Dynamic Frame Rate: A Study on Viewer’s Perception in Changes in Frame Rates within an Animated Movie Sequence

A Thesis
Submitted to the Faculty
of
Drexel University
by
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in partial fulfillment of the requirements for the degree of
Master of Science in Digital Media
June 2016
Acknowledgments

I would like to thank Professor John Andrew Berton for advising my thesis. He has been a great help in guiding me towards the right direction and supporting me, my concepts and ideas throughout this entire process. I would also like to thank my committee members. Thank you Professor Theo. A. Artz for all the insights, feedback and support throughout this process. Thank you Professor Chris Sims for all the help on test methods, data analysis and feedback for my thesis.

To the rest of the Digital Media faculty, thank you for all the support and guidance. Thank you to my DIGM classmates for the feedback, support and jokes that helped kept me sane throughout my graduate career.

I would like to thank my family and friends for supporting me throughout my graduate life. I wouldn’t have succeeded this far without you guys.
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Abstract
Dynamic Frame Rate: A Study on Viewer’s Perception in Changes in Frame Rates within an Animated Movie Sequence
Kai-Lin Chuang
John Andrew Berton

Dynamic Frame Rate (DFR) is the change in frame rate of a movie sequence in real time as the sequence is playing. The idea of using dynamic frame rates in digital cinema has not been explored in depth despite the researches and attempts in using high frame rates. As such, there are very limited information on how people perceive it and how DFR actually works. Additionally, we do not have a good knowledge of whether or not it would look good or bad. By understanding DFR and how viewers perceive the changes in frame rate, it will help us adapt new techniques in the creation of cinema. This thesis aims to understand the basics of DFR, how different implementations of DFR changes viewer perception and how people perceive a changing in frame rate of an animated movie sequence displayed in DFR.
Chapter 1: INTRODUCTION

Throughout the majority of the past century and after the introduction of sound in films, frame rates used in films have been kept at a standardization of 24 frames per second (fps) despite technological advancement. 24 fps was adequate for sound syncing and was the minimum number of frames per second that would be needed to prevent the flickering effect [Salmon et al. 2011]. In the past decade, spatial resolution has been increasing in display systems to create improvements in the picture quality in cinema. However, the playback speed for cinema have not been changed. With the increase in spatial resolution but the continuing stagnancy in temporal resolution, researchers and filmmakers stress that film judders and blurriness are much more apparent [Banitalebi-Dehkordi et al. 2014][Emoto et al. 2014][Kuroki et al. 2012][Salmon et al. 2011].

One solution to film judder and flicker on screen is to increase the film frame rates [Banitalebi-Dehkordi et al. 2014][Emoto et al. 2014][Kuroki et al. 2012][Oh and Kim 2014][Salmon et al. 2011][Wilcox et al. 2015]. In theory, increasing the frame rate should improve the motion picture resolution and reduce the motion artifacts such as strobing and judders created by fast moving objects or camera movements. A study done by Routheir and Perez-Pellitero concludes that when comparing the level of detail, a video sequence with 2K resolution and a 30fps playback speed is inferior to a 720p resolution at 60 fps playback speed [Routheir and Perez-Pellitero 2015]. Filmmakers such as Douglas Trumbull and Peter Jackson claim that by increasing the frame rate, immersion level can increase [Howson 2011]. Jackson mentions that using high frame rate will provide “a gentler experience on the eyes” and “give a heightened sense of reality” [Oh and Kim 2014].

Despite the research and attempts, some viewers still cringe at high frame rate content. To them, the motion within high frame rate feels too hyper-real and looks like something from a low budget soap opera [Gallagher 2013][Wilcox et al. 2015]. Yet, when people look at video games, they would want the highest frame rate they can have. A research done by Kajal Claypool and Mark Claypool states that “low frame rates can reduce the feeling of game immersion and impact playability in all
phases of the game” [Claypool and Claypool 2007]. So this comes to a question of why high frame rates work in games while it does not seem to work as well in cinema? One of the reasons for this problem is that the universal standard of the 24 fps has given a particular look that we are used to. This look is known as “the film look”. Due to our long term exposure of “the film look” for nearly a century, there has been a lot of debate on high frame rate used in digital cinema that generally involves with opinions from industry experts and critics [Wilcox et al. 2015].

