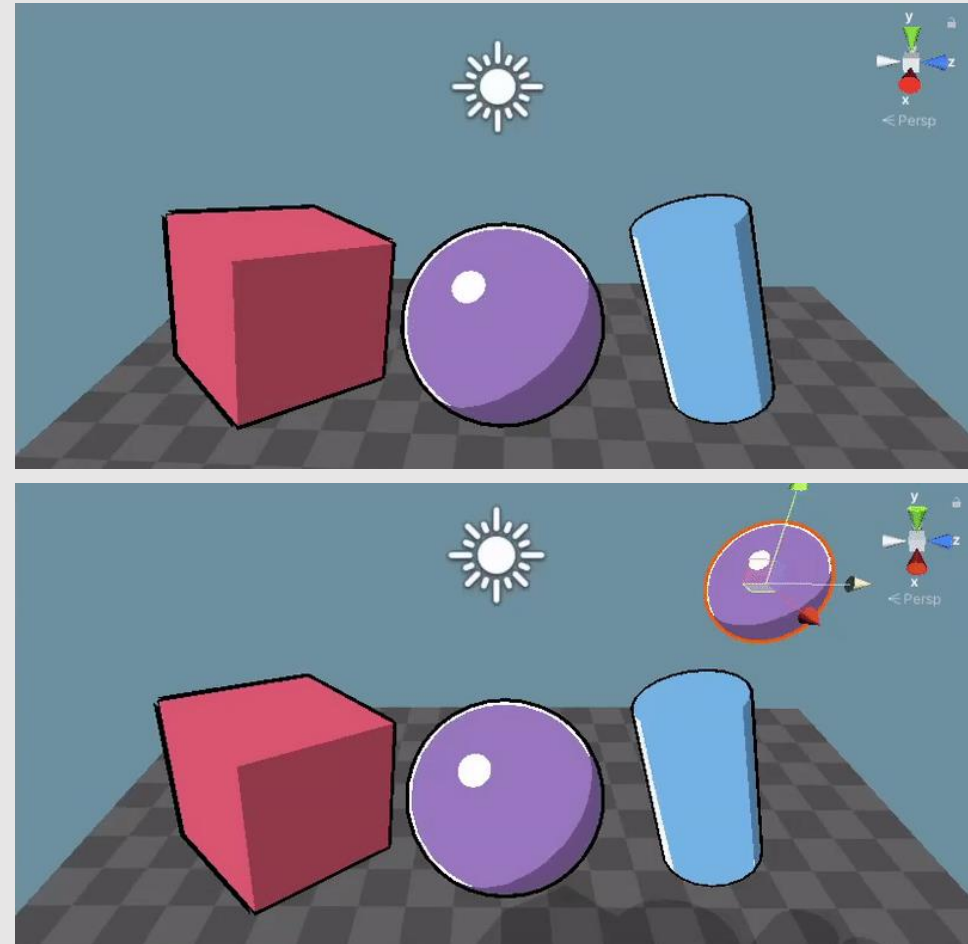
- Shading was an expensive task in 2D animation
 - Saved time by drawing hard shadow layers instead of shadow gradients
 - Replicated in NPR for the '2D look'
- **Algorithm:**
 - Extract world-space normal
 - Take dot-product with camera look-at direction
 - Threshold values, mapping to 0 or 1
 - Creates a binary mask
 - This is now your hard shadow
 - The larger the threshold, the larger the shadows
 - Repeat, changing threshold and shadow opacity for multiple hard shadows



Making A NPR Shader In Blender (2021) Maxime Garcia

Hard Shadows

- **Problem:** Hard shadows change as camera moves around
 - What if we instead want to add hard shadows from a light source?
- **Algorithm:**
 - Extract world-space normal
 - **Take dot-product with camera look-at direction world-space light vector**
 - Threshold values, mapping to 0 or 1
 - Creates a binary mask
 - This is now your hard shadow
 - The larger the threshold, the larger the shadows
 - Repeat, changing threshold and shadow opacity for multiple hard shadows
- Can also use for specular highlights + casting shadows!



