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Creating Cartoon Style with 3D Animation

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CREATING CARTOON STYLE WITH 3D ANIMATION

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ABSTRACT

Computer-generated three-dimensional animation is often used to imitate live-action filmmaking and photorealistic objects and effects. However, it is equally possible to use three-dimensional computer-generated imagery to imitate cartoon, hand-drawn two-dimensional animation. Cartoons and hand drawn animation have their own sets of limitations which change their visual style. Animators may choose to draw scenes with elements that break continuity or are not realistic. Every choice from the color to the scene composition is different from now-conventional three-dimensional CGI. With this thesis, I investigate how to create a three-dimensional scene that closely resembles the appearance of a two-dimensional cartoon animated scene drawn with traditional media instead of a computer. I will use 2D stylistic tools to create a scene that emphasizes the main subject and is calming and introspective. In this paper, I will explore the techniques used to make three-dimensional computer-generated imagery resemble traditional, two-dimensional animation through the examination of modeling, rigging, staging, composition, lighting, texturing, shading, and animation. Together all of these can be used to enhance and communicate feelings of calm and contemplativeness.

ARTIST STATEMENT

Photorealism, a style of art with detailed realism resembling a photograph, is not the correct choice for every story. In fact, photorealism only fits the themes and ideas of a few stories. Animation is a broad medium that encompasses a lot of styles and potential ideas. Animation is able to communicate complex ideas through its visuals through stylistic, meticulous control of what the audience perceives. In live action or photorealistic films, there will always be a certain amount of noise and detail in the scenes which draw the audience's attention from the main subject. This dilutes the ideas that the creators are trying to express. Animation offers the power of images in motion while giving creators control over the composition and elements of their work. And yet, in recent years animation has primarily been used to create photorealistic elements that imitate live films. Photorealism is a certain stylistic choice and should not be considered the default option when making animated films. Years ago, I was actually disappointed by the hyper-realistic rendering of textures and objects in the PIXAR film *The Incredibles 2*. Compared to the first film, the visuals of *The Incredibles 2* were less focused and therefore less impactful. As impressive as the photorealistic water was, for example, it actually detracted from the high-energy, cartoon tone of the film.

Compare that to the controlled, focused visuals of artists such as Mary Blair and Lou Romano. The shots are planned and use color and simplified shapes to highlight the most important elements of a composition. Even something as simple as an establishing shot can be filled with beauty and thematic significance. This is the aesthetic I want to capture with this project. I want to capture the power of simple animation and demonstrate how 3D CGI can be used to imitate 2D visuals, not photorealistic imagery.

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1. INTRODUCTION

1.1 Realism and Cartoon Style

Realism is an artistic aesthetic where art closely resembles the real world from the perspective of one person. Photorealism, therefore, is art which resembles the real world as if the artwork was a photograph.

From its early days, animation was not photorealistic. Drawings and animations were done in a simplified, cartoon style which did not reflect reality. Instead, this cartoon style was exaggerated, with simplified shapes and colors which communicated the essence of what it represented without truly appearing like its subject. No one would mistake the character Mickey Mouse for a real-life rodent, for example.

With the creation of 3D computer generated imagery, imitating the physics and appearance of the real world in animation became possible to the degree that animation can be photorealistic. Today, 3D animation is expected to be smooth and indistinguishable from the movement of live action film. In many films, the CGI blends seamlessly with live captured footage. In addition, the demand for spectacle has guided the development of 3D animation and the tools used to create it. This has resulted in increasingly impressive, realistic renderings of complex images like underwater shots and plant life.

However, much less attention has been paid to the cartoon styles of older animation. As the technology for photorealistic animation has improved, even projects that would be better served by cartoony aesthetics and less detailed objects have used photorealistic elements alongside their simplified characters.

Figure 1.1: Photorealistic Water and Glass with Cartoon Character [3] (c) 2018 Pixar Animation Studios

Figure 1.1 above is taken from a scene from Pixar's *Incredibles 2*. [3] The simplified, cartoon character Violet is depicted with photorealistic water shooting out of her nose, and realistic glasses with water and ice inside them taking up the foreground of the image. In my opinion, these elements are jarring when placed together. The more detailed elements of the scene, the water and the glasses, draw the viewers' eye and create visual noise which detracts from the central character, Violet. If these elements were rendered with less detail, the scene would be more cohesive, and the two sets of elements would not contrast so heavily with each other.

Figure 1.2: Cartoon Characters with Grass and Animals [24] (c) 2015 Pixar Animation Studios

Similarly, Figure 1.2 is taken from Pixar's *The Good Dinosaur*. In this image, there are three or more styles with different levels of detail for each set of elements. The cartoon characters in the foreground have exaggerated and simplified eyes and body shapes, but the dinosaur character has more detailed scales. The plants which take up most of the shot are photorealistic, but the animals and clouds behind the characters are slightly simplified and not photorealistic. Taken together, these elements are distracting and not cohesive. This makes the image less appealing overall.

However, realism and photorealism are not the only artistic styles. Mary Blair was an artist for The Walt Disney Company from 1940 to 1953. Her work often featured simplified shapes and an exuberant, simplified color palette which drew the eye to the most important parts of the artwork.

Figure 1.3: Cartoon Concept Art by Mary Blair [5]

Figure 1.3 is an example of Mary Blair's art style. Most of the shapes are filled in with single, solid colors. The cooler colors towards the bottom of the composition are used to highlight the character in the middle. Any visible shading, such as on the gray path towards the bottom of the picture, is simple. The path is divided into shaded and unshaded regions, with little to no in-between. The single character is not realistic but is made of simple shapes like the rest of the artwork. This picture is more cohesive visually, and I believe it is more aesthetically pleasing than Figures 1.1 and 1.2 for these reasons.

Figure 1.4: Cartoon Background Art by Lou Romano [23]

Similarly, the above picture, Figure 1.4, was created by Lou Romano, an animator who worked on the Cartoon Network animated series *The Powerpuff Girls* from 1999-2000. [23] Figure 1.4 is a background concept art for the series and demonstrates the aesthetic of the show. The picture shows the soft, watercolor style of coloring, use of bright and dark colors to highlight important elements, round foliage, and exaggerated proportions. This is another example of an artistic style that is not realistic. However, the exaggerated parts of the image and unified elements are what make the image more appealing.

What if animators used more advanced technology not to create photorealistic elements, but to create animation in the style of older 2D pieces? Is this possible, and what are the challenges to this approach? What capabilities for better expression are there?

1.2 Differences Between 2D and 3D Animation and Live Action

The way a scene is created varies depending on the medium its created with. 2D animation, 3D animation, and live action each pose their own challenges which changes how the scene can be shot and composed. The hallmarks of one medium do not translate easily to another.

2D animation is limited by the animator's skill in picturing and drawing objects relative to an imaginary camera. It's much easier to portray a scene where the "camera" does not move relative to the scene and where any human characters are viewed from straight on or profile. If the shot calls for the camera to move around wildly, it will be difficult for the animator to decide how to draw a character based on the character's movement and new relation to the camera. As a result, many animators choose to draw scenes as if the perspective camera is static. The most lauded shots in 2D animation are ones where the movement of the characters and the "camera" are complex but rendered in a consistent style. Because of the medium of 2D animation, some characters are actually impossible to portray from certain angles if they have flat features or if certain features of a character are always drawn as if they are perpendicular to the camera or which change their shape without explanation depending on the camera's orientation. As an example, Mickey Mouse's model, shown below, changes shape depending on whether he is facing the camera or the side. When he is facing the camera, both of his ears are on top of his head. Whereas when he turns so his face is in profile, both ears rotate so they are visible from the side, one ear moves to the center of his head, and the other ear drops to the back of the head.

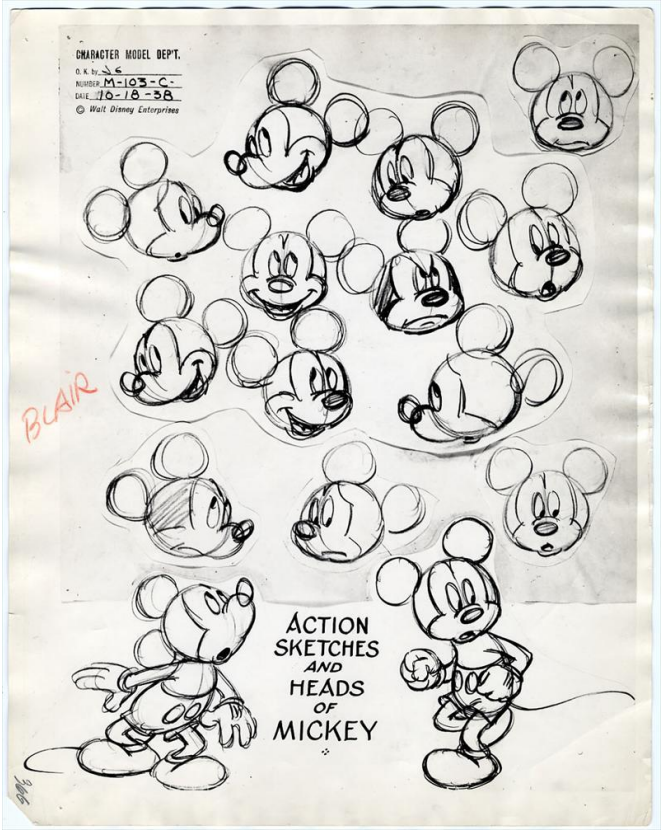

Figure 1.5: Mickey Mouse Head Model Sheet [11]

In contrast to 2D films, 3D animated films have much more flexibility about how they move a camera through a scene. Provided that a scene is fully constructed and can be viewed from every angle without losing its style, a camera can make impossible motions or catch angles that are difficult to draw, moving through the scenery or at incredible speeds to catch different angles of the same scene within a single shot. 3D animated films are also more likely to have characters at different depths and shots at angles or over the shoulders of characters. These types of shots are easier to capture in 3D than in 2D animation.

Because of these limitations, 2D and 3D animated films each have different styles and common methods of composing the same kind of shot within the frame. A comparison of several shots from 2D animated, 3D animated, and live-action films can make these differences more apparent.

Figure 1.6 below is an image from the 1995 traditionally animated television anime *Neon Genesis Evangelion*. The shot is taken from a scene where the two characters pictured are eating dinner together. The shot is composed in profile, with the two characters set on the thirds marks of the camera to place them in focus. The top of the table is not visible. Only a few objects on the table can be seen. This perspective deemphasizes what's on the table and focuses on the characters, so the audience can read their entire body language and so the expressions of the 2D animated characters are clearer. It is also easier to draw characters in profile. This is a standard method of drawing animated characters eating together.

Figure 1.6: *Neon Genesis Evangelion* Episode 2 Dinner Scene [28] (c) 1995 Gainax

Of course, it is possible to find exceptions to this method. Figure 1.7 below is from the 1988 anime film *Akira*, taken from a motorcycle chase scene where the camera briefly cuts into a diner to show the scene before a motorcycle crashes through the window. This shot is from a bird's eye view so that the audience can see the top of the table. The characters are not in profile, and the expression of one character is only visible in the reflection on the window. On the other hand, the film *Akira* is known for imitating the cinematic style of live-action films, so the comparison is imperfect.

Figure 1.7: *Akira* Diner Shot [12] (c) 1988 Tokyo Movie Shinsha

The next shot, Figure 1.8, is taken from the Pixar 2021 film *Luca*. None of the characters are in profile and do not sit on opposite sides of the table perpendicular to the camera. Instead, the characters and the camera are each at a three-quarters' view, which gives the audience a clear view of all of the characters' expressions and the scene around them. Additionally, the characters are placed at different depths from the camera. The character in the center right is placed further from the back than either of the two other characters, while the rightmost character is placed closer to the camera. Additionally, the center right character is on the right third line of the camera, whereas the other two characters are slightly off of the lines of thirds. This serves to emphasize the center right character in the scene, which a shot from profile would not do. The top of the table is also visible. The characters' proximities to each other also conveys their relationships. The two characters on the right are closer friends at this point in the story than they are to the leftmost character, who is further from both of the other two characters than they are to each other.

Figure 1.8: Dinner Scene from *Luca* [6] (c) 2021 Pixar Animation Studios

Finally, the two shots below, Figures 1.9 and 1.10, are taken from the live action 1989 film *When Harry Met Sally….*

Figure 1.9: First Diner Scene from *When Harry Met Sally…* [22] (c) 1989 Columbia Pictures

Figure 1.10: Second Diner Scene from *When Harry Met Sally…* [22] (c) 1989 Columbia Pictures

Interestingly, the two characters are also filmed in profile, like the characters in Figure 1.6. However, there are subtle differences which are characteristic of a live-action film. The camera is placed at eye-level, which is slightly above true profile. In both scenes, the top of the table is visible, allowing the audience to see what the actors are doing with their hands and the set-pieces. The shots are also much closer to the characters than Figure 1.6, which allows the audience to read the detail on the actors' faces. 2D animated characters are easier to read from profile even from a further distance, whereas in live-action film it's much more important for the actors' faces to be clearly visible. This allows the actors' art to get across. It should be noted that the distance of the camera is also used to emphasize the characters' relationship in the film. In the first shot, Figure 1.9, the camera is further away to show the empty space around the characters and emphasize their emotional distance from one another. The second shot, Figure 1.10, is made to parallel the first, and the camera is closer to the actors to emphasize that the two have grown closer over the course of the film. Both shots have been included to demonstrate how the camera is still further from the characters than in Figure 1.6.