While the use of a constant high frame rate in cinema and television have been explored by researchers and filmmakers [Banitalebi-Dehkordi et al. 2014][Emoto et al. 2014][Howson 2011][Kuroki et al. 2012][Oh and Kim 2014][On et al. 2008][Routheir and Perez-Pellitero 2015][Salmon et al. 2011][Wilcox et al. 2015], the idea of using a dynamic frame rate (DFR) in digital cinema is still a relatively new topic. Dynamic frame rate is defined as the changing of frame rate in real time within a movie sequence. There are very limited information on the process of creating a dynamic frame rate content, excluding the methods done in the silent film era. How viewers react to the change in frame rate is also not widely understood. By using a variety of frame rate within a sequence, it may allow us to see a whole new level of effect and can lead to a wider artistic choice for filmmakers. At the same time, using DFR can preserve “the film look” within a movie while slowly introducing high frame rate contents to the viewers. Studios and companies looking to use high frame rate within their projects can also cut down cost in production by using high frame rate in scenes where they deem necessary while leaving the rest in standard frame rate. The purpose of this thesis is to understand the basics of how DFR works, the different implementations that can be used to create DFR content and collect data on viewer's noticeability and reaction to changes in frame rate.

Chapter 2 of this thesis goes over the history of frame rates and how it has evolved. Chapter 3 gives an overview of the related works and researches done by filmmakers. Chapter 4 states the problem in regards to dynamic frame rate and why we should be researching into this topic. Chapter 5 to 8 discusses the process of this research and the analysis of the data collected. Chapter 9 covers the expected results and compare it to the actual results from the test. Chapter 10 is the conclusion for the thesis and Chapter 11 will provide ideas for future studies in dynamic frame rate.
Chapter 2: On Frame Rates

Frame rate is the frequency at which an imaging device displays consecutive images. What we are seeing in a video or movie is not true motion, but an illusion of motion. It is a sequence of images that appear to our eyes as moving objects rather than a succession of still photographs. This phenomenon is known as the Phi Phenomenon which was first explained by Max Wertheimer and later led to Gestalt Psychology [14]. It was believed that our eyes will start to perceive motion at a frame rate of around 12 fps. In the following content of this chapter, we will cover the history of frame rates and how it relates to the issues seen today. Recent uses of high frame rates by researchers and filmmakers will also be discussed in this chapter.

2.1 A Brief History of Frame Rates

In the silent era of films, the idea of standardizing frame rate was nonexistent. Rather, the frame rate ranged from 16 fps to 24 fps because cameras had to be hand cranked. The speed at which the cameraman cranks the camera will determine the speed of the frame rate. At the same time, projectionist was also able to vary the projection speed. In some circumstances, the cameraman and projectionist would vary the speed of the frame rates accordingly to the content that was shown [Salmon et al. 2011]. This created different effects that could be used in the film. The most common technique was a technique called undercranking. The person in charge of cranking the camera would turn the mechanism more slowly than usual, which would make the objects or characters on the screen to appear to be moving faster. This technique was useful for a comedic effect as well as for building suspense and action in films [Turnock 2013]. Another technique used was overcranking which was the exact opposite of undercranking. This created slower look and smoother motion within the movie. These two techniques allowed filmmakers to be able to change the effect and mood of the film. Therefore, in the era of silent films, the movies were already in dynamic frame rate.
It was not until the 1920s when frame rate was internationally standardized. With the introduction of sound and lip sync into films, people found that 16 fps was not enough to keep up with the sound. The higher rate of 24 fps was used instead since it yield to better sound fidelity and was the minimum requirement for the addition of optical soundtrack [Howson 2011]. The introduction of sound also meant that the frame rate had to stay consistent and predictable [Wilcox et al. 2015]. Additionally, 24 fps was a number that could be divided by 2, 3, 4, 6, 8 and 12 which allowed filmmakers to know how many frames is needed for one second, half a second, three quarters of a second and so on. Film strips were also not cheap and to create movies that utilize frames higher than 24 fps would be costly. As a result, the frame rate was standardized to 24fps and has not been changed despite our technology advancements.

In the modern day, the digitization of cameras and projections allows a greater reduction in the cost of production. Intermediate steps of film production with film strips can be disregarded which eliminates the additional cost of using higher frame rates. Digital storage spaces are also getting more affordable as the years progress. Monitors and projection systems can go beyond 60 Hz. Yet, the frame rate used in cinema remains mostly stagnant and there is very limited attempts of using different frame rates in movies.