Cel Shader (2021) Lewis Gadsby

N-dot-V Outline

- **Problem:** Want to identify where the outlines are in our model
- **Idea:** outlines are areas in the mesh that sit in between areas that face towards us and areas that face away from us
- **Algorithm:**
 - Extract world-space normal
 - Take dot-product with camera look-at direction
 - Look at areas where the dot product is close to 0
 - These are the edges to your model
 - Shade them darker



Ryner (2015) Lucas Gogol

Inverted Hull Outline

- **Problem:** Want to identify where the outlines are in our model
- **Idea:** outlines are areas in the mesh that sit in between areas that face towards us and areas that face away from us
- **Algorithm:**
 - Create geometry
 - Duplicate geometry
 - Create outline
 - Flip normals/Invert hull
 - Enable backface culling
- Outlines are now a separate geometry that sit on top of the original geometry



Cel-Shading (2020) Andrey Torchinsky

Painting

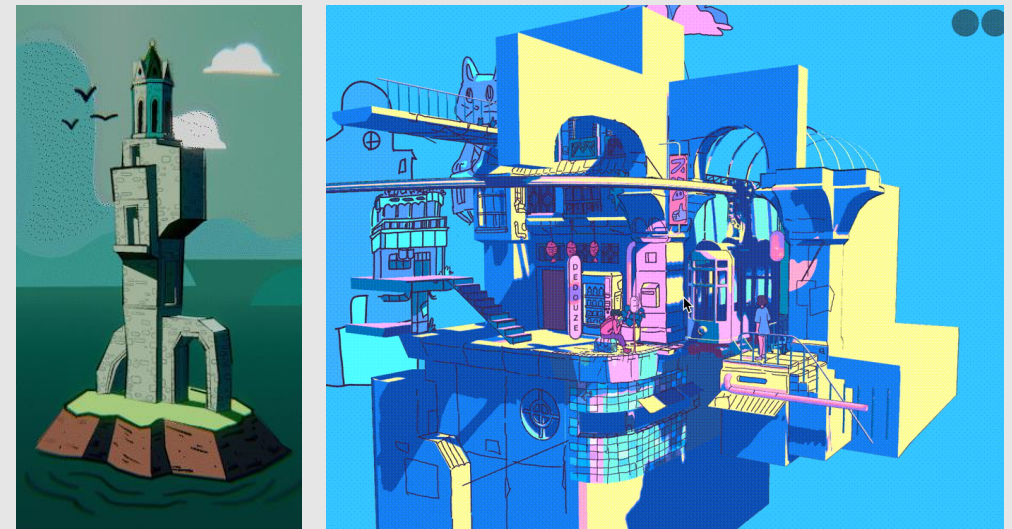
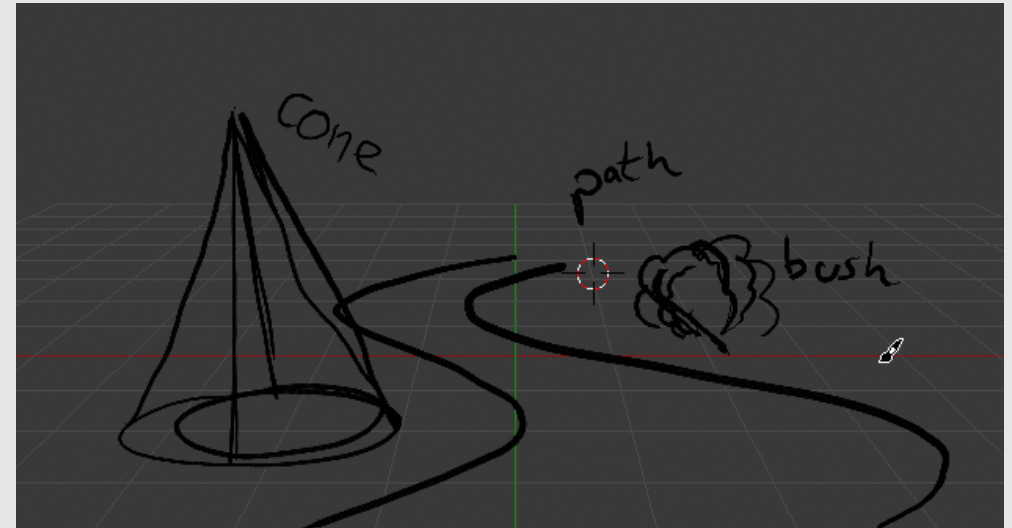