All of these shots could be broken down further by genre, budget, and audience as well as many other factors that go into making decisions about the type of shot that goes into a scene. However, they are good indicators of some of the genre conventions of 2D animation, 3D animation, and live-action films.

1.3 Modern 2D Animation

Most modern 2D animation is performed using digital tools instead of physical paper or animation cels. Digital animation software today resembles 2D drawing and editing software but includes different frames and the ability to keyframe drawn objects in different positions based on the chosen frame. This is known as “puppeting” because it resembles using the drawn objects as puppets by moving them around the scene instead of redrawing them for each frame.

Some digital animation software like this includes Adobe Animate, Blender 2D files, and ToonBoom Harmony. These tools can also incorporate frame rate settings, keyframes, interpolation, layers, ratio, and rendering settings in addition to common editing software tools. ToonBoom Harmony also includes z-space that allows the animator to move drawings on the z axis to give a multiplane camera effect, and to import 3D models into the program to help give the illusion of depth to their animations.

1.4 History of Imitating 2D with 3D Animation

In recent years, there have been several attempts to imitate some of the features of 2D animation with 3D animation. However, usually these efforts involve adding onto 3D animation with 2D animation, thus adding more time and effort to the process instead of simplifying it.

In 1986, Disney released the animated film *The Great Mouse Detective*, which featured a scene inside a clocktower, Figure 1.11, where the traditional 2D hand drawn characters interacted with CGI 3D models of the clockwork gears in motion. The CGI clockwork was used to create

wire-frame graphics on a computer which was then printed onto animation cels. Then, color and other cels were added to create the final images [26].

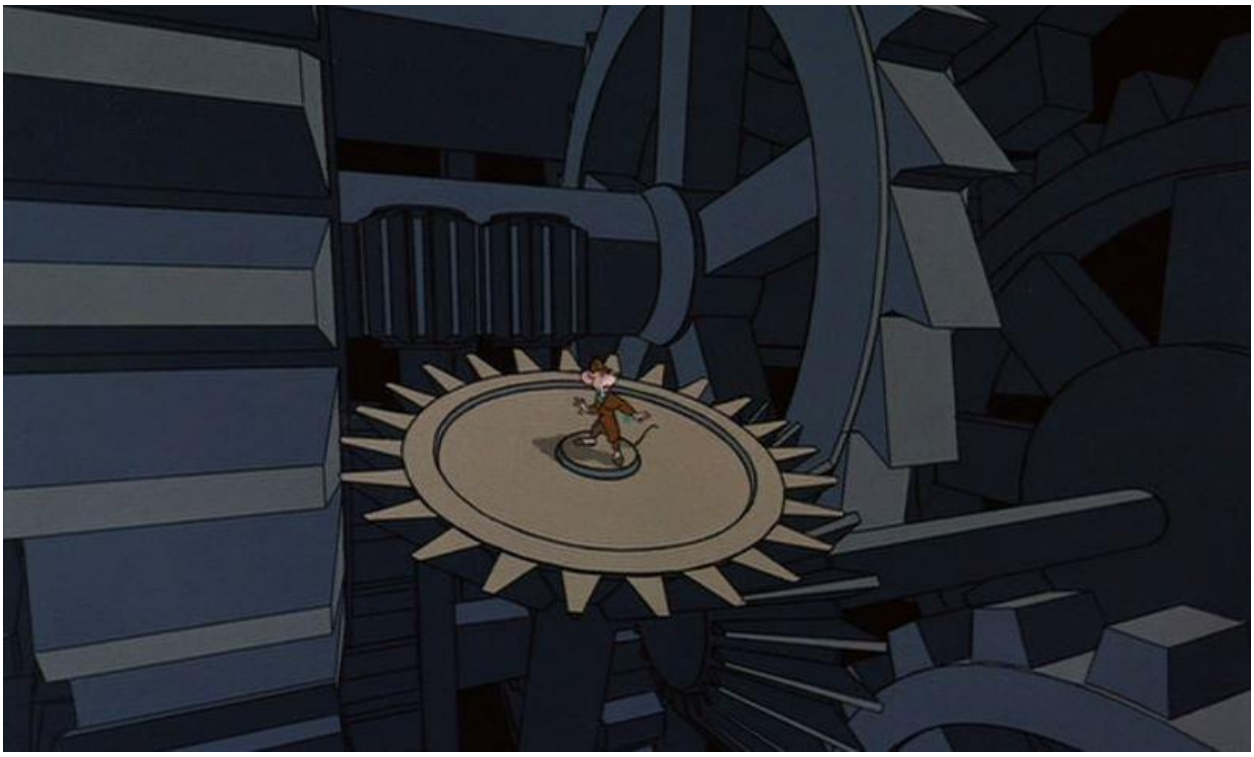

Figure 1.11: *The Great Mouse Detective* Clocktower Scene [26] (c) 1986 Walt Disney Animation

In 1999, another Disney movie, *Tarzan*, used computer generated imagery for the backgrounds, especially the complex trees of the jungles Tarzan moves through. This was called Deep Canvas, a 3D painting and rendering technique using the Computer Animation Production System, or CAPS, software to allow the computer to remember digital brushstrokes in 3D space and determine whether they should be visible based on the position of the camera [25]. This system was the forerunner of the digital graphics system which was later used by Sony Pictures Animation to create their film, *Spider-Man: Into the Spider-Verse*.

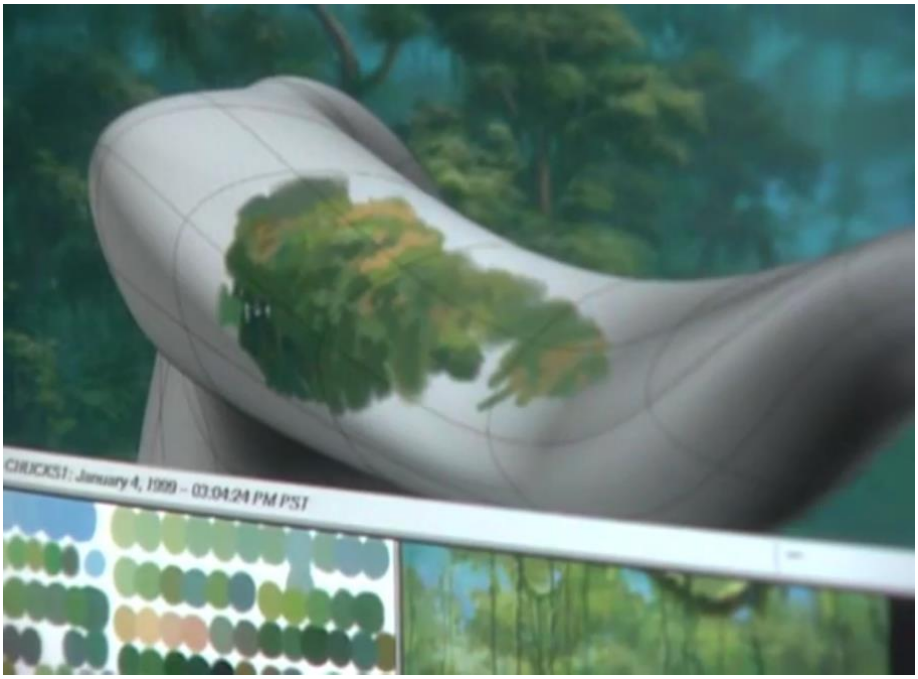

Figure 1.12: *Tarzan* Deep Canvas Imagery [25]

In 2004, the Sunrise Inc. animated film *Steamboy* used CGI 3D models for complex 3D machines such as steam locomotives and the complex gears and clockwork which contributed to the film's aesthetic. Then, traditional 2D hand drawn cells were placed over the renders of the CGI models, allowing the 2D objects to appear to interact with the 3D models. The frames of the film were also subtly desaturated, allowing the CGI models to blend in with the 2D animation.

In 2012, Walt Disney Studios released the animated short film *Paperman* alongside its feature-length film *Wreck-It Ralph*. The film became well known for its use of 2D animation alongside 3D animation. The animation in *Paperman* was 3D, but 2D drawings were attached to the geometry by a program called "Meander," to create drawings for the in-between frames [21]. This produced a smooth, computer-assisted animation that still retained the personality and beauty of 2D animation. The short became one of the earliest examples of using 3D CGI programming to assist with 2D animation.

In 2018, Sony Pictures Animation released *Spider-Man: Into the Spider-Verse*, a film that used digital 2D drawings, shaders, and advanced compositing over the 3D graphics. The animation for the film began in 2014 and was finished in 2018 [14]. However, the animation techniques, animating the characters at different frame rates, and the added 2D effects greatly increased the appeal of the film. The same technology was used for *Sony Pictures Animation's* later film, *The Mitchells vs. the Machines*, and a similar style was used in Netflix's 2021 series *Arcane* and Nickelodeon Movies' 2023 film *Teenage Mutant Ninja Turtles: Mutant Mayhem*, though they did not have the same pipeline and technology.

Recently, there have been many uses of 2D animation to enhance existing 3D CGI as well as 3D CGI technology used to enhance 2D animation. These techniques allow for the creation of new aesthetics and artistic expressions which would not be possible with only 2D or 3D animation.

1.5 Machine Learning Techniques

It is possible to use machine learning algorithms to imitate traditional 2D animation. Studios and individuals have researched different ways of creating and training algorithms on how to create or modify images for use in animations.

In 2019, Sergio Pablos Animation Studios released the Netflix 2D animated film *Klaus*. *Klaus* was notable for its use of a machine learning tool which could interpret digitally drawn lines as 3D objects and use that information to light the objects as if they were three-dimensional [9]. This way, the artists could quickly light the usually flat 2D drawings. When the trailer for

Klaus was first released, many people questioned whether the film was 2D or 3D animated because the lighting was so complex.

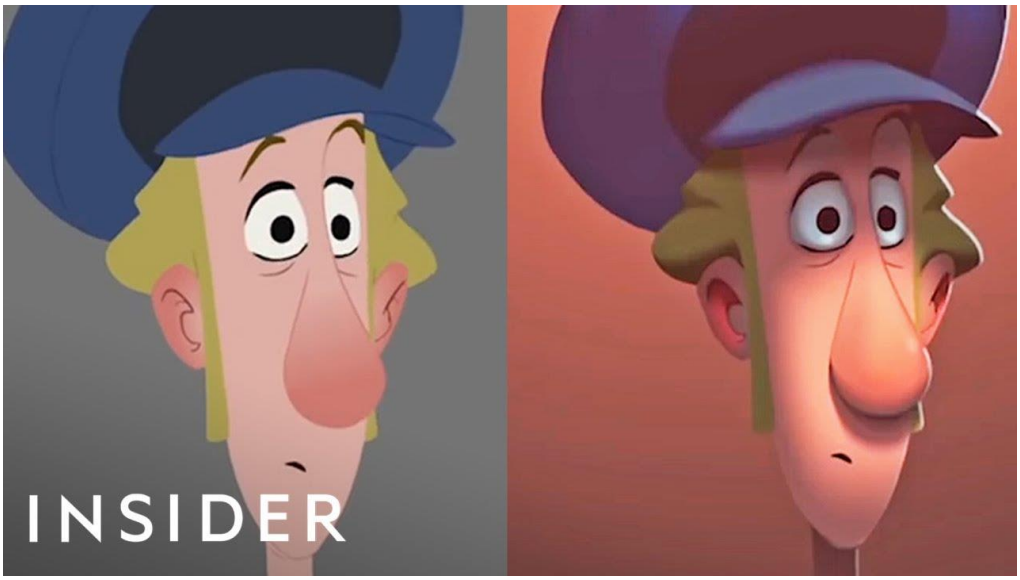

Figure 1.13: *Klaus* Lighting Example [9]

The studio Corridor Digital has used machine learning to create its animated parody video “Anime Rock, Paper, Scissors.” The video was created using live captured footage of the studio’s employees on a greenscreen. Next, the frames of the video were run through the machine learning tools Stable Diffusion, Dreambooth, and Davinci Resolve. Then the final video was composited with extra edits and CGI elements as well as added voicework [7]. The result is an impressive, 2D short film with reduced flickering and inconsistencies compared to traditional image generation techniques.