### 2.2 Discussion on High Frame Rates

While there are little attempts, the idea of using high frame rates in movies and films have been discussed widely by filmmakers in the recent years. With emerging technology of heterogeneous display devices in the market, video contents can be delivered to users with a variety of frame rate [Ou et al. 2008]. Promoters of high frame rate hope that it can help solve viewer’s complaints of eyestrain and blurriness, especially in 3D films [Turnock 2013]. It is also believed that the use of high frame rates allow films to achieve “greater realism” and allow viewers to become more immersed. A recent example of a film that uses high frame rate is The Hobbit, which was filmed at 48 fps. Peter Jackson, the director of the film, mentions that shooting a film at 48 fps eliminates the issues of motion blur and judders in the image while making the movie more lifelike and easier to watch [Turnock 2013]. On the other hand, some people felt that the movie had a “soap opera effect” and did
not enhance realism [Gallagher 2013][Turnock 2013]. Despite complaints, counterarguments suggest that people are accustomed to “the film look” and are not yet use to seeing high frame rates and that they would eventually grow to prefer the new look when compared to the standard 24 fps [Gallagher 2013][Turnock 2013].

Television screen and resolution play a huge role in quality. Ultra High Definition Television generally has a high spatial resolution of 4320 by 7680 pixels that aims to provide viewers with immersive viewing experience and a spectacular view of the picture quality. However, only increasing the resolution of television causes new problems. The main problem is using standard frame rate on these television system causes flicker and degradation of the motion picture quality [Emoto et al. 2014]. Douglas Trumbull states in his interview that the increase of brightness of a projector or television can also cause the flickering to happen with a film that is shot at 24 fps [Turnock 2013]. The flickering and degradation of the motion picture has the potential to cause motion sickness to the viewers [Emoto et al. 2014]. In order to prevent that issue, a television with four times the spatial resolution should need four times the temporal resolution to maintain the motion picture quality [Emoto et al. 2014]. As spatial resolution of television continues to increase, it is also important to increase the frame rate to maintain a balance between static and dynamic pictures [Salmon et al. 2011]. In the article “All-digital Super High Definition Images”, it suggests that a High Definition Television should be above 50 fps while anything beyond 75 fps would be meaningless [Ono et al. 1992]. However, the specific frame rate that should be used in High Definition or Ultra High Definition Television is still uncertain.

Various tests and research have demonstrated that high frame rate is beneficial. Trumbull believes that in order to intensify cinematic imagery, the key is to remove the flickering effect of projections and smooth out the motion in the film [Howson 2011][Turnock 2013]. This resulted in his invention of the Showscan, a system that combined capture and projection in high frame rates with large format film [Turnock 2013]. By capturing motion in 60 fps, Trumbull noted that not only was there an increase in physiological response, but the color, sharpness and a sense of three-dimensionality was also better. Researchers have also reported that high frame rates can improve the quality of
television and is a necessary consideration as spatial television standards are continuing to increase [Banitalebi-Dehkordi et al. 2014][Emoto et al. 2014][Salmon et al. 2011]. Capturing and displaying at high frame rates will allow a step up in picture quality and it can also ‘offer a choice of ‘looks’ to the director [of a film] at the post-production stage”[Salmon et al. 2011]. Elimination of blur and jerkiness in motion picture is further improved at a frame rate of 120 fps compared to 60 fps [Kuroki et al. 2012]. Tests with 3D videos and high frame rates have also been done and the result is people preferred watching 3D videos at 60 fps over 24 fps [Salmon et al. 2011]. Quality improvement of the motion picture does not depend on the viewing distance, rather, it depends on display picture characteristics [Emoto et al. 2014]. In other words, the quality of motion pictures will be improved if the frame rate standard is increased.
Chapter 3: Related Works

In this chapter, relevant works done by filmmakers will be discussed. Throughout the past few years, a few film directors have been looking into the use of high frame rate in cinema and attempted to show high frame rate to the public. The most well known attempt was from Peter Jackson and his The Hobbit Trilogy which was shot at a frame rate of 48 fps [Turnock 2013]. Although the result of shooting at 48 fps received criticisms and negativity, it did not stop other filmmakers from pursuing high frame rates. Recently, the Oscar-winning director Ang Lee is directing his new movie Billy Lynn’s Long Halftime Walk at 120 fps. This suggest that despite the negativity with high frame rates in digital cinema, filmmakers are pushing forward and learning from the experiences they encounter.

While more filmmakers are producing movies at higher frame rates, there are also filmmakers who are currently researching into ways to make use of different frame rates. Among them are Douglas Trumbull and Jonathan Erland. Their research involves with utilizing different frame rates which is similar to what this thesis is about.

