

Lighting & Rendering Techniques in Animation & VFX

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A Brief History of Lighting in Photography and Film

Lighting has been one of the most important aspects of visual media since its emergence, long before the world of computer generated imagery, and having an understanding of this is absolutely crucial for also understanding the digital technologies used in media production today.

Early photography relied entirely on natural light, which despite its limitations, was still experimented with and manipulated for artistic effect extensively by photographers at the time.^[1] The 19th century saw the introduction of artificial lighting, which opened possibilities even further (if dangerously in the early days of flash photography)^[2] and has only widened in following years with new techniques and technologies.

From photography came film. At the turn of the 20th century, film became more than simply moving pictures, but multi-scene narratives which gave way to the birth of special effects.^[3] By the 1920s, black and white film had truly found its footing, with three-point lighting becoming a standard technique and the limitations of no colour being used artistically for dramatic and bold lighting to convey depth and carry the tone of a scene. The 30s and onwards brought colour to the screen, allowing for further methods of communicating through use of symbolism, themes, and tone in a way that wasn't possible without.^[4]

Digital cinema is comparatively a very new concept, and a rapidly developing one at that. While film only first saw use of CGI technology in the 70s, rapid improvements followed, resulting in a boom for digital effects, and eventually in 1995 being brought Toy Story, the first feature length film created entirely with computer animation. From there, digital effects have only gotten more detailed, being able to do anything from photorealistic imagery to highly stylised works.^[5]

The technology of lighting and rendering is an absolutely crucial part of how we've gotten to today's high standards of animation and effects, which will be explained going forwards using this foundation of photography and cinematography history. From here on out, all discussion will be in relation to 3D rendering unless stated otherwise.

The Importance of Lighting in Visual Media

It's been firmly established that lighting is important for digital effects and animation, but why exactly is it so important? What is being achieved?

Jeremy Birn, long time Pixar animator specialising in lighting ^[6] highlighted a few key goals of a lighting designer in the book *Digital Lighting & Rendering*:

- Making things read
- Making things believable
- Maintaining continuity
- Directing the viewer's eye
- Emotional impact

He also said that lighting is designed to *'achieve certain visual goals that help a viewer appreciate a scene'*. ^[7 p9] Both practical and artistic uses are clearly outlined, presenting the work of lighting design to first be needed technically to make a scene understandable, and then to enhance it further to engage a viewer on a deeper level.

The work of lighting in a scene is one that should rarely be acknowledged, much like sound design in that aspect, where its invisibility speaks to its effectiveness. Birn summarised this best in a very simple statement:

'Your audience never consciously sees your lighting; instead they feel it' ^[7 p.13]

Lighting is a way of silently communicating emotional depth to an audience, not just visual depth in the image itself.

Physically Based Rendering, and the Transition to Ray Tracing in Animation

Physically based rendering (PBR) techniques are those which mimic real world physics to create realistic lighting, using a combination of different algorithms based on how light responds to different kinds of surface. This allows for amore intuitive workflow where very little tweaking of shaders is required when changing the lighting of a scene, especially in comparison to models such as Phong or Blinn. ^[7 p32]

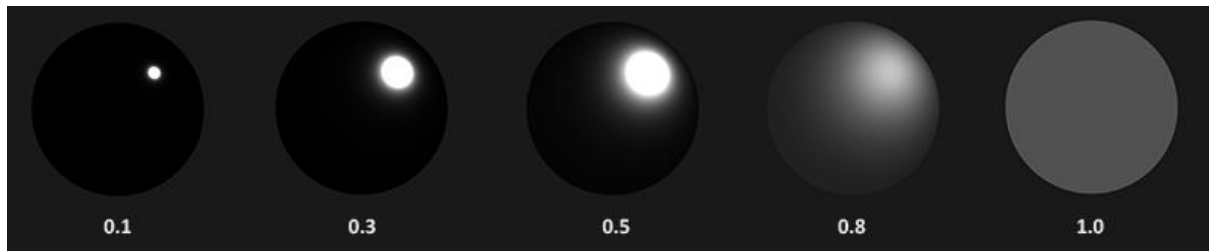
Some of the fundamental concepts it includes are:

- Microfacets/microsurfaces

These are used to simulate the roughness of a surface on a microscopic level- tiny imperfections in a surface that cause light to scatter more chaotically.



In practice, this means assigning a value of roughness to a surface which results in different levels of reflectiveness based on this scattering of light.

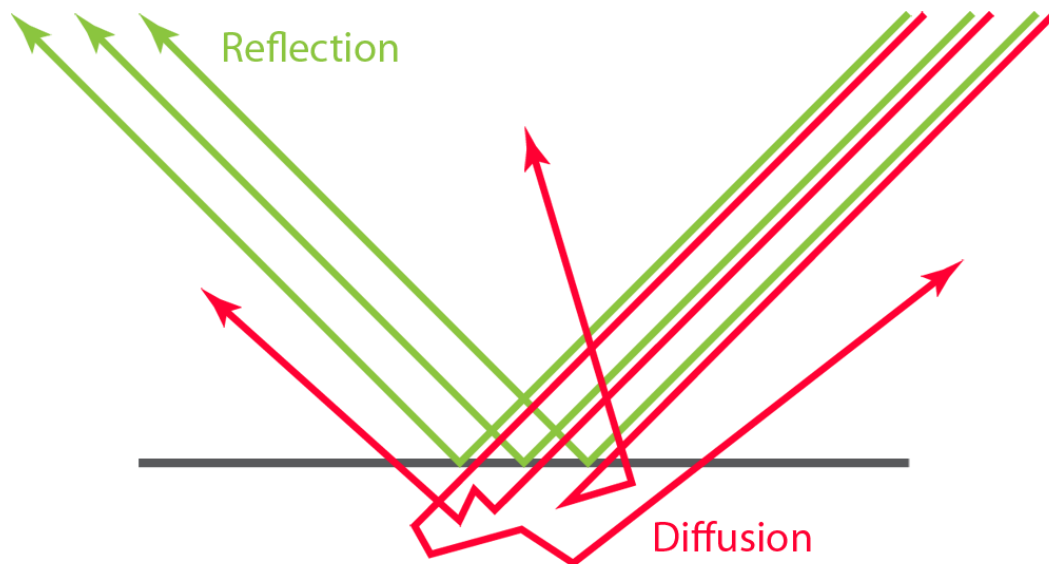


- Energy conservation

This is the concept that the amount of light emitted cannot be greater than the light hitting the object to begin with. The implementation of this is clear in the above image, where as the reflection becomes more scattered due to the surface roughness, the intensity is reduced and gives dimmer, wider spread reflections in comparison to its smoother counterparts.