Though machine learning can be useful, there are weaknesses to using it for animation. The first is that the algorithm needs to be created, or an existing algorithm must be used. In most cases, coding a machine learning algorithm takes more time and effort than creating the

animation by hand. The results created by existing algorithms need additional editing and corrections done by hand to even look passable as hand-drawn images. Overall, until this technology improves, it won't be useful for precisely duplicating the appearance of 2D animation using 3D assets.

1.6 Process for Combining 3D and 2D Animation

My intention is to make a 3D modeled character in a scene using the software Blender 4.0 and use techniques like cel shading, stepped animation, and layered composition to make it look hand drawn. To that end, I have compiled a list of methods from several sources in order to imitate 2D animation.

1. Use Line Art Modifier in Blender to create outlines around the characters.
2. Focus on composition and mimicking the "foreground, midground, background" look.
3. Don't fill the frame with needless detail just because it's cheap to do so.
4. High poly count to make the character models smooth and flexible like hand-drawn characters.
5. Focus on a specific palette of colors which are less saturated to appear as if the frame was painted with a physical set of colors.
6. Use single-tone shaders, including just a single color for the material instead of complex shading done by a computer.
7. No global lighting affecting characters, each character has their own light as if an artist were drawing them, so the lighting was inconsistent.
8. Hand set the normals on each part of character, especially the face.

9. Multiply base texture with a tint texture for a shaded texture. For example, red for human skin.
10. For the lines, a second set of polygons are generated and expanded outward, then their normals are reversed. This is tweaked.
11. Inner lines are Axis Aligned Beams, no freehand curves, along the seams in the UV.
12. “Limited Animation”
13. Less frames, no interpolation. Every frame is a keyframe.
14. Added discontinuity to make it look 2D. “Kill the 3D.”
15. Riggs are manipulated and Scale manipulation is used on each body part to exaggerate the perspective.
16. Faces don’t maintain natural positions.
17. Reduce the frame rate from 24 frames per second to 12.
18. In 90s anime, there was a focus on static establishing shots and still landscapes instead of moving or tracking shots. Know what a moving camera means. It gives the scene more action, and the camera movement must be intentional, to highlight some specific aspect of a scene. They also had bold colors with a restricted color palette. A lot of the backgrounds were either pure black or white, with objects then drawn on.
19. Use parallax. Use 2D for extra detail and close up motions like hands, legs, and emotional faces. 2D can also be drawn over a 3D model.
20. Use 2D backgrounds, perspective, and cutouts for certain elements, especially background elements. It’s much cheaper and more time effective than modeling an entire new object just for one scene.
21. Include hand drawn motion blur lines.

22. Reuse animation and cut corners. A shaking effect applied to a still image of a city can give the impression that something is rumbling. Repetitive animations of a character can accentuate a point about them. A still panning shot can emphasize relationship, scale, or power.
23. Create a small drop shadow under the fake cell layer to create a sense of depth between the layers.

I've compiled these methods from research of artists such as the artist Noggi [19] and other creators who shared their techniques in YouTube videos. This includes "GuiltyGearXrd's Art Style : The X Factor Between 2D and 3D," a panel at the 2015 Game Developer's Conference by *GuiltyGearXrd's* creators. [18]

I also believe it should be possible to procedurally generate errors to make rendered CGI frames look like they were drawn on cels or paper. Original cel shaded animated frames would often contain dust or subtle line variations on single frames, giving a unique look to the animation. Using procedural generation, artists could create a paper filter for every frame of animation, so each frame looks slightly different from the others. Noise could be added onto the image to create colors with slight variations compared to the "true color." Finally, line widths could disappear when they end or curve sharply. The article "Creating a Pencil Effect in SVG" [27] contains a similar process related to digital maps. These inventions are beyond the scope of this project, but they could add more to the effect of imitating two-dimensional animation with computer generated imagery.

2D and 3D animation both have challenges which require time and money to address. 2D traditional animation requires the elements of a shot to be hand drawn repeatedly for every small action. While with 3D animation, every element of a scene must be modeled by hand no matter

how significant it is. These challenges and others can dramatically increase the labor animation needs to look pleasant.

In addition to requiring each frame to be drawn by hand, traditional 2D animation also necessitates fine motor skills which must be developed over a lifetime of practice. In order to be convincing, an element of a scene must remain consistent in its design, including its proportions and animation. A 2D animated object needs to follow certain parameters to appear three-dimensional and imitate weight and motion. If an animator makes a mistake for even a single frame, the illusion of movement and beauty can be shattered. If an object appears to float or move unnaturally, the audience will be unnerved or simply disappointed. Even after hours of work, an animation can still fail. And 2D animation is time-consuming to test and iterate on. If a scene needs to change for the story, days of work may be erased completely and requires days more to reproduce. These problems can be mitigated with careful planning, storyboarding, model sheets, pencil tests, and other best practices, but the problems cannot be completely eliminated. Technology such as digital art programs can also make it easier to create changes to a scene after it is finished, but this is only useful for making minor corrections or alterations.

3D animation requires every element of a scene to be modelled in order for the elements of a scene to mesh well. Some backgrounds can be painted, but that restricts the possible movement of the camera and the characters. Depending on the object, modeling it in 3D can take far longer than drawing the same object for a 2D project. Additionally, 3D animation requires more effort than 2D animation to make convincing. With 2D animation, the audience is more willing to suspend their disbelief. A 2D object can appear cartoonish and does not have to operate according to conventional physics. With a 3D object, it can take months of work to get the object to act cartoonishly in a way that does not break it or ruin the illusion. Conversely, the

more photoreal an object looks, the greater the audience's expectation that the object will behave according to realistic physics. This can add more work after the object is created. Where in 2D animation, drawing an object to change is easy, modifying an existing object in 3D is time consuming.

1.7 Conclusion

In order to demonstrate the possibility of using 3D software and animation techniques to imitate a 2D animation style, I created several versions of a scene in the 3D animation program Blender 4.0 which will be meant to duplicate the style of 2D animation as closely as possible.

The reason I chose Blender software is because it is a free all-purpose modeling and animation software which allows for the incorporation of 2D elements. The use of free software was important to emphasize how these tools can be used instead of more expensive technology to create aesthetically pleasing work.

In order for 2D and 3D animation models and techniques to be used together, there are several important elements to keep in mind. The modeling and rigging of the characters must be smooth and high-quality, and the models must have some kind of line art. The staging should reflect the way 2D animation is drawn instead of 3D. The shading should be minimalist, and the models should be lit individually. And finally, the animation should not be fully interpolated, should incorporate squash and stretch, and may even need to be slowed down.

2. MODELING AND RIGGING

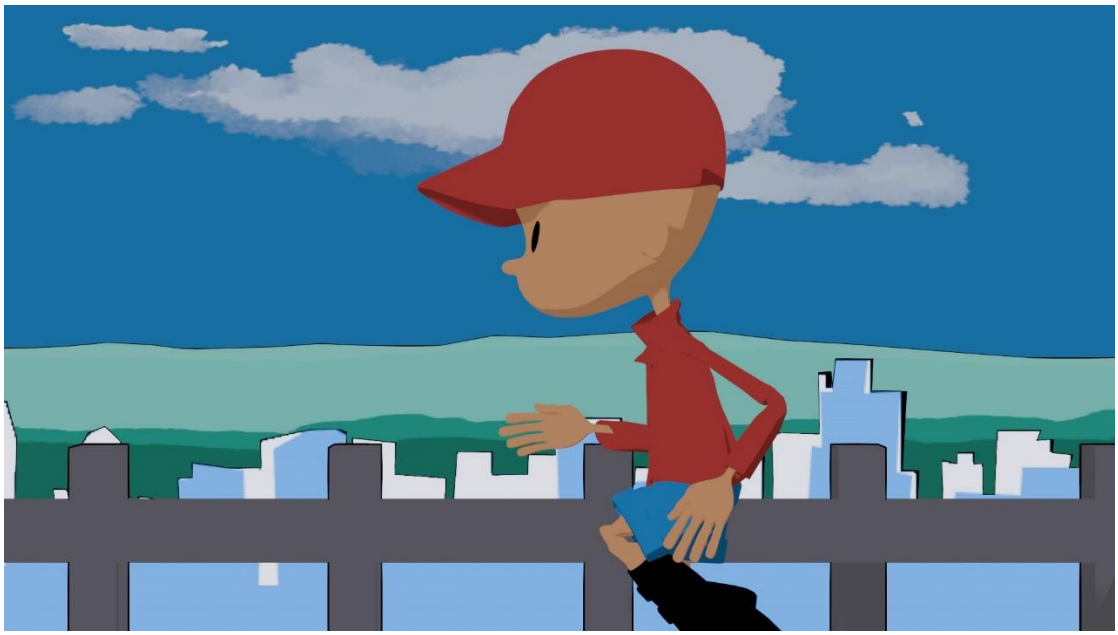

Figure 2.1: Model without Outline

There are several techniques which can be used to create 3D character models that more closely resemble 2D drawings. These include having a high number of polygons so that the models are smooth, simple textures and shaders, and a shell with the normals inverted or a line art modifier to give the character the appearance of line art. These are techniques I learned from the creators of *GuiltyGearXrd's* presentation. They were the first and biggest step towards achieving my goal. However, while simple in theory, these techniques were complicated to implement. I discovered this with a test character model I created myself, Figure 2.5.

2.1 Modeling

Having a high number of polygons in a model makes the model look smoothly drawn and allows for more complex rigging and manipulation. The vertex properties of a model should be manipulated instead of using texture or normal maps. Texture and normal maps will give a sense of complexity and depth to the character when the goal is to make them appear simplified.

Characters in 2D animation usually look very similar under different lighting conditions. In keeping with this, the global lighting of a scene should not affect the 3D character models. Each model should have its own individual light. In 2D characters usually have simplified shadows, a shaded portion and an unshaded portion. The texture and normals of the 3D models should each be simple 2D shaders, taking into account the light vector, normal vector, and the threshold between the lightened and darkened part of a character. The base texture can be multiplied with a tint texture in order to create the shaded portions. This tint texture can vary depending on the scene and the model. For example, the texture could be slightly red for human skin or blue in nighttime scenes. Normals should be handset so that if a surface normal is facing a light source it is lit but is not lit if facing more than 90 degrees away.

There are several methods for creating the outline of characters in 3D rendering software. The simplest method is to create a second set of polygons that are generated and expanded outward, creating an opaque shell. Then the normals of these polygons are reversed. This creates an outline which only appears on the opposite side of the character from the camera and does not obscure the character. The thickness of the shell should be thin enough to imitate hand drawn lines and not 3D geometry. This is called the inverted hull method, which is demonstrated below in Figure 2.2.

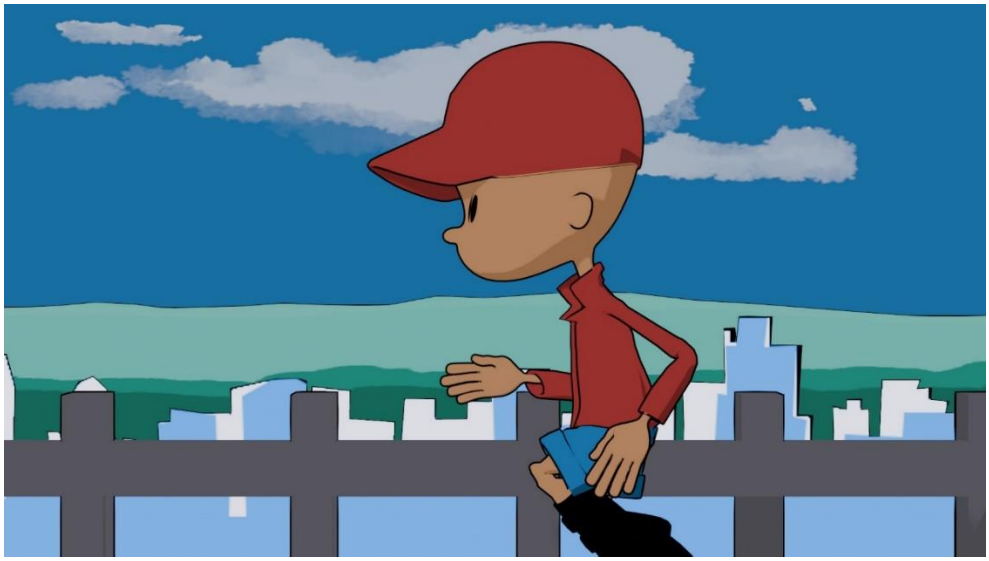

Figure 2.2: Model with Inverted Hull Method

With the inverted hull method, the lines are imperfect. There are several points where the outline does not show, such as along the rim of the cap pictured, and there are other areas where an extra line is added, such as on the left side of the eye. This breaks up the image in a way that is not visually appealing, because the elements lack consistency with no motivated reason.