The Mitchells vs. the Machines (2021) Sony Pictures Animation

- **Problem:** want to get the hand-drawn look in animation
- Sometimes it is more work to automate a process than just doing the process
 - More work to write a shader than just draw it
- **Idea:** Draw 2D brushes on top of 3D frames
 - **Issue:** Where do those brush strokes sit in the scene?

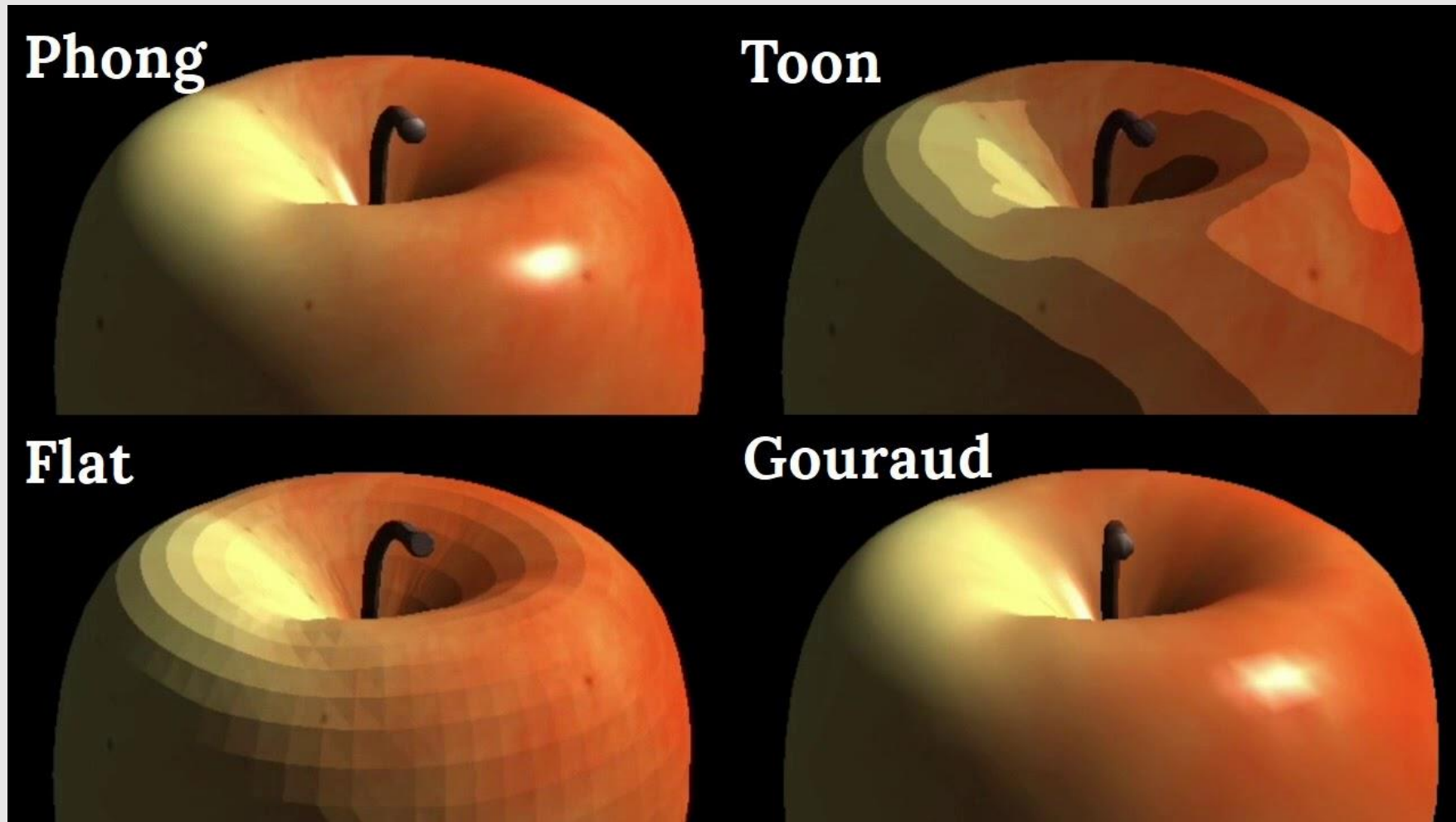
Grease Pencil

- Released in Blender in 2008
- Draw strokes on screen
 - Saved as a collection of points with vector paths passing through
 - Can be warped or manipulated
- Strokes saved to the XZ plane
 - Planes can be transformed in 3D
 - Changing the view of the camera changed where new strokes would be generated
- **Workflow:**
 - Draw strokes
 - Move strokes
 - Repeat