- Specular and Diffuse

PBR views specular and diffuse light as entirely distinct from one another. Specular light describes light that bounces and reflects off a surface. Diffuse light is a little more complicated however- it's based on how light penetrates the surface of an object, some of which is absorbed and some of which will scatter and leave the object again.

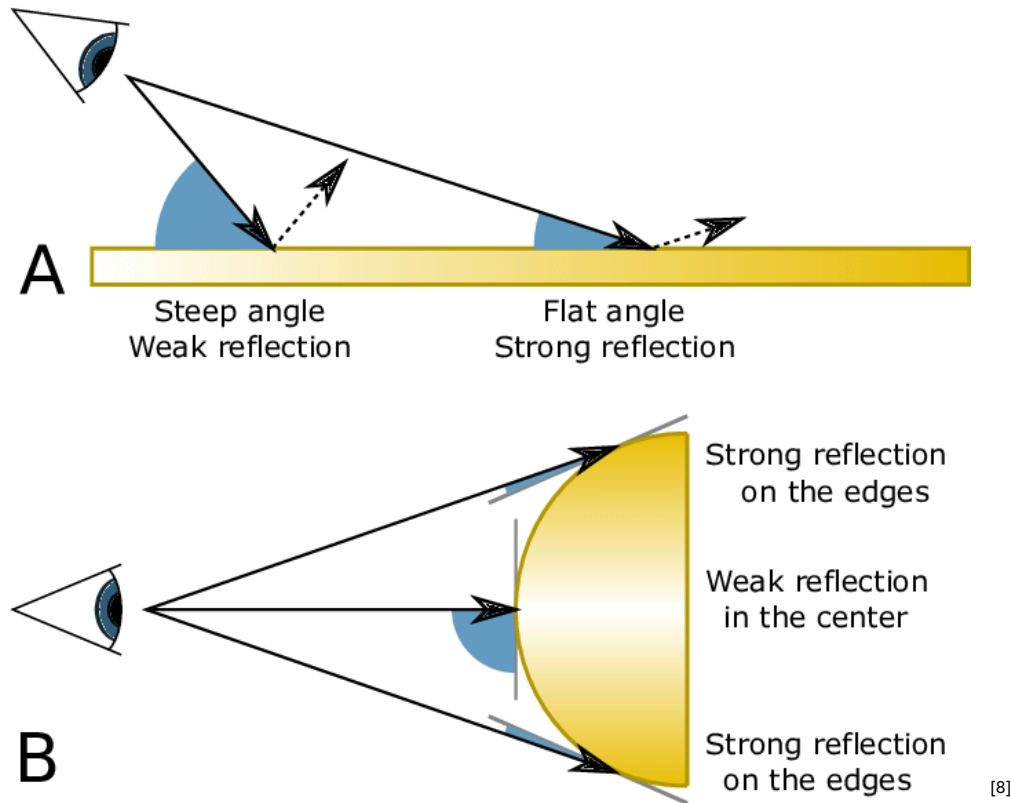


When this effect is incorporated into shaders, it's known as subsurface scattering.

Another important feature of diffuse and specular light in PBR is that for the sake of energy conservation, they are mutually exclusive to one another. Light that is reflected cannot also be diffused, and vice versa.

- Fresnel

The Fresnel effect describes the way reflections appear dependant on the angle an object is viewed at.



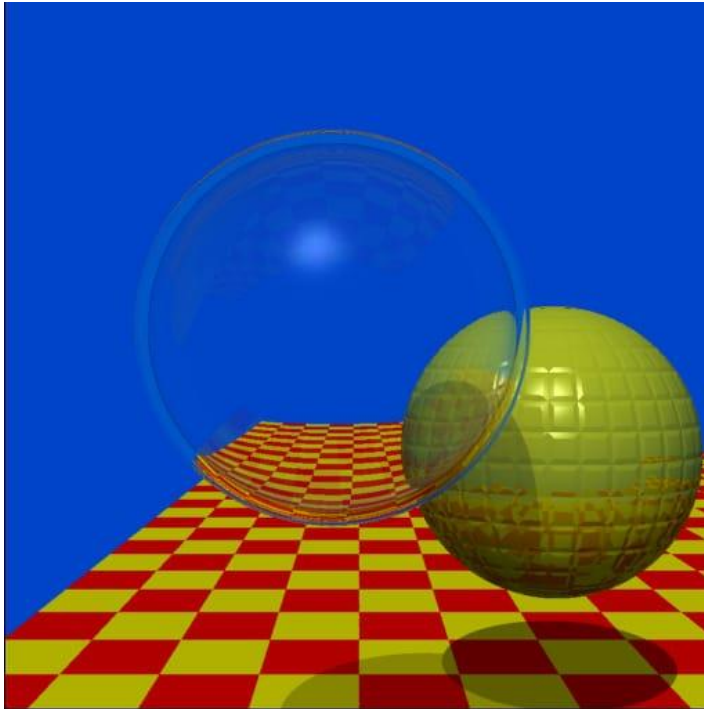
A reflection will appear stronger at a shallower angle on a flat surface, while on a curved surface the effect will be most visible on the edges of the object and weaker in the centre. ^[9]

- Metalness

Due to the unique qualities of metallic surfaces, some renderers will incorporate metalness as an adjustable surface parameter. This makes it far easier to display and account for the differences in how metals reacts to light, such as having very intense reflections with tinted colours, an effect not seen in other kinds of surface.