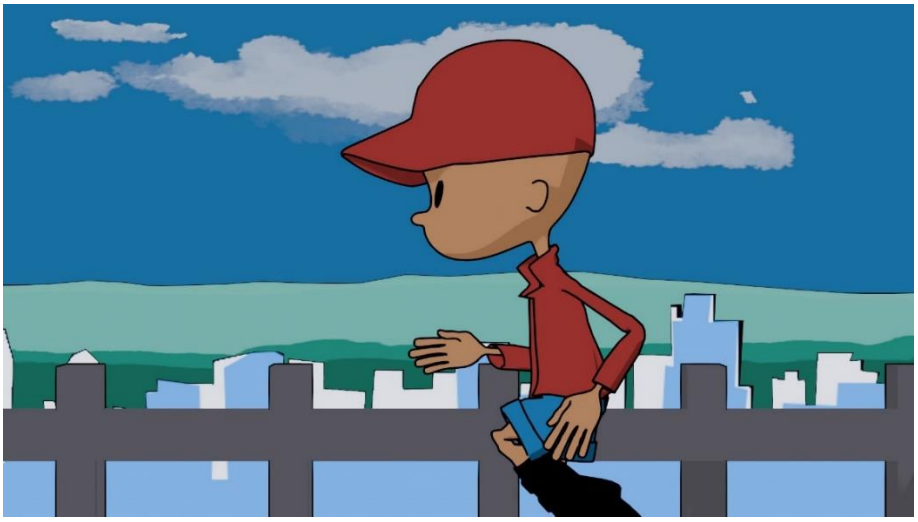

Figure 2.3: Model with Line Art Method

Another software-dependent method is the use of the line art feature, Figure 2.3, which creates lines around assigned objects based on the position of the camera. This creates even lines without any extra, as pictured above.

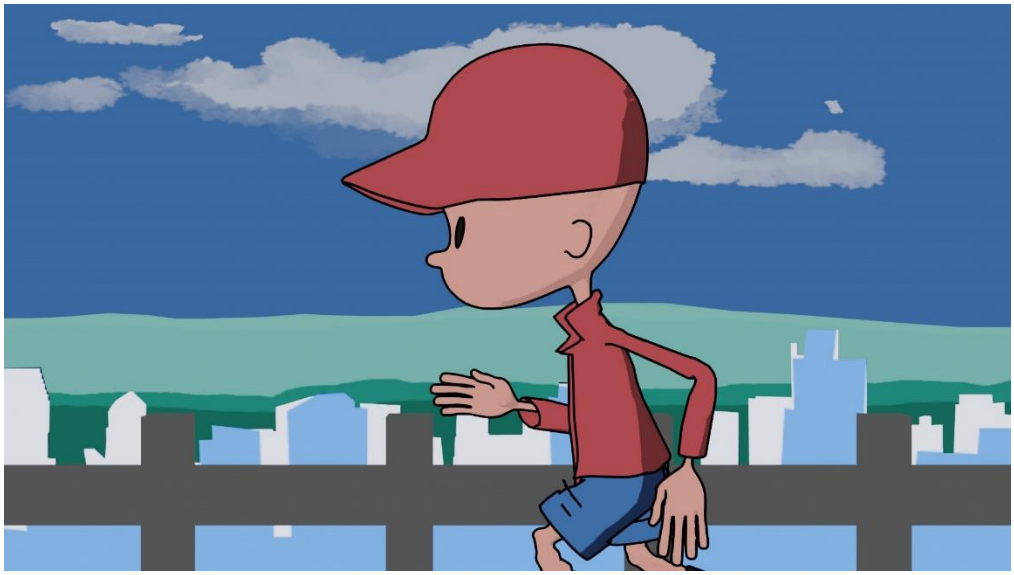

Figure 2.4: Line Art Method with Grease Pencil

Finally, Blender 4.0 modeling software includes a tool called “grease-pencil” which is designed to allow 2D lines to be drawn on 3D models. While this tool may seem ideal for making 3D models imitate 2D drawings, the tool has several drawbacks. For example, the lines are not animated along with the objects they are drawn on. Figure 2.4 demonstrates how grease pencil lines stay fixed in place while a model animates, which undoes the illusion that the model is a hand drawing. Rigging the grease pencil lines did not help with this issue.

I determined that using the line art tool alone was the most effective technique for recreating the cartoon aesthetic I was attempting.

2.2 Original Model

At the beginning of my project, I crafted the original model by hand as a test concept for what I wanted to achieve. It was designed based on a 2D sketch I had created in Adobe Photoshop, and it was meant to appear as two-dimensional as possible.

Creating the original model taught me about the importance of high polygon count, symmetry in character modeling, and creating a model with different shading methods in mind. The model pictured below uses the inverted hull method, using a shell with the normals reversed to give the appearance of a black outline to whatever portion of the model is facing the camera.

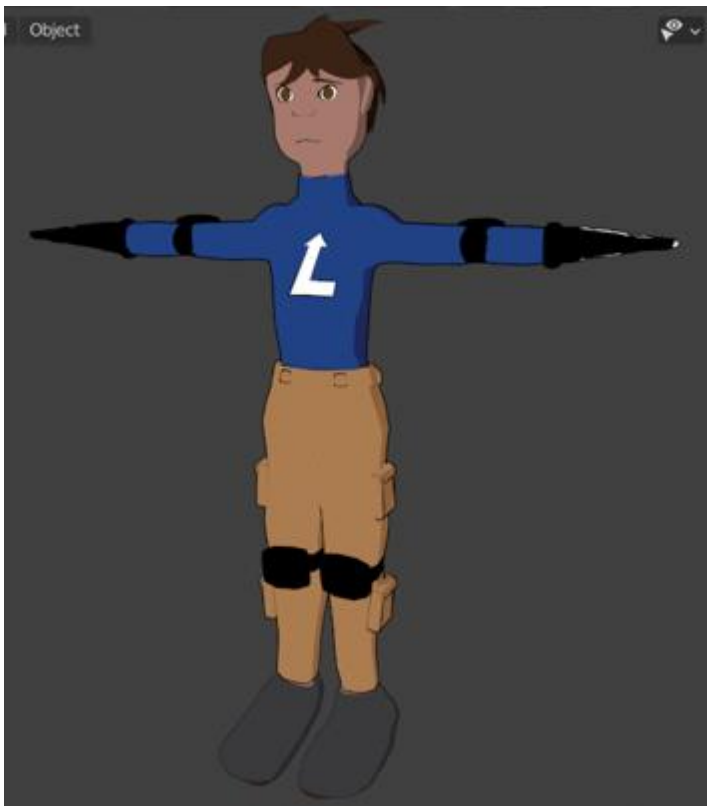

Figure 2.5: Original 3D Character Model Created for 2D Imitation

2.3 Rigging

When rigging a 3D model to imitate 2D animation, the rig needs to be complex enough to provide smooth movement. Ideally, the rig should also allow for squashing and stretching of the model. This is necessary to imitate 2D style, especially because stretching a model is necessary for certain forced-camera perspective tricks to mimic how 2D animators will exaggerate the poses and models of their 2D characters to best express the action of a scene.

I chose to use a pre-made rig from the Adobe website Mixamo. The website offers free character models, rigs, and animations for use in projects. So I could focus on the shot designed instead of revising my original test model.

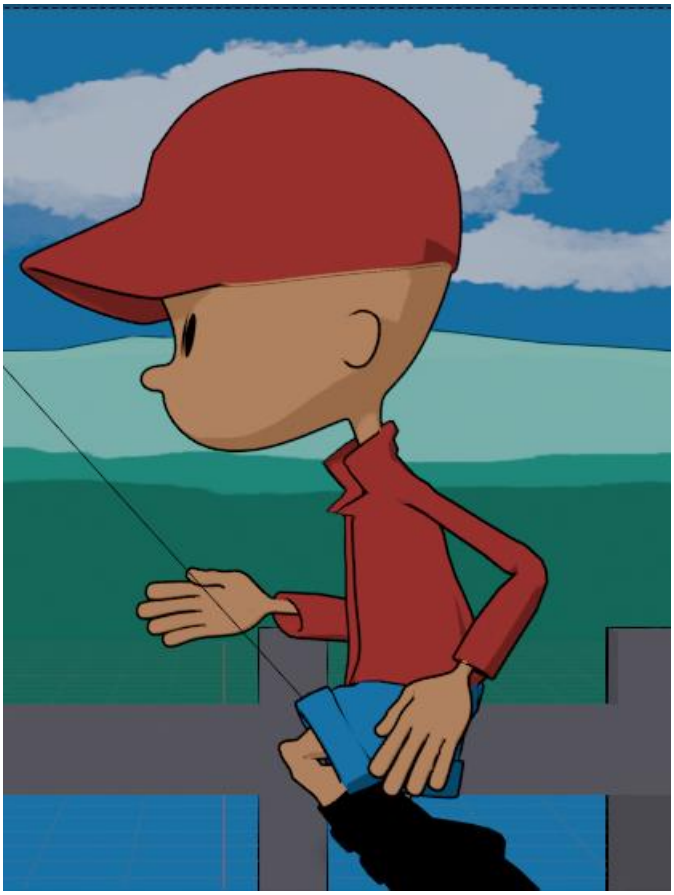

Figure 2.6: Mixamo Model Modified to Imitate 2D Animation

I used the model in the figure above provided by Mixamo in my final animations. The geometry and rig of the model is unaltered, but the texture and shading of the model have been changed to imitate the 2D style. The image above features the same inverted hull method for the line art that I used on my original model. This brought me closer to the results I was looking for, but there were imperfections I later had to address.

3. STAGING

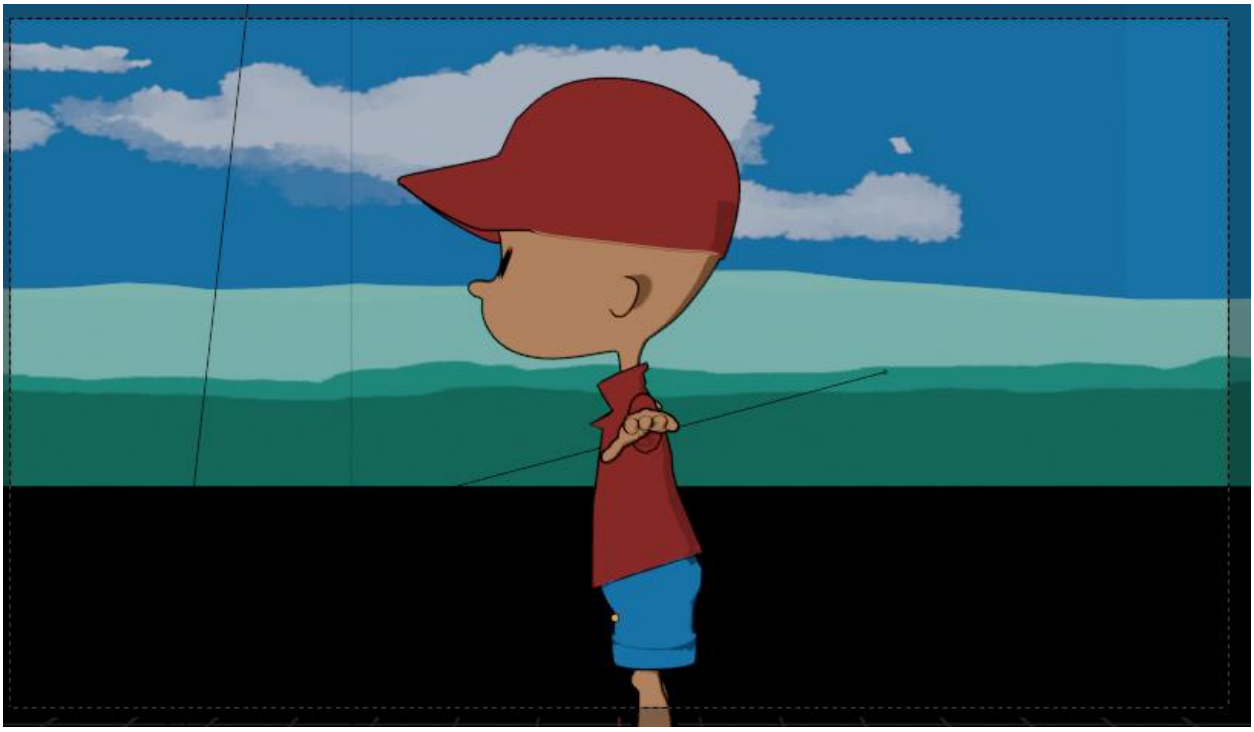

Figure 3.1: Composition of the Shot with Several Layers

Staging in animation is important for creating the illusion of depth or the illusion of a lack of depth. In the past, traditional and computer animation used layers of hand drawn cells to save on work and allow for simple camera movements. In the past, this has been achieved through a process called “parallax,” which is the technique of moving some of the layers behind a subject at different speeds as if the objects in the back were farther away.