Digital Showscan is a camera technology created by Douglas Trumbull which can capture footages at 120 fps without any shutter closure [Trumbull]. The process of Trumbull’s research is to capture content at 120 fps and then down-sample them to fit lower frame rates such as the standard 24 fps. To convert a 120 fps into 24 fps, every three frames are combined together while the next two frames are deleted to obtain a 24 fps look [Trumbull 2010]. This method can also be done with other frame rates such as 60 fps. Through this method, a single high frame rate shot can be embedded and switched out with the lower frame rate shot to enhance the crispness and clarity of motion when a character or object is most blurred in a specific scene while keeping the whole movie at a constant frame rate.

Similarly to Trumbull, Jonathan Erland’s Creative Frame Research also utilizes similar methods. The heart of Erland’s research is to understand the methodology of shooting contents at very high
frame rates and combining the footages in different ways to generate different visual effects [Erland]. Unlike Trumbull, the different camera shutter angles are explored to achieve distinct motion effects when the high frame rate contents are combined to convert into a lower frame rate content. The purpose of this research is to explore a way to keep the same look as a conventional 24 fps film while utilizing high frame rates to produce interesting visual effects and hopefully be used to ease the transition of 24 fps to high frame rate in digital cinema.

At first, it may seem that the research by Trumbull and Erland are related to dynamic frame rate. However, the end result of their process keep movie sequences at a constant frame rate, or at least a constant 24 fps. The main concept of their research is that high frame rate footages are utilized and switch out with lower frame rate footages in specific parts of a sequence to improve the clarity of motion. This is different from the concept for this thesis.
Chapter 4: Problem Statement

This chapter will state the research question for the purpose of this study. The chapter will also cover the significance and why we should bother researching into dynamic frame rates. Subsidiary question will also be asked in this section.

4.1 Research Question

What is the perception of a viewer watching a change in frame rate of an animated movie sequence that is displayed in dynamic frame rate?

4.2 Subsidiary Question

If the change is frame rate is detectable, is it a positive, neutral or negative experience?

4.3 The Why

The idea to research into dynamic frame rate sparked from explorations in high frame rates. From the result and suggestion made by researchers and filmmakers, we can confidently say that high frame rate can improve the motion picture quality of a video content. However, the general public are accustomed to the standard 24 fps or 30 fps “film look” which set off a number of negativity by critics. One possible way to stay within in range of the “film look” while enhancing motion picture quality is to utilize dynamic frame rate.

There are a few advantages that we might benefit from using dynamic frame rate instead of using a constant high frame rate for an entire movie. The cost of production for DFR will be less than the cost of production for HFR. Less frames will be needed which lowers the cost of storage space required. Filmmakers will be able to maintain standard frame rate for contents that may not need or benefit much from high frame rates while other contents can utilize higher frame rates for better motion picture quality. This can provide filmmakers with more artistic choices and techniques to
use for the production of their films. Furthermore, there are different implementations of DFR and
directors can make use of these implementations to achieve different visual effects for their film.

Dynamic frame rate has potential to be used in the cinematic world. However, we currently have
very limited understanding of what dynamic frame rate is, how it works, how to create it and how
people perceive it. Additionally, we do not know how different implementations of DFR can effect
the way a movie sequence looks. We will need to understand what DFR is and what methods we can
use to generate such content before we can bring it to the entertainment industry. As a result, this
thesis aims to understand the basics of DFR as well as touching the surface of viewers perception
to changes in frame rate.
Chapter 5: Overview of the Different Phases in this Thesis

This thesis has three major phases: Production, Testing, and Analysis. In the Production Phase, different dynamic frame rate implementations were explored and created through the use of computer generated imagery (CGI). The animation tests were created with Autodesk Maya by utilizing key frame animation, physic collisions, dynamics and TimeWarps. The animation were rendered out with V-ray and compiled in The Foundry Nuke to generate the dynamic frame rate implementations. The Test Phase involved with having participants view the animation test conditions. Subjects were asked to press a button when they felt they have perceived a change in frame rate in the test conditions. A short post-test survey were handed out for the purpose of gathering information that may point to possible future studies. In the Analysis Phase, data collected from the button system were analyzed with the use of Signal Detection Theory to calculate each subject’s detectability of dynamic frame rate. More detail of each phase will be explained in the next few chapters.
Chapter 6: Production Phase

In order to create contents in dynamic frame rate, we must first explore how it can be made. The most simple concept is to take sequences that are shot or rendered at different frame rates and stitch them together into a bigger sequence that consists of a variety of frame rates. However, there are currently no known technology that can allow a movie content to change frame rates in real time. Cameras are unable to change frame rates while recording. Current media players are also unable to switch between frame rates in real time. As such, there is no way to display movie sequences at a true DFR. To solve this problem, one possible way is to emulate what it would look like if DFR was to happen. This method can be done by matching the lower frame rate content with the highest frame rate in the movie sequence.