All these effects and more combine together to create what we know as Physically Based Rendering. ^{[10][11]}

Due to computational power, what was able to be produced using PBR was limited, even if revolutionary for the time. In 1980, computer scientist Turner Whitted created an early ray tracing model to improve upon the limitations of Phong shaders, creating



[13]

several images including the one attached here to demonstrate its applications in global illumination and reflections for materials. The image here took 74 minutes to render. ^[12]

While the technology continued to develop through the 80s, in practice it was generally unviable due to the high demands of ray traced, PBR graphics compared to the far more efficient rasterisation based rendering such as the Reyes algorithm. ^[14 p.49]

That was, until the 90s. Blue Sky

Studios began using a PBR work pipeline, catching attention with the unique visual appearance of their media which featured ray tracing using the Monte Carlo method (aka path tracing). The development of technologies was fast though- While Blue Sky's Ice Age (2002) was due to be the first ray traced feature length film, in the end it was Jimmy Neutron: Boy Genius (2001) which released three months prior. Regardless, their works represented a shift happening within the realm of computer generated works, serving to prove that ray tracing and PBR pipelines weren't just possible on a theoretical level, but viable for the industry as a whole. ^[15] Further ray traced films followed this as more ray tracing engines were developed and released commercially, such as Arnold which was first used on Monster House (2006). ^[14 p.51]

Up until this time, Pixar's RenderMan used exclusively Reyes based rendering in their films outside of very sparing uses, with ray tracing first used in A Bug's Life in two shots to create glass reflections. ^[16] Cars (2006) was the first film released by Pixar to utilise ray tracing as a key aspect of the rendering process, with RenderMan becoming a true hybrid software to maximise efficiency and quality. It used Reyes 'for rendering directly visible objects' and ray tracing 'for reflections, shadows, ambient occlusion' ^[17] to create the desired appearance of the film while combatting the challenges of having so much more complex scenes than seen in previous films. Ray tracing was particularly useful for creating the distinct appearance of the highly reflective and polished metallic appearance of cars in the real world.

[17, figure 1]

The image seen to the right demonstrates a test comparing the use of environment maps (left) and a combination of environment maps and ray tracing (right), which clearly shows the improved quality of reflections and light from the object itself such as the eyes being visible on the bonnet.

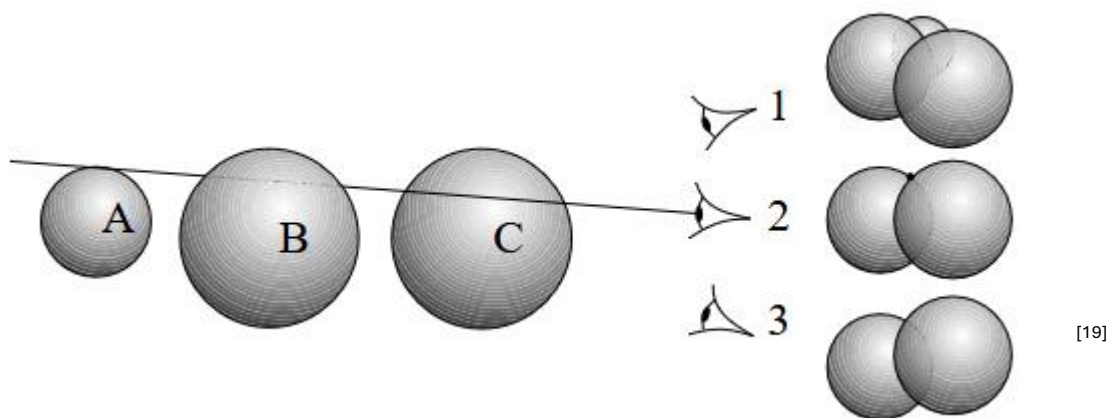


Since then, Pixar's RenderMan has been fully re-worked to be a ray tracing software over a hybrid, with its Reyes rendering systems being deprecated in 2016 to streamline working with its newer, more efficient ray tracing technologies. ^[18]

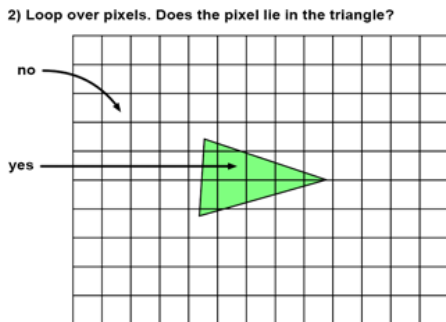
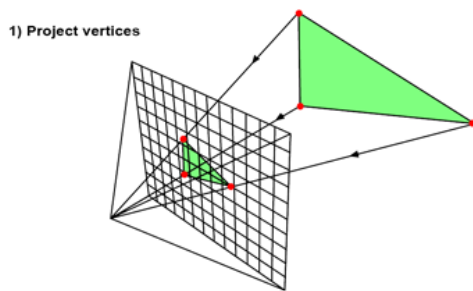
Rasterisation Vs. Ray Tracing in Modern Media

Throughout the discussion of Physically Based Rendering, both rasterisation and ray tracing techniques have been mentioned. What these techniques are and how they are chosen to be applied will be explored now.

The core of computer graphics is visibility, what precisely is and is not visible when viewed from a particular point. Rasterisation and ray tracing are both methods of determining this. 3D images are complex to determine, as small changes in the viewpoint can significantly change what is visible, and so specific techniques have been developed to make the outcomes both more realistic, and more computationally viable.