With a physical camera, objects which are further away from the lens appear to move less than objects that are closer when the camera shifts. Parallax is the process of imitating this effect without moving the camera. So, the camera remains static while the objects in the background are moved.

Animation studios have created parallax in a number of different ways. In 1933, Fleischer Studios patented the stereoptical camera, a camera on a track which could adjust background layers at different speeds behind a cel in frame of the camera. In the same year, Walt Disney Studio's animator and director Ub Iwerks invented the multi-plane camera, a tower which could hold multiple cels for different layers, which could then be moved to create parallax.

Today, parallax can be created by computers and doesn't require the same amount of heavy, sophisticated equipment. Adding parallax and shifting, flat, layered backgrounds can dramatically improve the illusion of 2D because it is actually using 2D elements. I discovered this from several sources, especially the video "I remade Spirited Away… but in Blender" on YouTube [19]. I took this advice because I agreed that the use of flat backgrounds added to the effect I was looking for.

3.1 Project Staging

When I was working with the original model I created, I had envisioned a much more complicated composition with a rotating camera that followed the subject as they ran past the camera (Figure 3.2). However, as I did more research, I realized this shot did not resemble traditional 2D animation. My original plan included complex camera movement and rotation which would usually only be animated in 3D. It was the kind of camera trick that a live action or CGI film would use to show off their technical capabilities, which is the opposite of what I want to achieve with this project. So instead, I decided to create a simple running scene which used parallax to create the illusion of movement while the character remained static in the shot and in profile. This much more closely resembled a shot from traditional 2D animation.

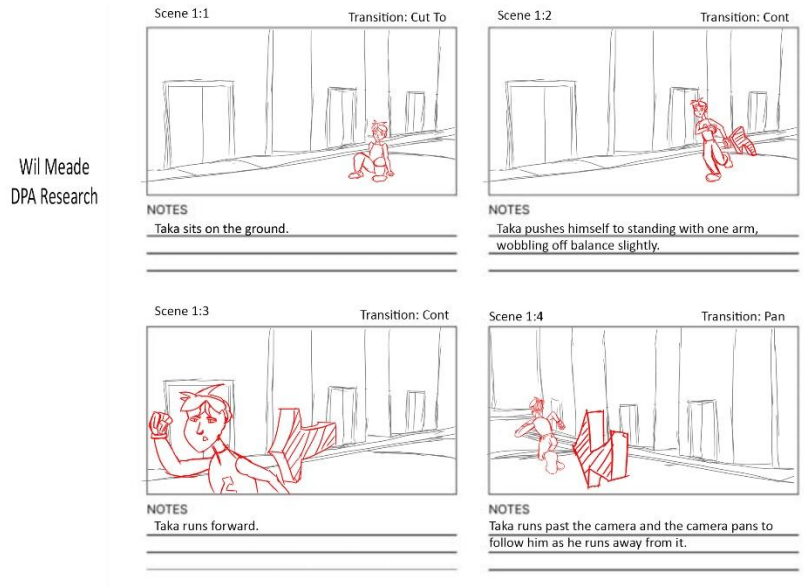

Figure 3.2: Original Storyboard for Project

The final scene is made up of six layers. These layers are the character in the foreground, the fence behind them, a skyline of buildings, green hills, clouds in the sky, and finally the static blue background for the sky, Figure 3.3. I chose this number of elements to resemble the foreground, midground, background composition of traditional two-dimensional animation. The soft colors and exaggerated shapes are reminiscent of the art styles of Mary Blair and Lou Romano. The lack of black outlines in the background serve to emphasize the character in the foreground, because the character's black outline stands out. The foreground character also uses bright, warm colors which contrast with the cool, cold colors of the backgrounds. These layers also created variety and a sense of parallax.

The fence was originally a homogenous concrete railing similar to a divider, but with flat colors this did not create the sense of movement, so I changed it to be a segmented fence, so it was clearly moving across the screen.

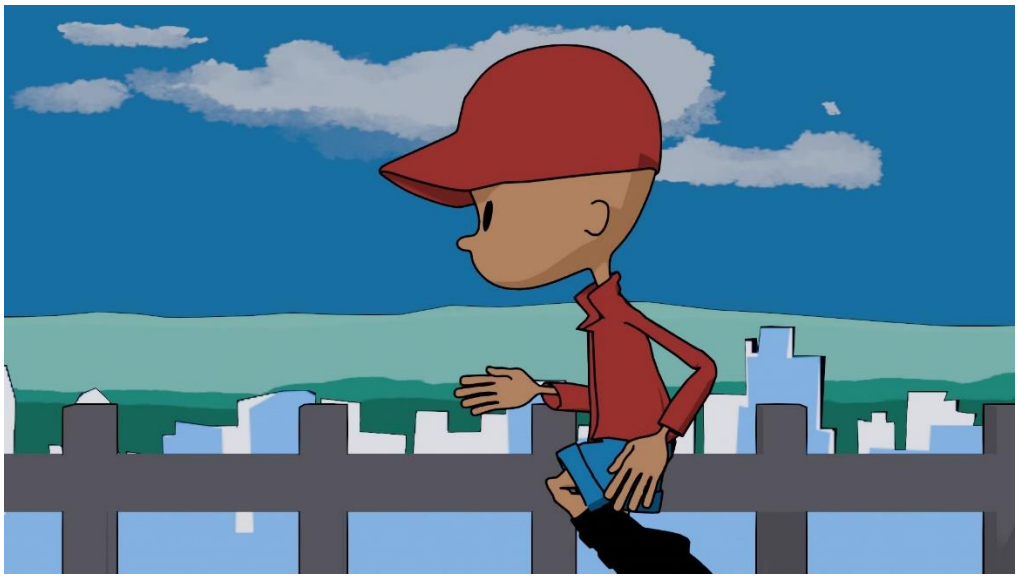

Figure 3.3: Scene Layers Together

3.2 Adjusting the Staging

There were several iterations of how to stage the scene. Originally, the scene was a more complex 3D scene with boxes for buildings. But when the composition was changed, stand in planes for the different layers were added. In the final project, the four background layers used were two-dimensional planes, mimicking the flat animation cels traditional backgrounds would have been painted on, as I described above. This helps to create the appearance of 2D animation.

In one version of the project, the layers of the background remained static while the character and the camera moved. Eventually, I determined this version was not as convincing as the original version and that it was more difficult to manipulate. So, I reverted to the previous version where the backgrounds moved behind the character and the character remained in place.

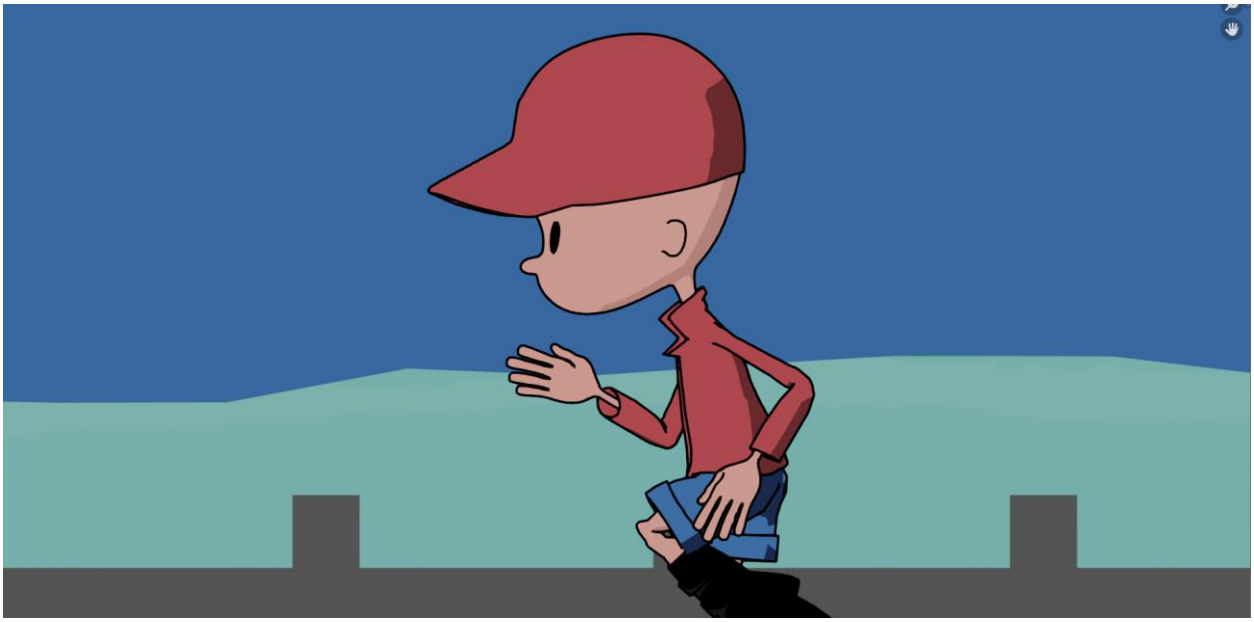

Figure 3.4: Orthographic View

3.3 Camera

The camera settings of a computer-generated scene has a major impact on it's style. The above image, Figure 3.4, shows what my scene looks like with an orthographic camera. Orthographic projection is a way of depicting objects so that any lines that are parallel with each other remain in the same place from the perspective of the camera. This is in contrast to perspective projection, which draws parallel lines so that they move closer to the center of the image as the object gets further away from the camera. Orthographic projection is a common way of simplifying a 3D scene into two dimensions, but orthographic projection does not fit the aesthetic of my piece. This is because artists that draw for animation draw objects in perspective, the way a perspective camera depicts them. So, an orthographic camera less accurately resembles a scene drawing in the style I am attempting.

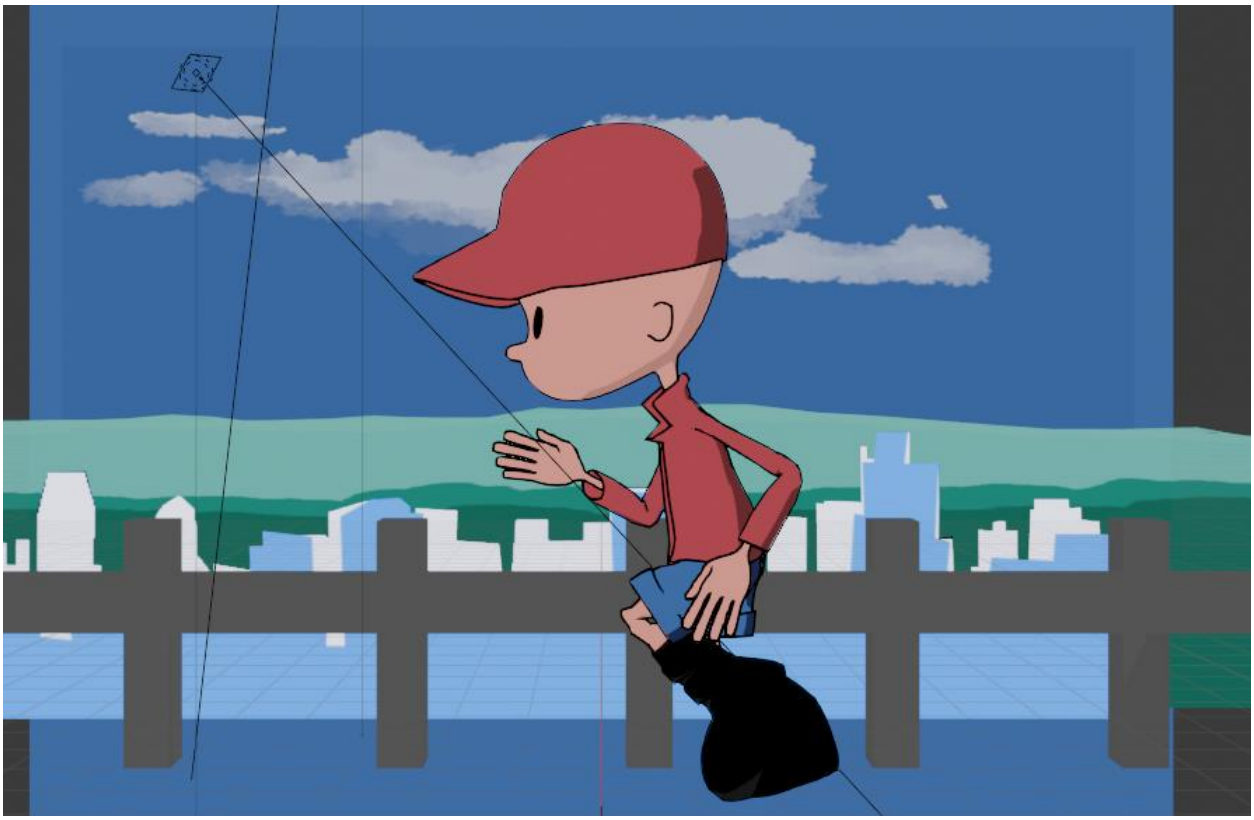

Figure 3.5: Default Camera Settings

In Blender, the program I was using, the default focal length of the digital camera lens is thirty-five millimeters. This makes objects seem further away from the camera and increased the distance in perspective of objects further away from the camera. This focal length was not appropriate for my scene. I wanted the character to appear closer to the camera and the backgrounds to move quickly behind the character. This meant a longer focal length. I used fifty-five millimeters.