Blender Grease Pencil (2019) Nicola Sap, gskinner, Dédouze

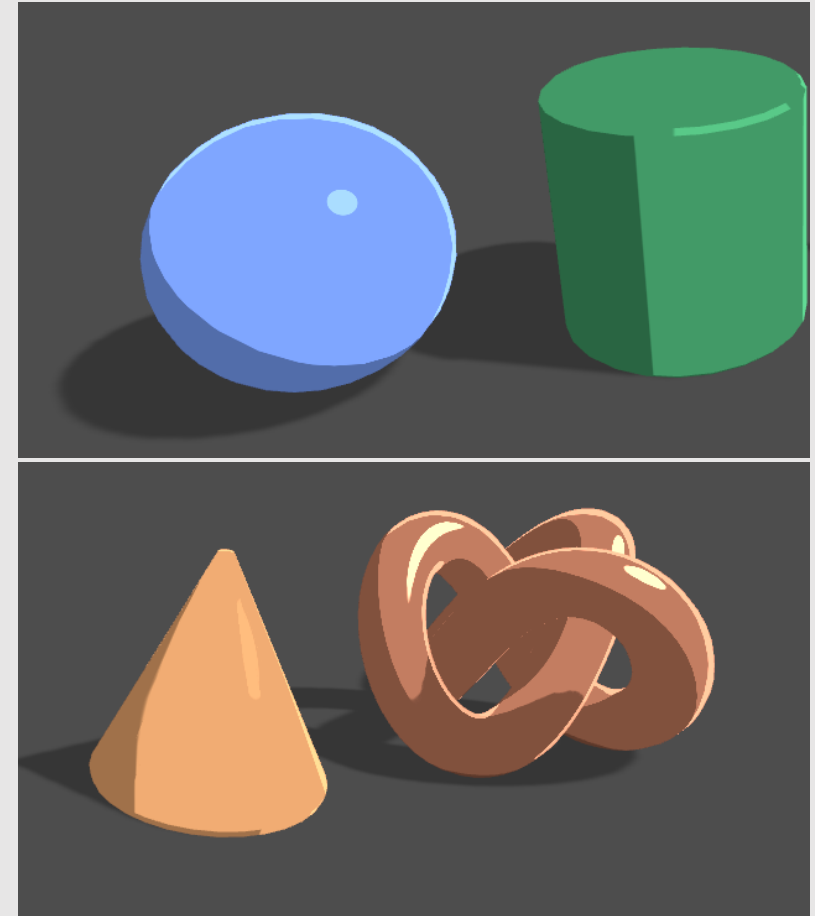
Shading Methods



Phong, Gouraud, Flat, and Toon shading in OpenGL (2017) Chih-Chun Hsu

Shading Methods

- **Flat Shading**
 - Shade entire primitive with the same surface normal
- **Phong Shading**
 - Interpolate normals at vertices using barycentric coordinates, then shade with interpolated normal
- **Gourad Shading**
 - Shade at each vertex with its vertex normal, then interpolate vertex colors using barycentric coordinates
- **Toon Shading**
 - Flat, Phong, or Gourad, with thresholding on lighting/color



What rules of rendering still apply in non-photorealistic rendering