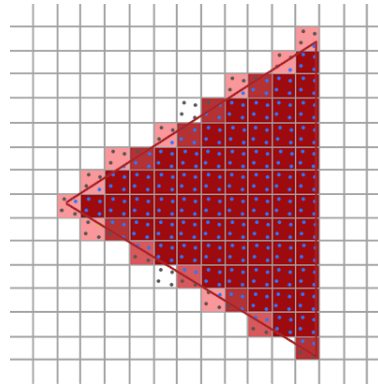
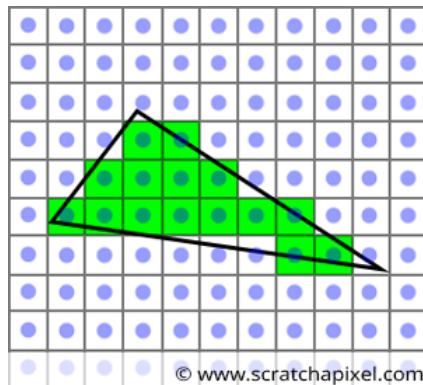


[19]



Rasterisation: This method projects 3D objects onto a 2D plane and converting it into pixels using a raster grid, removing anything that isn't visible and assigning colour values to what is. This process is highly efficient, and creates a simple way of determining whether an object should or should not be visible on any given pixel.

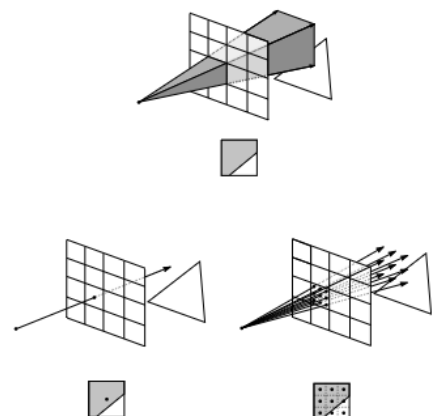
This process can be improved further through the use of sub-pixel values. The images below show basic rasterisation algorithms in action, with the left image showing single point samples, and the right with sub-sampling (aka anti-aliasing), which will assign different coloured values to give the appearance of softened edges and remove the jagged appearance. [20] [21] [22]

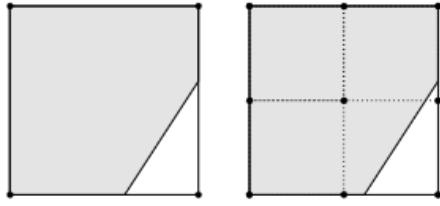


Ray tracing: The methods for ray tracing work a little differently to rasterisation.

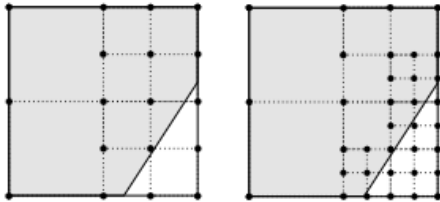
Rasterised images are built around the objects themselves; ray tracing uses simulated rays of light to determine what is and is not visible. A ray is traced from the viewpoint to each pixel until it hits a surface, and from the light source to the surface being rendered to determine light and shadow. If a ray's path is blocked by a surface, it will produce a shadow. [7 p.84]

Anti-aliasing can also be utilised in ray tracing, however in this instance it is done through casting additional rays per pixel. This makes the already slow and computationally intensive process even slower though, so adaptive sampling can be utilised to combat this to create a balance between quality and resources.





This doesn't remove the problem entirely, as ray tracing remains an intensive method of rendering regardless, but such solutions as this aid in reducing the intensity without fully sacrificing the quality of imaging. ^[23]



The toll on a computer's memory and the slow rendering speeds have always been the key difficulties with ray tracing, which is why its use in visual media is still relatively new with fast changing technology.

Ray tracing is implemented most significantly within film than anywhere else. As discussed previously, Pixar introduced ray tracing gradually, but 2013's *Monster's University* was the turning point for the studio in this regard, where their rendering process was rewritten to fully embrace the use of ray trace technology, and set a golden standard for lighting in animation. ^[24]



Ray tracing technology has seen just as much popularity in visual effects for live action media for film, and recently, television as well with shows like *The Mandalorian* and *Watchmen*. ^[25]

The main industry that hasn't seen the same sweeping popularity, is the realm of video games. While ray tracing is supported in more and more games now, it hasn't taken off in the same way as in other industries. This is because of the need for real time rendering. As mentioned before, ray tracing is a slow and intensive process, but an interactive game that has to render in response to your inputs needs to be near

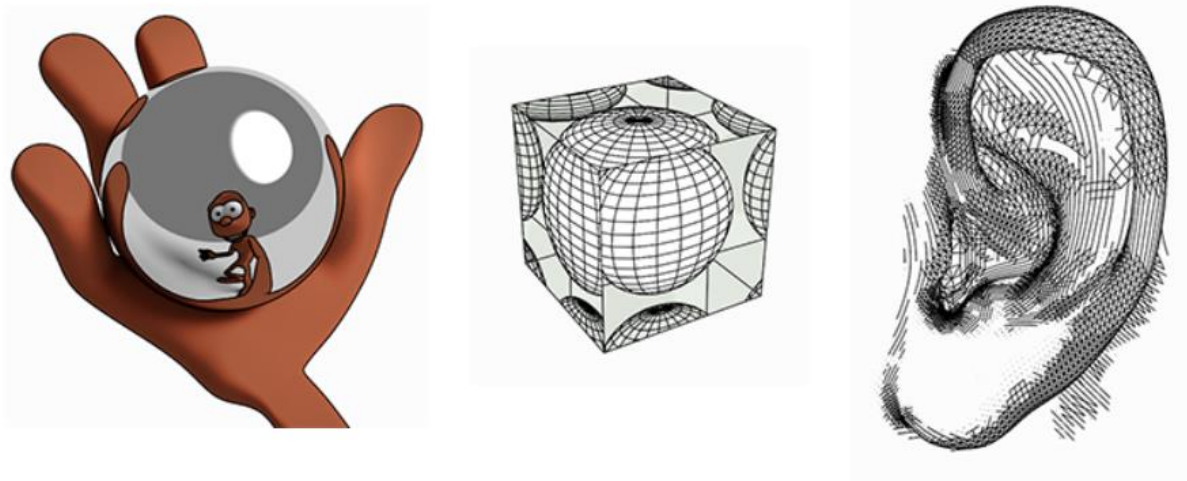
instantaneous. Because of this, rasterisation has remained the primary technique for video games.