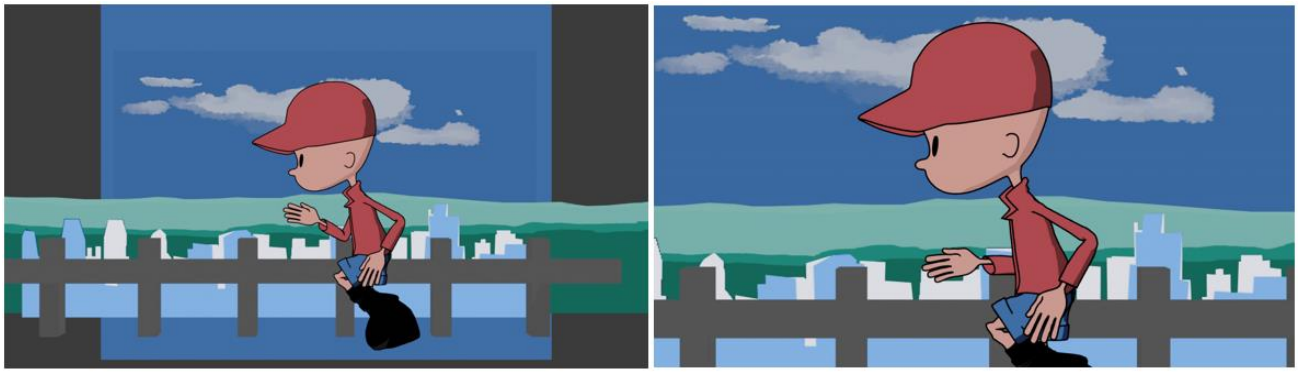

Figure 3.6: Default Camera and Final Shot

Figure 3.6 demonstrates the differences between the default camera and the camera focal length I chose. With the default settings, the objects would all have to be moved much closer together to fit within the camera, and the center character would have to be moved so close to the camera that details would be cut off. In the final shot, the character fits comfortably in frame while the background elements sit behind them.

Figure 3.7: 75 Millimeter Lens and Final Shot

For comparison, Figure 3.7 demonstrates the difference between a longer focal length and the length I chose. The shot on the left was taken with a seventy-five millimeter camera, and the shot on the right uses the final camera settings. Even with the distance between the camera and

the character adjusted, the seventy-five millimeter shot is too cramped. The objects are too close together, and much of the background is not visible. Ultimately, I decided that the fifty-five millimeter focal length most closely resembled the style of shot that I wanted.

4. SCENE LIGHTING

Lighting is an important aspect of animation. How a scene is lit can completely change its appearance and style. A scene rendered with photorealistic lighting will look dramatically different from a scene rendered with flat or unmotivated lighting. These differences can be leveraged to give a scene the appearance of flatness, resembling traditional animation.

4.1 Lights

To imitate the style of 2D animation, I originally intended to have a single scene light representing the natural source of light in the scene, the sun, and a point light for the character in the scene.

In traditional and 2D digital animation, characters are usually drawn with a simple shaded/unshaded style using one color for the unshaded portions and a slightly darker or tinted color for the shaded portions. The scenes most often use single-direction lighting, which involves only one light source instead of several light sources which would have to be blended together to achieve realism.

This is very different from the style of lighting which is commonly used in live action films as well as 3D animated projects. In modern filmmaking, it's common for each actor in the scene to be artificially given an edge light, key light, and fill light to make them as visible as possible. This style is also used in 3D CGI projects, where the process is much easier given that the lights can be source-less in the scene without any heavy machinery or crew members.

Additionally, in computer generated images, it's common practice to use a process called global illumination, which involves different algorithms to calculate how light bounces and reflects off of objects to add more photorealism to the lighting.

I wanted to avoid both of these styles of lighting, multiple light sources and global illumination, for my project. Either style would be a clear indication to the audience that I was imitating live-action film making instead of 2D animation. Most 2D animated projects do not bother to paint their characters with this amount of lighting. In fact, even in projects with more sophisticated lighting, such as *Klaus*, the characters retain single-directional lighting. [20] Characters may be lit in a way that more subtly transitions from shaded to unshaded lighting, and the light may come from a single, continuous direction instead of following them. But the light remains single-directional.

Additionally, in 2D animation, characters' lights usually remain constant even when they move in a scene, as if they each have their own individual light. This suggests the lighting conditions of the room but does not realistically match it.

I imitated this individual light by giving the character a light that only applied to it, and I set the scene light to not affect the character. This means that the character's lighting condition remains constant so long as their personal light moves with them.

4.2 Texturing and Shading

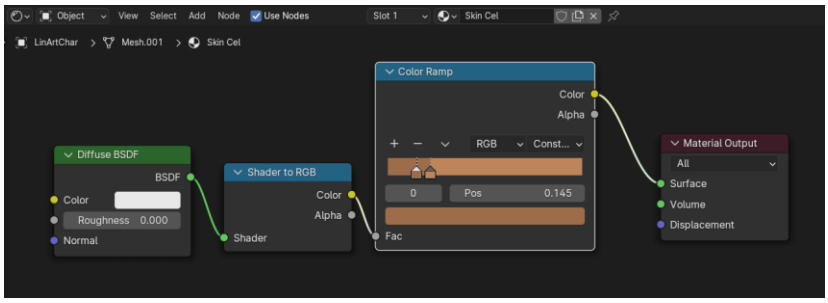

Figure 4.1: Original Material Network for Character Skin Shader

The shader for the character is very simple. To imitate the "cel shading" style of 2D animation, I used a color ramp with two colors piped directly into the surface of the material output, as shown above in Figure 4.1.

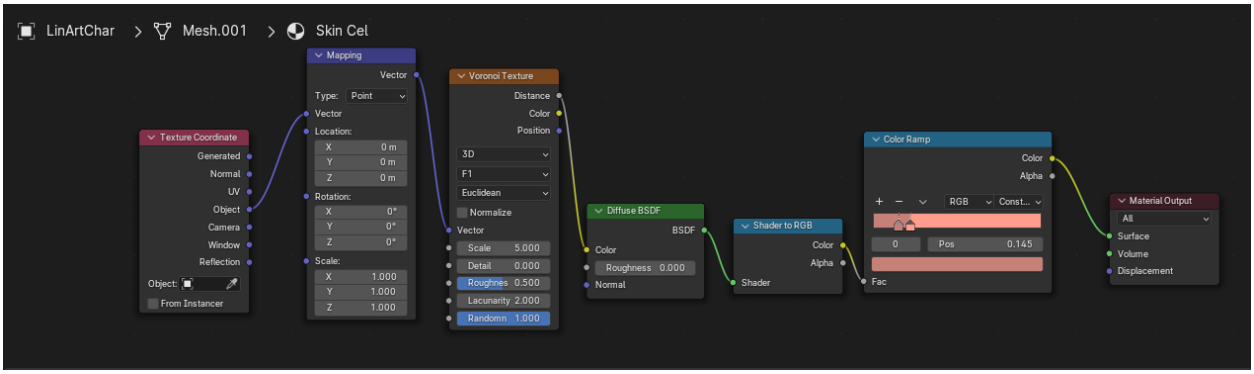

Figure 4.2: Final Material Network for Character Skin Shader

I then changed the shader to create more variation in the lines and colors. By mapping coordinates of the object's texture to the Voronoi Texture and plugging that into the color ramp, the border between the shaded and unshaded regions was blurred and more variation was added to the rest of the object, as shown in Figure 4.3 below.

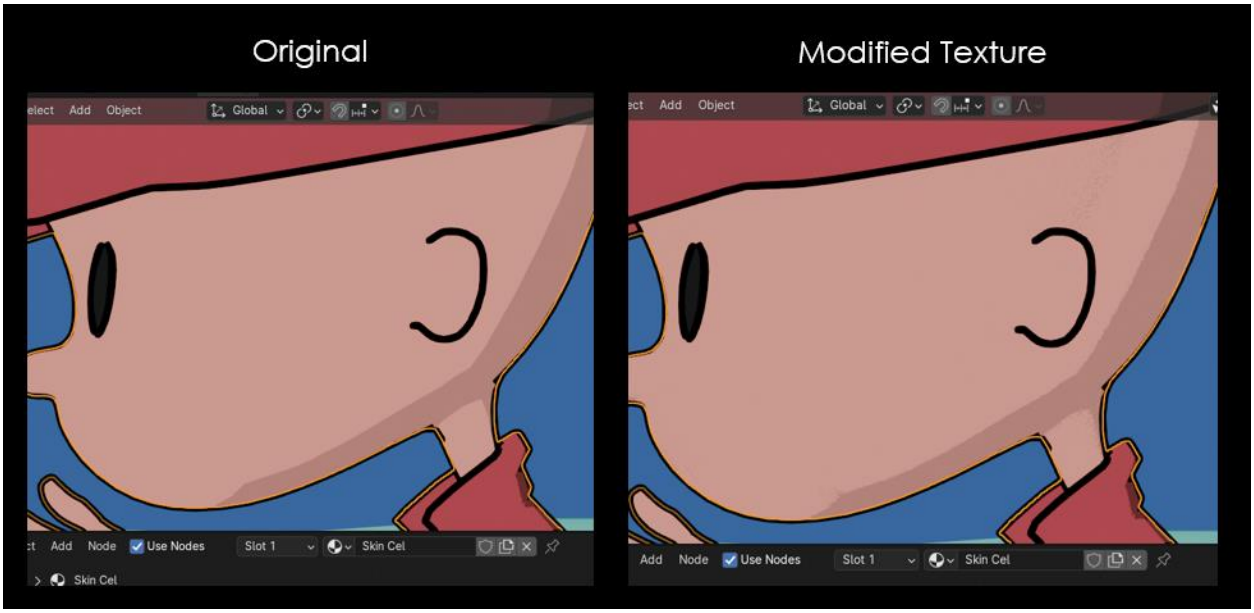

Figure 4.3: Original and Modified Textures

This could be made more complex by adding more colors. For example, a highlight could be added which only affected the lightest parts of the character, or a third color of even darker shadow could be added to give the shadows more depth and complexity. I also disabled automatic smoothing because I found the results were smoother without the automatic smoothing.

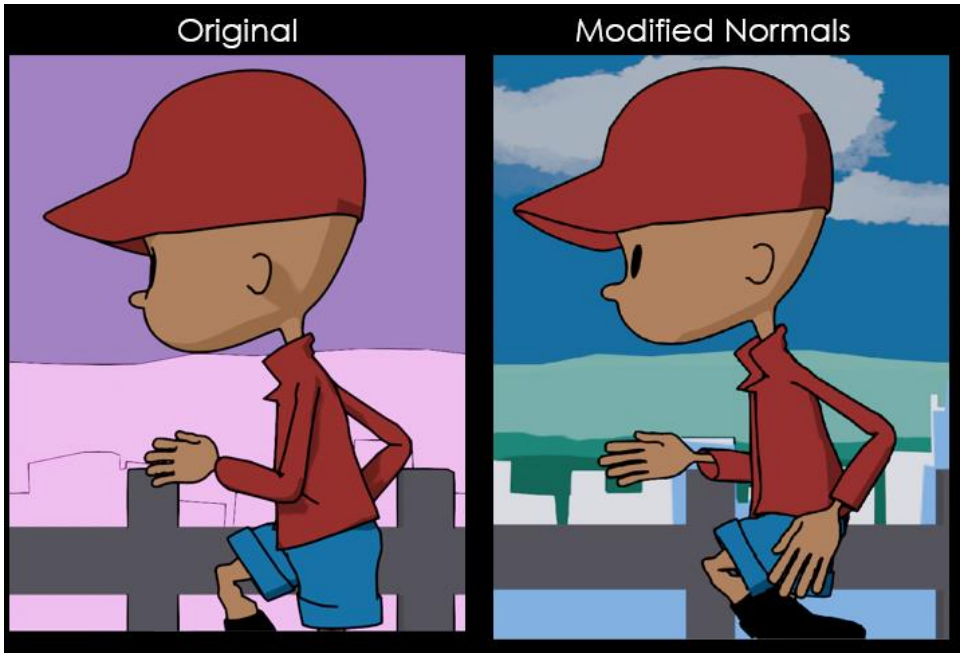

Figure 4.4: Original and Modified Normals

In addition to a custom shader, a character's shading can also be changed using the normals. The normals of a model refer to which part of the surface reflects light. In 3D computer generated models, the normals of a surface can be modified to point in different directions so that they reflect light only from certain angles or in a different direction. For the character in the scene, I modified the normals by hand to make the shadows of the character appropriate to the style. This is shown in Figure 4.4.