The Rendering Equation

$$L_o(\mathbf{p}, \omega_o) = L_e(\mathbf{p}, \omega_o) + \int_{\mathcal{H}^2} f_r(\mathbf{p}, \omega_i \rightarrow \omega_o) L_i(\mathbf{p}, \omega_i) \cos \theta d\omega_i$$

$L_o(\mathbf{p}, \omega_o)$ outgoing radiance at point \mathbf{p} in outgoing direction ω_o

$L_e(\mathbf{p}, \omega_o)$ emitted radiance at point \mathbf{p} in outgoing direction ω_o

$f_r(\mathbf{p}, \omega_i \rightarrow \omega_o)$ scattering function at point \mathbf{p} from incoming direction ω_i to outgoing direction ω_o

$L_i(\mathbf{p}, \omega_i)$ incoming radiance to point \mathbf{p} from direction ω_i

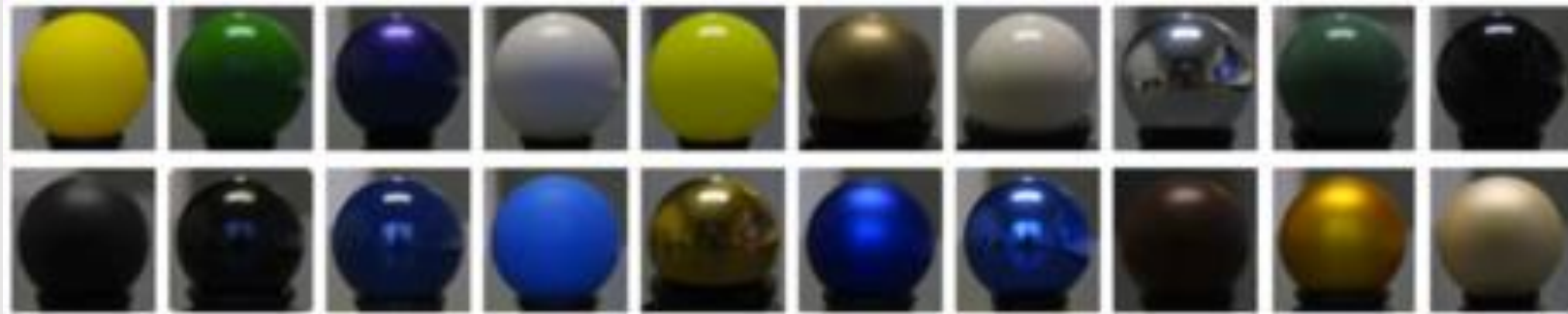
still the same rendering equation!