Ray tracing in video games is beginning to see popularity now as technology improves, but it remains a computationally intensive process that requires high-end, expensive hardware, and is inaccessible for many as a result. The change is gradual, but the challenges of real time rendering are continuing to be improved upon to bring game visuals to a higher standard. ^[26]

Some also wish to explore the viability of combined ray tracing and rasterisation techniques for anti-aliasing specifically to circumvent some of these challenges for technologies like VR. ^[27]

Creative Lighting in Recent Animation

Uses of PBR and ray tracing technology emphasise the realism of computer generated graphics for lighting, but recently certain animation studios have been exploring other approaches to make their work stand out visually in an entirely different way.



^[28]

Non-Photorealistic Rendering (NPR) is an alternative form of rendering which aims to push rendering in a different direction through artistic effects often inspired by other kinds of art such as pencil drawings or paintings. The outcome is a range of styles that are often used to create more traditional, cartoonish imagery within 3D animation. ^[29]

One excellent example of a piece of media created with NPR techniques is Teenage Mutant Ninja Turtles: Mutant Mayhem. The studio wanted a rough around the edges, hand drawn feel to their animation to convey the imperfect, teenage protagonists. They utilised the Arnold Toon Shader as a basis and adjusted it from there to capture the look they wanted, along with combining 2D and 3D visuals together throughout the movie. ^[30]



Along with other films like *Spider-Man: Across The Spiderverse*, and *Puss in Boots: The Last Wish*, highly stylised works within animation that push for something other than realism has seen its own rise of popularity and success, pushing the bounds of what 3D animation can accomplish even further than before.

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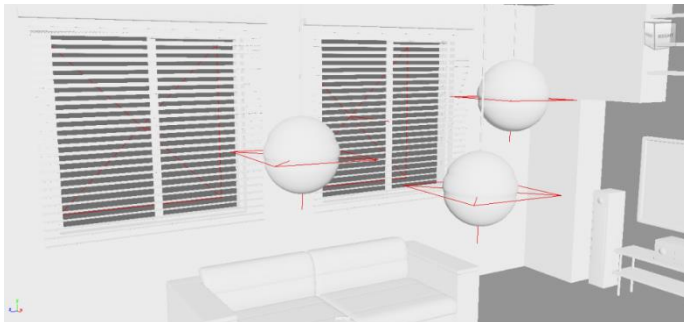
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Reflective Report

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Part 1: The Basics

In completing this module, before ever opening the scenes that would later be lit and rendered, the basics needed to be learned. Though Maya often proves to be a finnickier software to work with, aside from any typical issues associated with the program, the process of learning the basics of lighting was relatively intuitive.

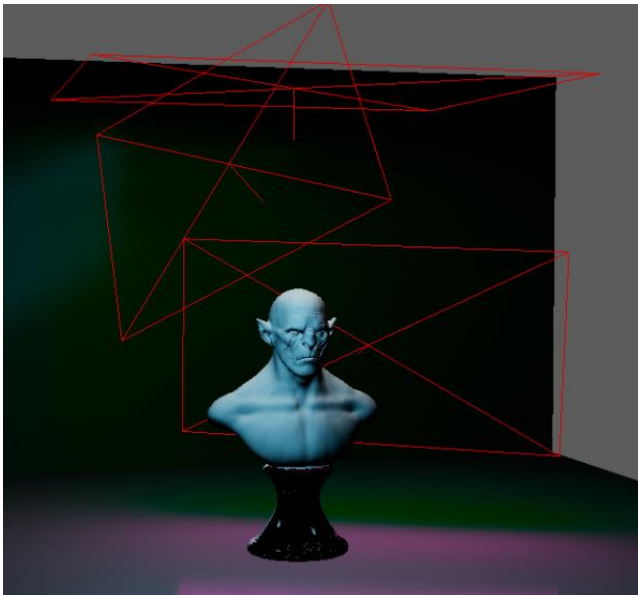


The first exercise was utilised for the sake of understanding the most basic requirements of lighting- placing the lights themselves into a scene and learning what each one would do and where it can be applied.

Lighting setup (above) and render (below) of initial practice scene



Following this, was more of a look on the cinematography side of lighting- utilising the commonly used technique of three-point lighting, often seen in both digital and live action media, while also becoming more comfortable with the Arnold render engine that is used throughout for the full scene renders.



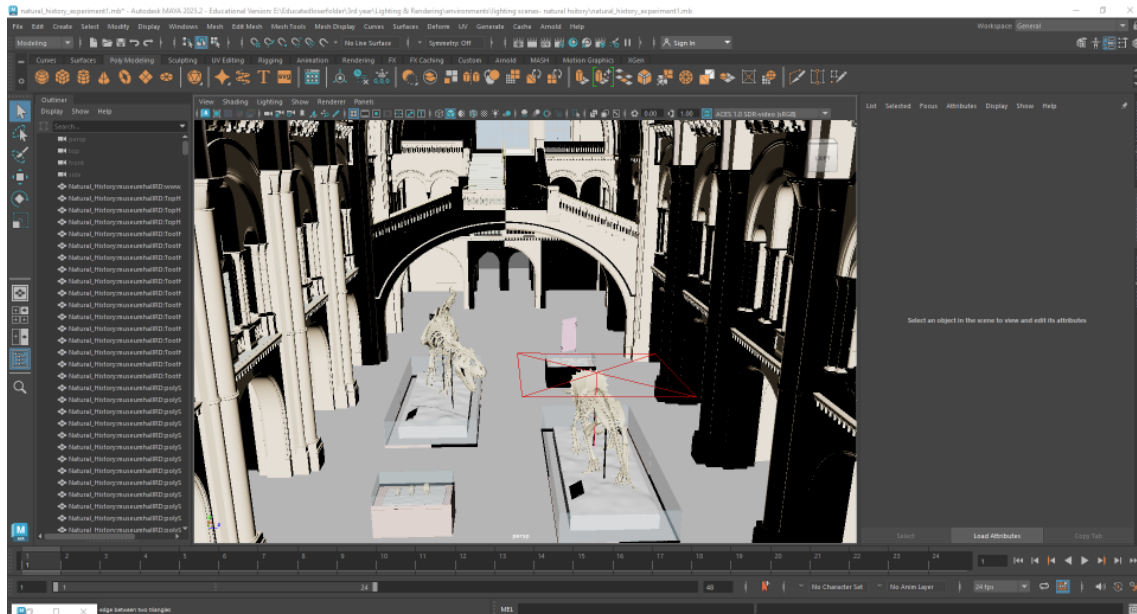
Render (above) and lighting setup (left) for three-point lighting