However, this could also have been achieved by modifying the shader so that more or less parts of the model were shaded. I also disabled the "shadows" of the light source which prevented the lights from affecting the character in an uneven way based on how the light rays bounced off the normals. Ordinarily, it's best practice to set the normals so that they work in all lighting conditions, not just for a specific shot. However, because this project focused on only a single scene, it made sense to hand set the normals to only be appropriate for the scene. It's also

possible to imagine a larger project in this style with multiple scenes where the base normals of the characters and scene elements were modified in each scene to meet the requirements of the lighting. With careful planning and coordination, this could be easier than perfecting the normals from the beginning.

It might also be possible to introduce an amount of noise onto the shader or the boundary of the shader to make the transitions between light and dark smoother or to introduce small imperfections in the lines of the shadows to imitate mistakes made when drawing traditionally. The problem with this final approach would be that the "imperfections" would remain the same for every frame, rather than changing with each frame the way traditionally drawn frame-by-frame animation would be. In traditional animation, each frame was a new drawing, so any imperfections in the lines of one drawing would not carry over to the rest of the drawings. Not to mention, in more modern examples of 2D animation, imperfections are digitally removed with a "clean up" stage. So, the lines are computer-generated and lack imperfections. In order to properly represent imperfections in hand drawn animation, a more complicated process would be necessary.

In traditional cel animation, the characters and other elements of the foreground would have a subtle "drop shadow" left on the background. It should be possible to imitate this drop shadow with a translucent flat plane or some kind of post-processing effect. However, this drop shadow would have to follow the character, which would be difficult to create either as a plane or a processing effect.

4.3 Scene Shading

The scene lighting needed to resemble the style of lighting of the character. This was made somewhat easier because most of the background elements were flat planes, so the lighting would be even on them even without special shaders or lights.

However, the bridge railing in the foreground posed several key problems because it was 3D modeled instead of a flat plane. The bridge railing was 3D modelled because of its closeness to the camera and because it was simpler to model it than to create another flat plane. However, the angle of the railing to the camera meant that the back edge of the railing was not caught by the line art modifier in Blender, making the top of the railing mysteriously lacking a black outline. This made the railing stand out awkwardly in the scene. The lighting of the bridge also changed dramatically as it moved across the screen, due to it changing its angle relative to the scene lighting. This is more realistic but takes away from the illusion of 2D. It might be possible to fix this issue by giving the railing a personal light which follows it in the same way that the character is given a personal light. In the future, I would like to modify the foreground elements so that they would more closely resemble a 2D animated style or create them using flat planes as well instead of 3D modelled elements.

When creating a 3D animated scene, it's important for the lighting of the scene elements to resemble the lighting of the character. So, the same process of cel shading and altering the normals needs to be done for the 3D modelled elements of the setting. The fence was given the same shader as the character model, but more time could have been spent modifying the normals to fit the style of the scene.

4.4 Lighting a Scene for Environment

In 2D animation, lighting conditions often change to resemble the environment or the mood of the scene. Lighting may become more dramatic in darkness with harsher cold blue light, it may become warmer and softer to give the scene a calm, moody feel, or the colors of the light may change to reflect the weather such as a hot summer day or cold winter morning.

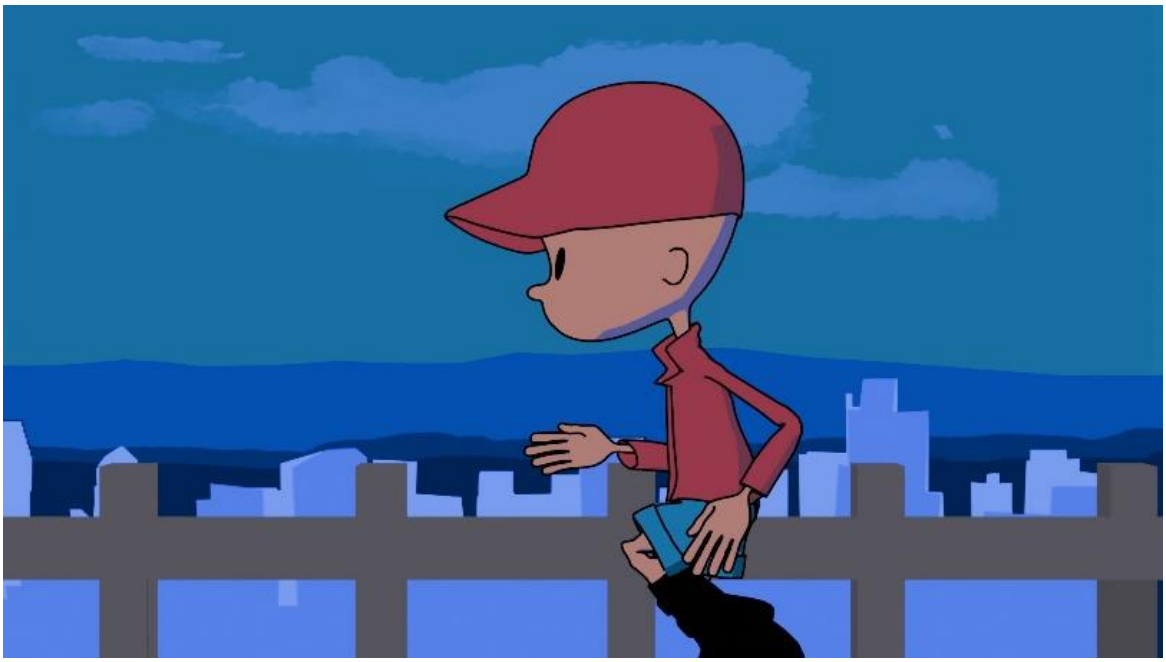

Figure 4.5: Blue Lighting

The above picture, Figure 4.5, features blue lighting. This lighting would be appropriate for a calm night scene or potentially an overcast or rainy day, though it would depend on the tone of the scene. A third layer of highlights could be added to the shader for yellow, to differentiate light from streetlamps or cars, for example.

Figure 4.6: Pink Lighting

Figure 4.6 above demonstrates pink lighting. This lighting could be appropriate for early morning or a romantic or nostalgic scene.

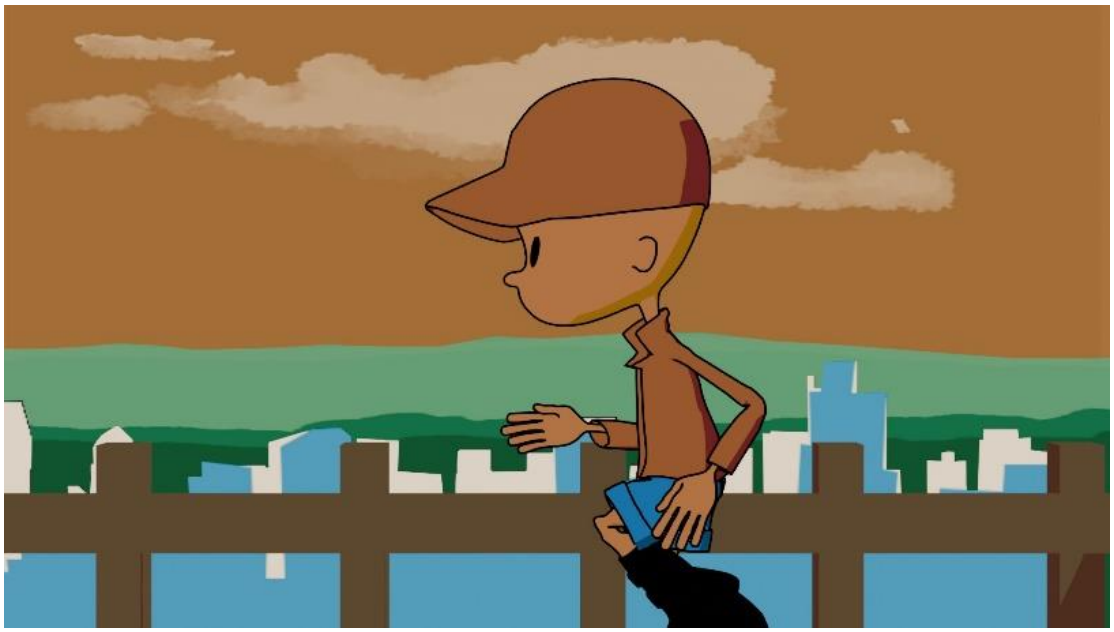

Figure 4.7: Orange Lighting

The next figure, Figure 4.7, demonstrates a version of orange lighting which is imperfect. The set behind the character needs to be altered, and the values of the orange on the character are too extreme. Overall, the image is visually appealing. The limited color palate of orange, green, and blue is distinct and eye-catching. But this image is incorrect as a modified version of the original shot.

The changes in the color of light required not just changes to the lights in the scene, but also to the shaders and textures themselves. Because the colors were attached to the textures and shaders of the model, changing the light to only one color resulted in the colors becoming black or gray, rather than a combination of the light and model colors. For each new scene and color of light, it was necessary to change the shader colors of each material. This had to be done individually for the shaded and unshaded portions.

While this took more time than I expected, it also allowed for a lot of control over the color of the shot, similar to painted 2D cels in traditional animation. This is an advantage that two-dimensional animation usually has over 3D animation.

4.5 Conclusion

There are a lot of techniques which can be used to help 3D computer-generated animation appear two-dimensional. The standard film and 3D CGI use of multiple light sources and global illumination can be replaced by single-directional lighting and a cel shader which divides the lighting on a character into shaded/unshaded regions. The style of lighting can be changed to imitate classic 2D cartoons with simple shading and solid colors.

5. ANIMATION

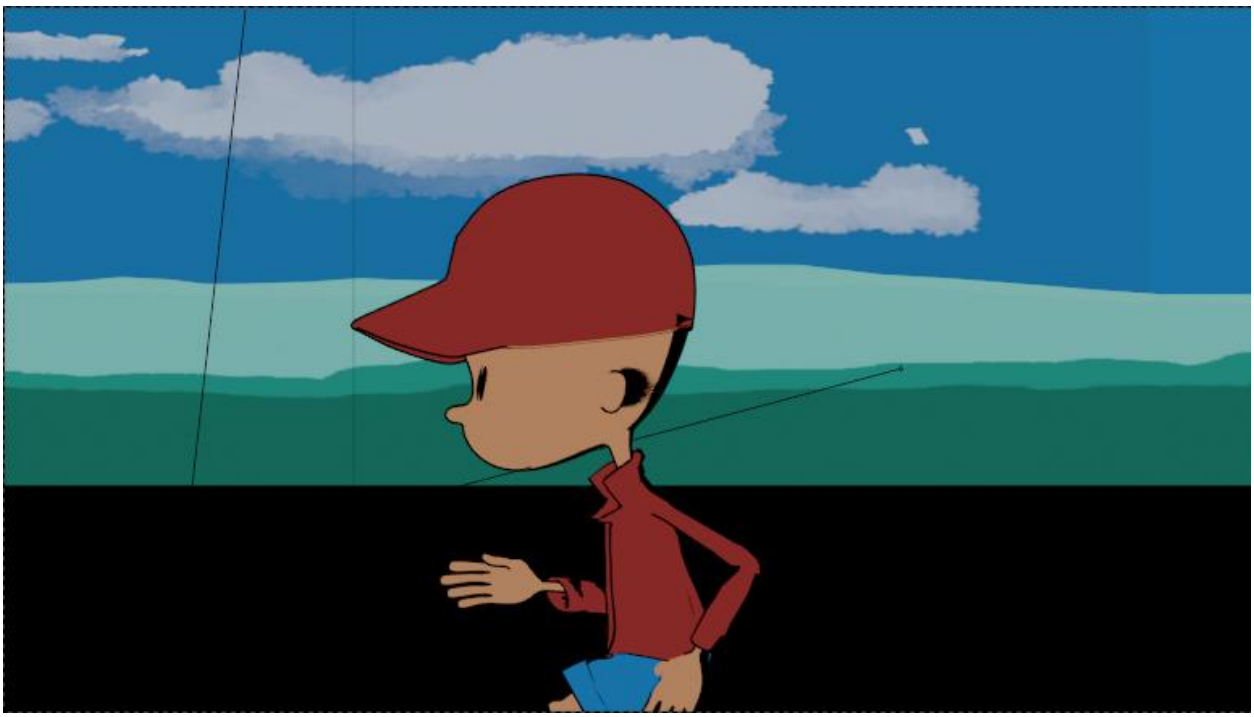

Figure 5.1: Early Animation for Character Model

One of the biggest advantages of computer animation is that computer software allows animators to create “interpolations” between keyframed poses. When two poses are keyframed, the computer can be asked to interpret what a movement between these two poses would look like. The speed of these in-between poses can be altered by the computer without the animators posing the model for each frame by hand. This saves an enormous amount of time. However, interpolation is impossible to do with traditional 2D drawings. Having an animation that is too smooth or averaged by a computer gives the animation a distinctly computer-generated aesthetic which should be avoided when imitating 2D animation.