**Rendering equation describes
how light interacts in the volume**

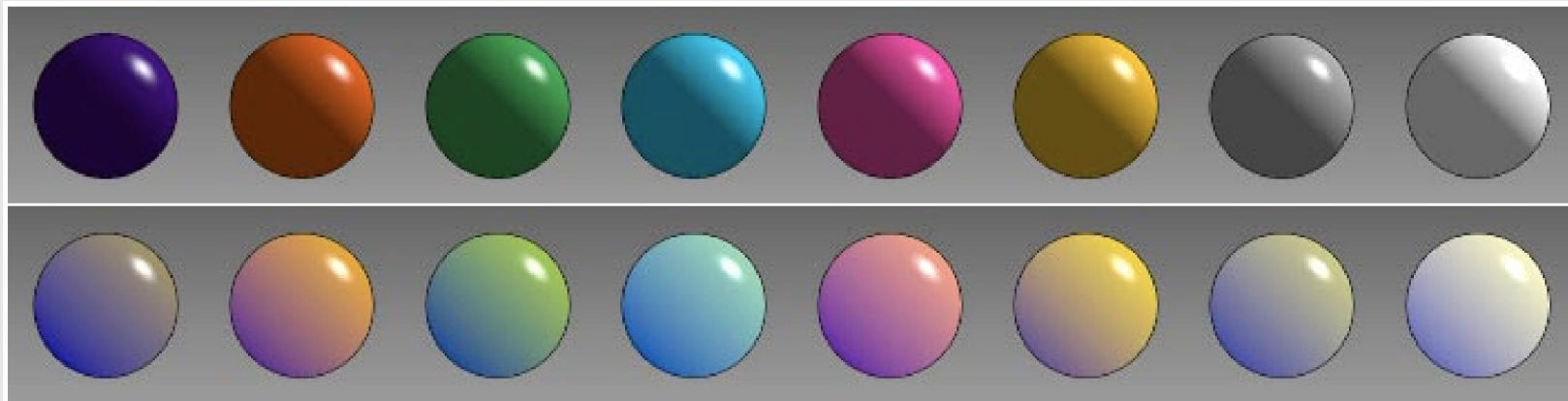
**between objects, not the objects
themselves!**

Materials

[Photorealistic Materials]



[Non-Photorealistic Materials]



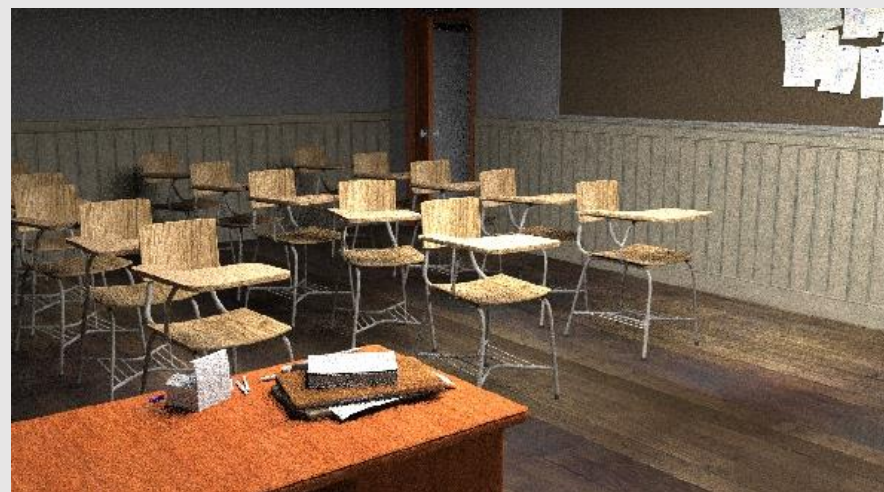
A Non-Photorealistic Lighting Model For Automatic Technical Illustration (1998) A. Gooch, B. Gooch, P. Shirley, E. Cohen

Number Of Ray Samples

- **Number of Rays**
 - How many rays we trace into the scene
 - Measured as samples (rays) per pixel [spp]
- Increasing the number of rays increases the quality of the image
 - Anti-aliasing
 - Reduces black spots from terminating emission occlusion



[1 spp]



[16 spp]

Bias & Consistency

- An estimator is **consistent** if it converges to the correct answer:

$$\lim_{n \rightarrow \infty} P(|I - \hat{I}_n| > 0) = 0$$



near infinite # of samples

- An estimator is **unbiased** if it is correct on average:

$$E[I - \hat{I}_n] = 0$$



even if just 1 sample

- consistent != unbiased**



[biased]

[unbiased]

do these rules apply to non-photorealistic renders?