Despite approaching 3D rendering as someone who has never done it before, having a background in traditional and digital 2D art proved useful in understanding the theory and aesthetic implementation of lighting in a scene. While adapting to the workflow of rendering a 3D environment was needed, the baseline understanding of what lighting aims to achieve aesthetically and the different ways colour and intensity can be used gave a strong groundwork to proceed with.

Part 2: Night at the Museum

The first scene chosen was that of a museum, with a provided reference showing a night scene with a strong visual identity through the contrast of the pale light of the moon against the warm and atmospheric lighting of the museum exhibit itself. I chose to follow this example due to the strong lighting composition.

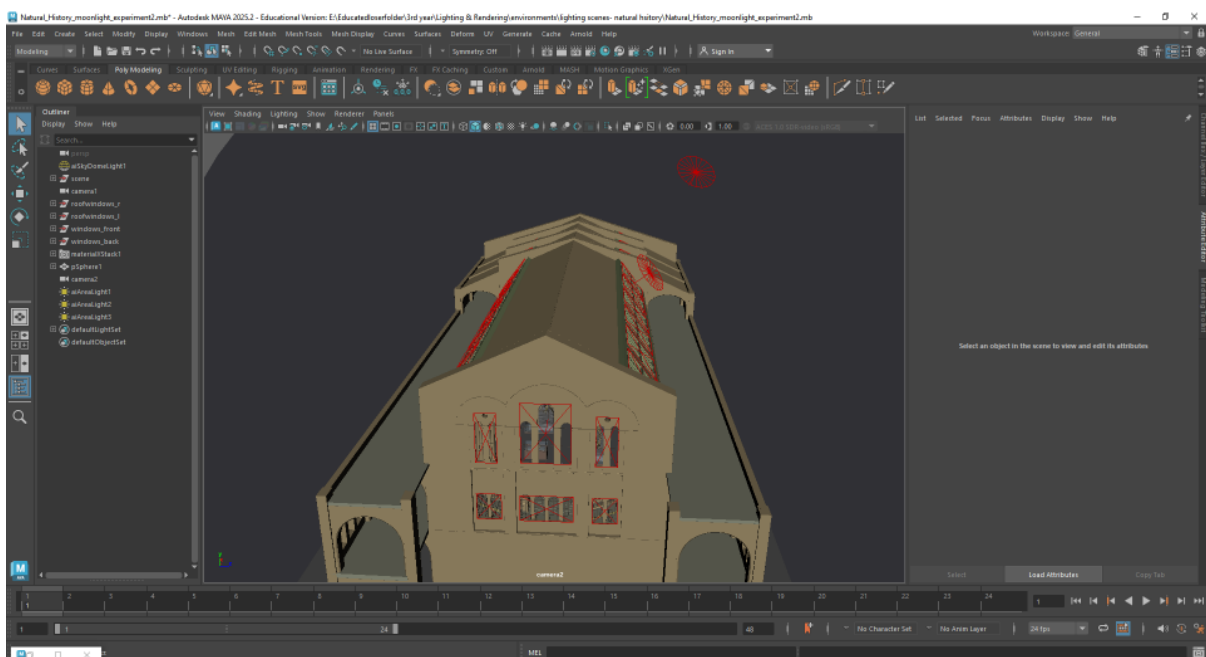
The first issue to arise with this however, was difficulties related to the model itself- the model seems to have originally been created using Mental Ray, which as of writing is not supported by Maya and as such it was impossible to save the scene.



Material errors on the base model

The error also significantly impacted the materials of the model itself. This problem was resolved however, by removing all unused script, which allowed the scene to be converted to one using Arnold to render instead of Mental Ray.

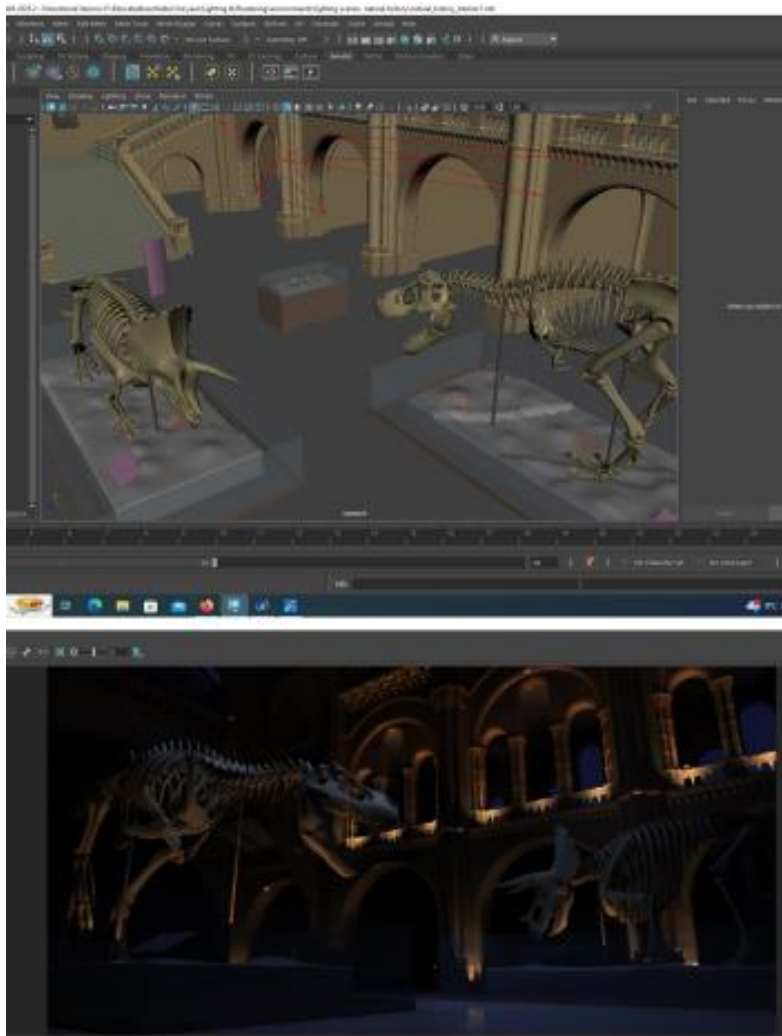
With this solved, it was then possible to begin lighting the scene. Initially, I attempted to start by creating the natural light first through the sky dome, a mesh light as the moon, and area lights to create the desired effect of the moon shining in through the windows. This attempt was ultimately scrapped, as it didn't produce the desired effect and was generally inefficient. I also didn't yet understand specular vs diffuse reflections, and as such the outcomes appeared overly shiny and almost plastic.