An easy way to avoid the issue of computer interpolation in 2D imitating animation is to use traditional “limited animation.” In traditional animation, every frame is a keyframe and any

interpolation is performed by hand. In limited animation, animators would use the same drawing for multiple frames. Sometimes, they would only use camera movements to create the illusion of animation with long pans over detailed painted backgrounds for establishing shots. They would also only animate the parts of the body that needed to move. So, if only an arm was moving it would be drawn on a separate cel and that cel would be replaced as needed to create the movement in the animation. Though this technique is most common in television animation, it can be found in even feature-length films. Most of the film *Akira* was shot with every other frame animated, though certain scenes were animated at a full 24 frames per second. [2] This is a stylistic choice which impacts the feel of the scene. Slower scenes can be emphasized by limited frames, while action-oriented or especially detailed scenes benefit from 24 frames per second.

There are several other tricks for animating 3D models to look like they were animated traditionally. This can include manipulating the scale of a rig's individual parts to create an exaggerated perspective and exaggerating the face past the point of natural positions. Finally, the frame rate of the animation can be reduced from twenty-four frames per second to twelve. 24 is the industry standard today, but twelve frames per second, which is also known as "animating on twos" creates a jerky, energetic look to the animation which, was a common practice in traditional 2D animation to cut down on the number of drawings needed in an animation. By using this method, it creates the illusion of traditional hand drawn animation.

5.1 Project Animation

For this project, in conjunction with the rig provided by Mixamo, I was also able to use one of the running animations provided for their models. This animation was then modified to suit the needs of the scene. For example, the original animation translated the character across the stage, which was unnecessary because of the use of parallax. For the same reason, the background elements were also animated to move across the screen at different speeds. The original animation resembled the high-energy sprint of a video game character, but the scene called for a slower run to give the impression that the character has already run a long distance. Because of this, the animation was also modified so that the character was standing up straight instead of leaning forward, which also helped to place them in the center of the stage. Finally, the up and down bobbing motion of the character was lessened for the same reason.

When editing the rendered animation, the time between the frames of the original animation was increased, slowing the animation to create the effect of limited animation and to provide the right tone for the scene. The slow motion of the character takes the energy out of the run, making the scene feel calmer and more relaxed than if the character were moving very quickly. This gives the audience time to absorb the details of the scene.

6. CONCLUSION AND VERSIONS

There are many techniques which can be used to make 3D computer generated animation look like traditional two-dimensional hand drawn animation. The appearance of a shot and whether or not it is perceived as 2D or 3D is influenced by the character models, the staging of the scene, the lighting, the shading, and the animation. A 3D model meant to look 2D should have a high polygon count, manipulated vertex properties, simple textures, individual lights, and a method of creating the illusion of line-art such as an inverted hull or line-art modifier. The elements of a scene should be staged from straight-on or in profile with the elements in distinct layers that don't overlap, and the composition of the shot should center the main figure or place them on the thirds of the camera. The shading of the objects in the scene should be simple, with portions divided into shaded and unshaded. The lighting of the scene should use single-directional lighting instead of the multiple light sources and global illumination which is common in live-action film and 3D animation. Finally, the animation should be "stepped" and limited to reflect how a 2D figure would be drawn. The layers should be animated separately with parallax as if they are moving behind the character instead of the character moving across them. Each frame of animation for a model should be its own keyframe of animation, to remove the interpolation of the computer. It is difficult to make a 3D scene look two-dimensional, but certain techniques can be used to create the illusion.

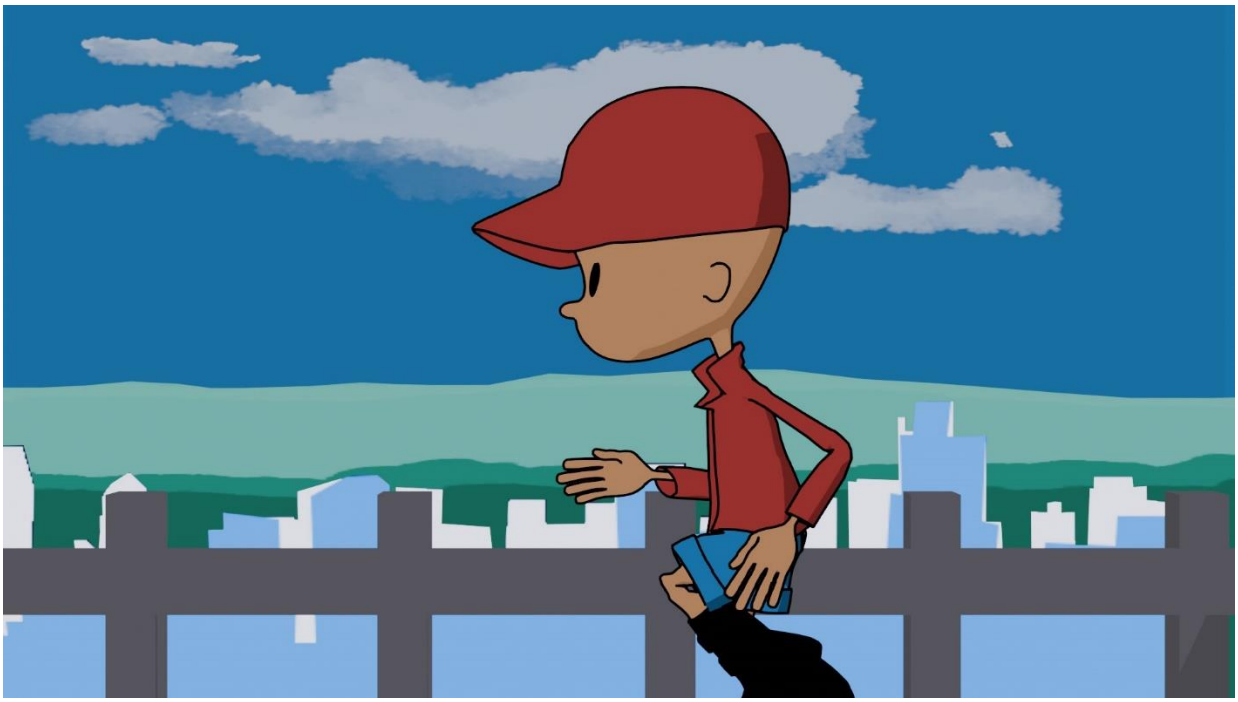

Figure 6.1: Original Animated Shot

As I worked on this project, I discovered several problems with the techniques I used to construct my scenes. The above picture, Figure 6.1, is a frame from the first fully rendered version of my project. While still, the effect of a 2D drawing is convincing enough, but in motion, I did not find the effects convincing for several reasons. The first was my choice of color. I believe the colors in this original version are too saturated. They have the appearance of artificial colors created by a computer. Additionally, the character's head originally moved wildly from side to side and rotated towards and away from the camera. This made it very obvious that the model was 3D, as no 2D animator would draw a character like that when the character was running in profile. The head tends to remain relatively still. To achieve the look I was going for, I corrected these errors in the next version.

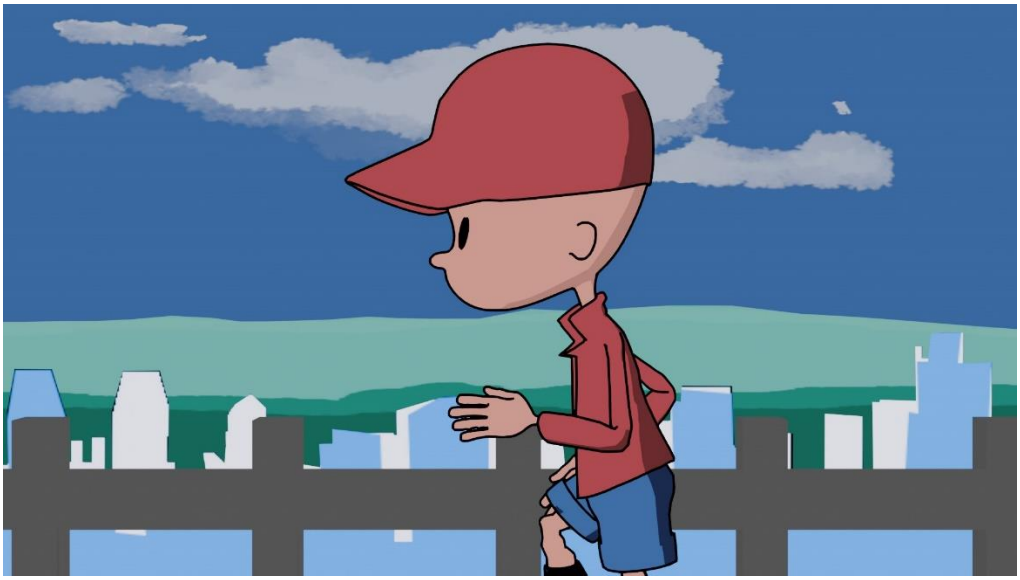

Figure 6.2: Second Version of Shot

For the second version of my project, I chose less saturated colors and changed the animation of the head. I believe this version is closer to my vision, but it is still not as convincing as I want it to be.

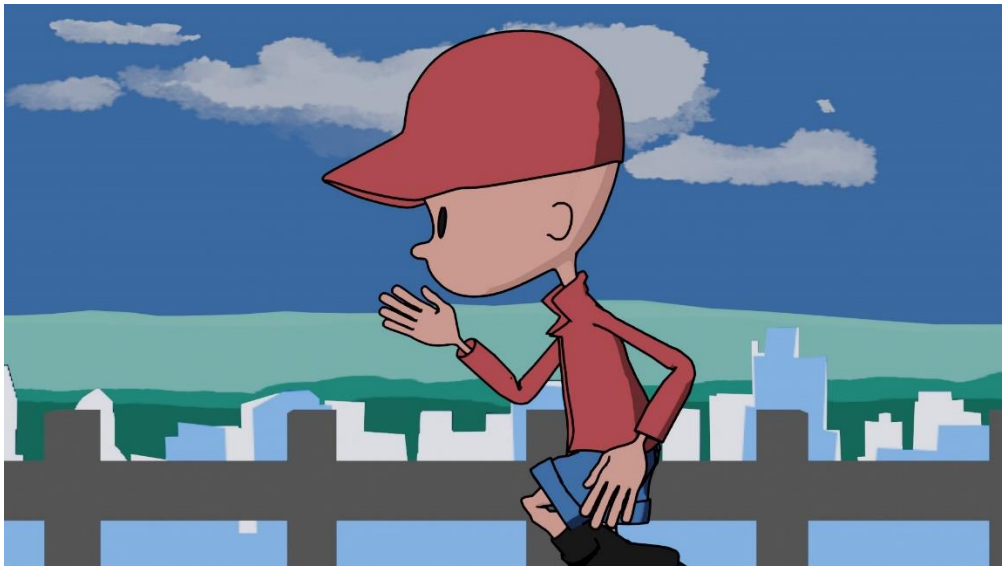

Figure 6.3: Final Version of Shot

The final version of the shot, shown in Figure 6.3, makes several corrections to the other versions. The animation has been changed to be more dynamic, resembling 2D animation. The shading has been changed on the hat to more closely resemble 2D artwork, and noise has been introduced to the boundaries of the shaders.

If I had an opportunity to start this project from the beginning, there are several changes I would make. I would use an original model instead of one from Mixamo. I would like to make the lighting more refined and complex. This would involve changing the boundary of the lighting on the shader. It could also include adding highlights and fixing the normals to work from every angle instead of just the angle of the present shot. I would add more color and texture to the models and backgrounds to determine how detailed I could make them look without losing the aesthetic of traditional animation. I would experiment with stretching the model to incorporated squash-and stretch in my animation, and I would attempt to use hand-drawn smears and motion-blurs.

More research could be done to make this process more effective at creating the desired illusion. For example, post-processing and compositing effects could be used to add drop-shadows or filters over the whole animation to create small errors or imperfections in the style of damaged animation cels. The shaders could also be more complex. Functions could be added to the shaders, so they behaved differently under certain conditions such as at hard corners or when clipping into another object. Projected textures could also be used so that imperfections in the objects remained in place while the object moved. This would imitate the appearance of paper, but would have to vary every frame to create the illusion that different elements are redrawn on different cels or papers.

Imitating traditional animation is a complex process. It requires careful consideration of all the elements of a shot, including the models, composition, lighting, shading, and animation. But using 3D animation to imitate 2D animation can create visually cohesive, beautiful works of art.

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