Bias & Consistency

- An estimator is **consistent** if it converges to the correct answer:

$$\lim_{n \rightarrow \infty} P(|I - \hat{I}_n| > 0) = 0$$

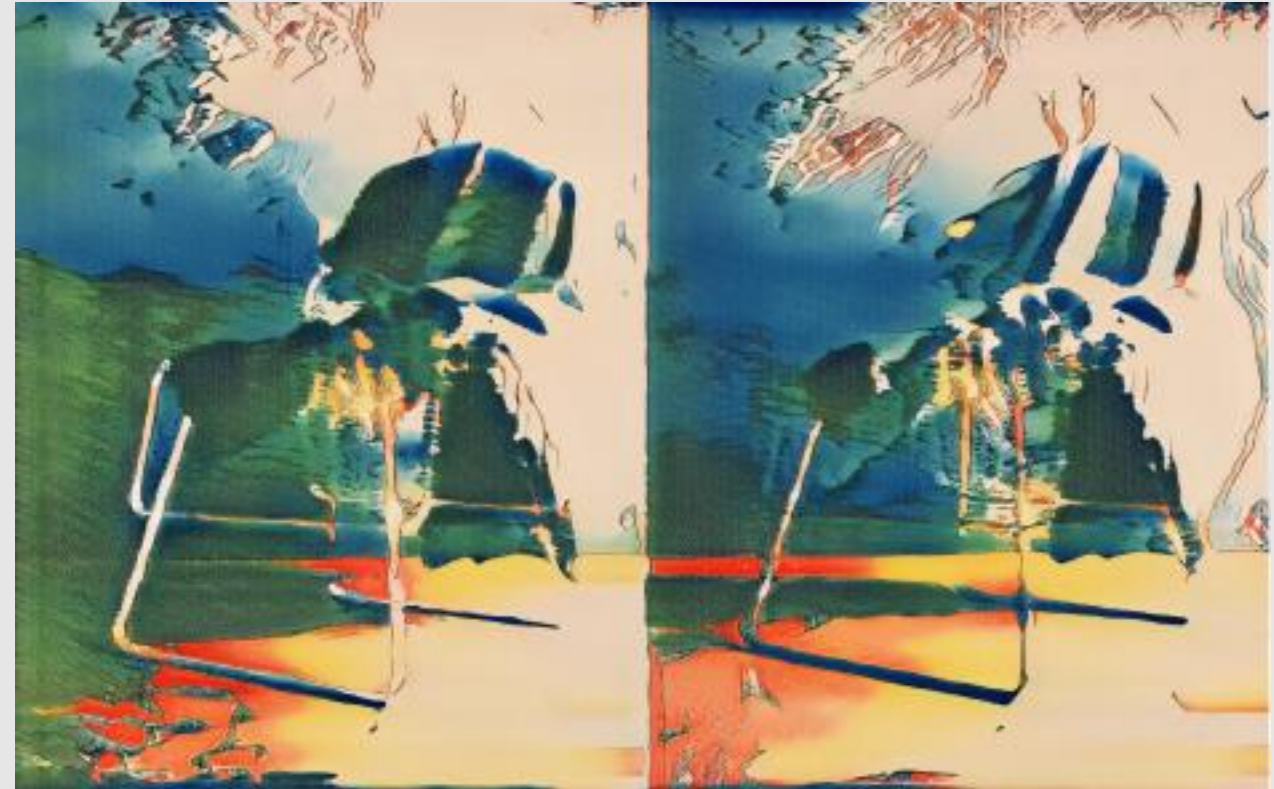
replace 'correct answer'

- An estimator is **unbiased** if it is correct on average:

$$E[I - \hat{I}_n] = 0$$

replace 'correct answer'

- consistent \neq unbiased



[biased]

[unbiased]

Course Roadmap



[A1: Rasterization]



[A2: MeshEdit]



[A3: PathTracer]



[A4: Animation]

Next Time