Lighting setup of attempt 1.



Interior (left) and exterior (right) of the render when concluding attempt 1.

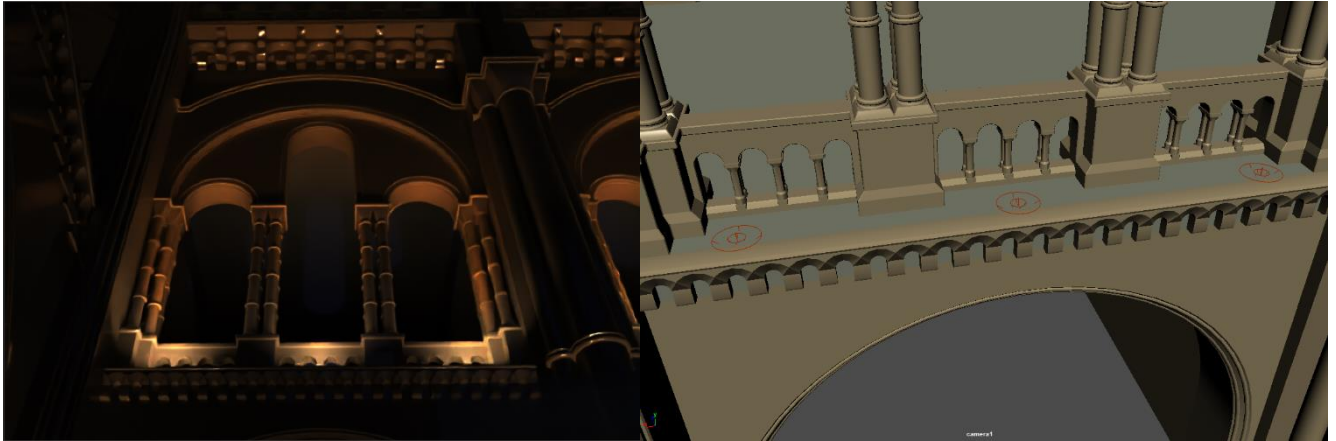


Early render setup for attempt 2.

The second attempt was approached using the inverse technique of beginning with the artificial lighting within the museum itself, beginning with the under-lit aspects of the dinosaurs, and the archways of the building using spotlights. Two larger, cooler toned area lights were also used to place within the scene to create the initial effect of the moon lit room as placeholders to be worked on further at a later point.

The arches also utilise two spotlights each to give the desired atmosphere. The brighter spotlight illuminates the area and simulates the bulbs, but there is a second one in the same position with a subtler, warmer light to give added depth.

Though basic, doing this allowed to give a first real look at what the scene was intended to be that wasn't achieved with the first attempt.



Arch lighting.

From here, the process was relatively simple. Additional lights were added throughout the interior to gradually make up the desired appearance in more subtle ways, as well as adding the exterior lights through the use of mesh and directional lights to make up the moon and the light entering through the windows. This also gave the reflections on the floor of the interior, adding to the atmosphere.



Exterior lighting setup and application.

The final step for this piece was volumetrics. Initially, the volumetrics were quite difficult to use, as it automatically is applied globally to all lights in a way that leads to a very over-exposed image with details flooded out by light. Some tweaking allowed to choose which lights did and did not have volumetric light though, and the issues were solved through manually adjusting this on each light as needed until finally achieving the desired look. This greatly improved the quality of the final image.

Rendering also presented some challenges, with frequent software crashes and difficulty using the settings, but with a combination of patience and additional research into how the render settings worked led to successful rendering of both a still image and a sequence to put into video.

On editing the sequence in Premiere Pro though, I found that the final image had been somewhat washed out and lost some of the depth in the rendering process, so additional editing was done to bring the deeper shadows and vibrant colours back into the image. The still images, both the Arnold render preview (top) and the final render edited in Photoshop (bottom) can be seen below, while the videos are included in the submitted .zip file.

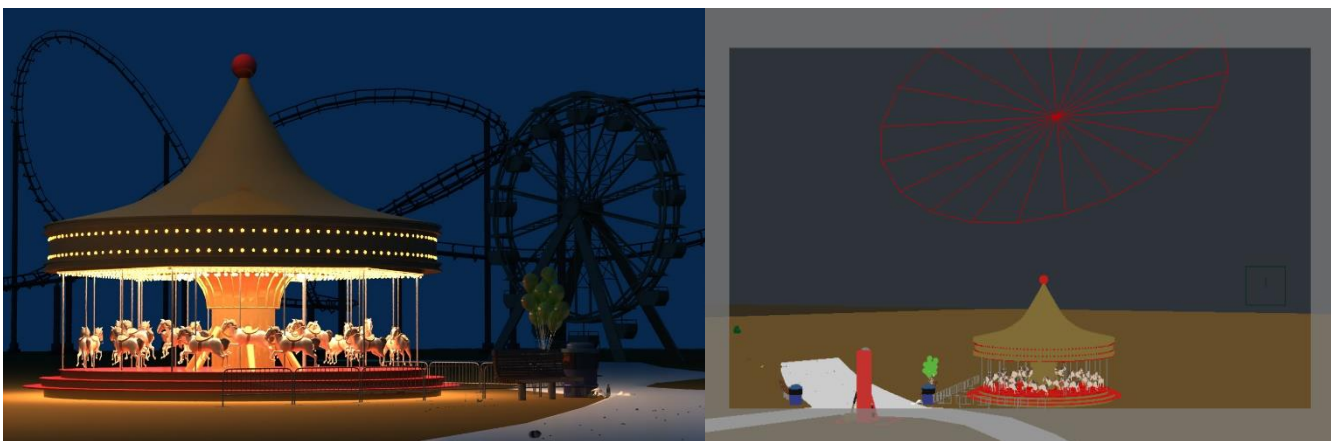


Part 3: Theme Park After Dark

Despite being a more complex and difficult scene overall, rendering the carnival scene was far easier to approach after having gone through the entire process once already with the museum scene.

It was clear immediately that this would only consist of one still frame, as the scene itself is spread out and made to appear a particular way with the perspective of the camera. As such, the first step of this scene (following the removal of unusable script as with the museum scene) was to set up the camera itself. Some elements on the scene were moved and adjusted slightly, as well as certain objects such as the tents being duplicated to fill in the space a little more and create a natural look.

After this, I discovered that the objects in the scene all had Lambert materials applied to them. This didn't cause too much difficulty in the end though, as it was a simple process to convert everything into standard AI surfaces. Most materials were left as default, but along the process a couple, such as the ferris wheel supports, pathway, and rollercoaster, were tweaked to create a more desired effect with their interactions with the lights.

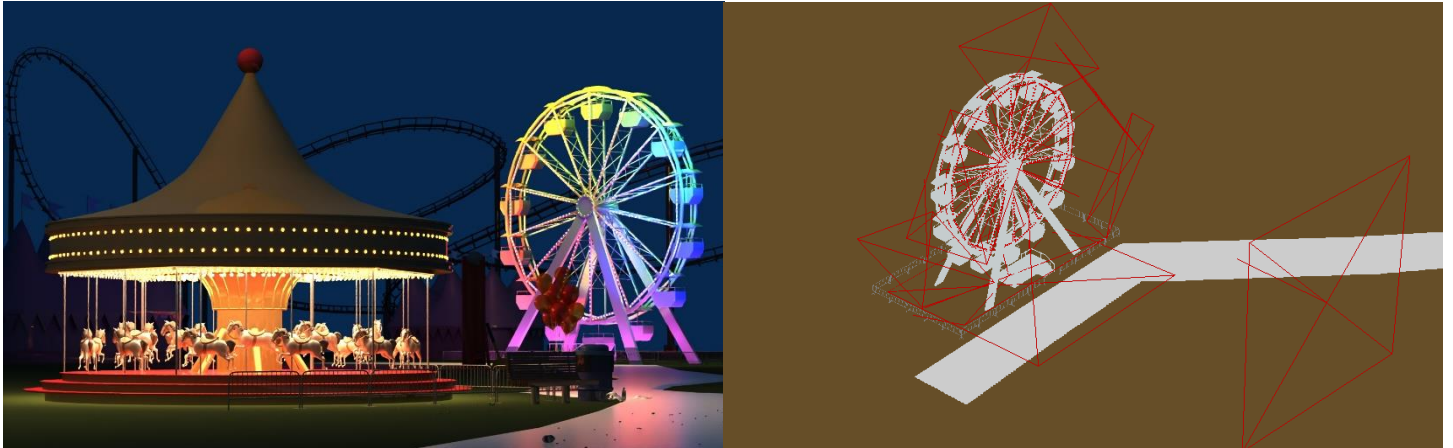


Carousel light setup and application.

The lighting was done one element at a time, starting at the front of the scene and working back. The carousel features many mesh lights, as well as a small number of area lights to create the warm, welcoming glow.

During the entirety of creating the carnival scene, real images taken by myself in theme parks at night were used as reference to see what is emphasised and how different moods are created. This real world reference for how lighting is applied for atmosphere proved useful in understanding how such an environment is actually lit. The lighting often enhanced particular elements of rides in different ways.

For the ferris wheel, it was decided to go with a soft rainbow gradient. This was achieved with a set of different coloured area lights with settings and placement adjusted to ensure a soft blend around the entire object.



Ferris wheel setup and application.

Both the tents and the hammer game were simple to light, requiring minimal work. For the tents though, an attempt was made to experiment with spotlights. Unfortunately, I was unable to have these spotlights work at all regardless of what settings they were on, and so I returned to using primarily area lights for the scene. Initially, the



Progress with tent, hammer, and rollercoaster.

rollercoaster was only given a single large light underneath it to give an initial impression of how it might appear later on.

The rollercoaster itself was lit further following this, with area lights being used to emphasise the highest points of the track. It also has lights flooding out into the rest of the scene and give backlighting to many of the other elements, with the largest impact visible on the carousel. Two versions were created with opposite colouration to better decide which atmosphere was preferred.



Both versions of the rollercoaster lighting. In the end, the warmer colour scheme (left) was chosen.

The last stage again, was to add the volumetrics. Knowing how to approach it made the process much faster and easier, though it needed much more adjusting than the museum scene did. There were also some software issues during, which meant some additional time had to be spent redoing volumetrics work.

The final addition was light specifically to make the balloons towards the front of the image look nicer, since as is they were generally unappealing and had an almost washed out, greenish tint.

Further issues arose in attempting to render the final image, and while originally the plan was to create a much higher resolution final image, a combination of time and software difficulties (several crashes happened throughout, including on one occasion occurring while choosing the file directory after half an hour of waiting) meant that I unfortunately had to settle on 'good enough' for the final resolution of the image itself, the results of which, after being edited once again in Photoshop, can be seen below.