The figure above shows the process of matching a lower frame rate content with a higher frame rate. To make a 30 fps content to look as if it is 30 fps while running at 120 fps, each single frame of the 30 fps will have to be duplicated 4 times. After the conversion process, we can then mix different frame rate contents together into one sequence. In this research, 30 fps was the lowest frame rate threshold while 120 fps was the highest frame rate threshold. 120 fps was chosen as the highest frame rate threshold since that is the highest possible frame rate that can be used with the equipments offered by Drexel Digital Media Department. 30 fps was used as the lowest frame rate.
threshold because it is one of the standard frame rates that are widely used. Additionally, it is easier to convert 30 fps to 120 fps rather than 24 fps. The purpose of using a standard frame rate and a very high frame rate was to obtain the maximum affect of frame rate change and see how that would affect viewers perception.

For this research, animation tests were created through the use of computer generated imagery (CGI). The main reason for using CGI to create DFR animations was repeatability. Compared to real life camera, it is more accessible to remake test conditions with CGI and have it rendered at different frame rates. Matching actions and object movements between frame rates would not be a big issue as well. Additionally, there is no technology that would allow cameras to switch between frame rates while it is capturing footages.

The following sections of the chapter will cover the production process of the thesis. The purpose of the production phase was to understand the methodology of creating dynamic frame rate contents. By learning how DFR is made and observing how it works, we can then decide on what type of animation tests would be suitable for the test phase.

6.1 Early Concept for Dynamic Frame Rate

In the early attempt to create dynamic frame rate, a range of frame rates were proposed to be used: 24 fps, 30 fps, 48 fps, 60 fps, and 120 fps. The idea was to create a short action sequence with two characters while utilizing all the different proposed frame rates. Different frame rates were to be used at specific shots within the animated sequence, such as a higher frame rate in more action-packed shots. Animation shots would be animated and rendered at different frame rates utilizing the TimeWarp in Maya. The rendered shots would then be put together in Nuke accordingly to the planned out storyboard and frame rate shots. Participants would watch the animation test two times, once in a constant 24 fps and once in dynamic frame rate. The concept was an attempt to prove that by switching shots that consist of heavy motion blur on character or object movements to higher frame rate, it will improve the motion picture quality of scene and viewers may prefer the increase in detail.

However, this concept was scrapped due to various reasons. First of all, using a wide range of
frame rate increases the variables that would need to be considered for the test. A jump from a 24 fps to 48 fps would be different than a jump from a 24 fps to a 120 fps. To consider all the different frame rate jumps and how they relate to each other in a test would add unwanted complexity. Second of all, we do not have enough knowledge of DFR to approach tests with this type of complexity yet. We would need to take a step backward and focus on how we can create dynamic frame rate with just two different frame rates before we can attempt to use a wide range of frame rates. DFR itself is a broad term and there are different approaches that could be done to generate DFR. Last of all, with the given amount of time for the thesis, the scope of the project would be too large. As a result, the concept was revised and changed into an attempt to understand the basics of DFR.

6.2 Revised Concept

To understand how DFR behaves, different implementations of dynamic frame rate were examined. The word implementation in this case stands for the different ways of changing the frame rate. Four different implementations were proposed in the early stages of the revised concept. These four implementations were instantaneous cut, crossfade change, linear change and accelerated change. Instantaneous cut refers to the instant change of frame rates. Crossfade change involves with fading out a frame rate content while fading in another frame rate content over a period of time. Linear change stands for increasing or decreasing the frame rate linearly over a certain amount of time. Accelerated change is a change that increases or decreases the frame rate exponentially. While there are possibly more implementations, these were the four most basic changes that were proposed for the thesis.

Animation test consisting of different variables were explored before deciding on what type of animation would be the most suitable for test phase. The tests were kept fairly simple in order to maximize the affect of perception in the frame rate changes. Each animation test encompassed a different variable or a combination of variables. A few examples of the variables that were used were movements in the xyz axis, object movement speed, the number of objects within a scene and defined motion vs erratic motion.

Two frame rates were chosen for the revised concept: 30 fps and 120 fps. As mentioned earlier,
120 fps was chosen due to the fact that it was the highest possible frame rate that can be utilized with the equipments provided by Drexel University. 30 fps was chosen since it is the standard frame rate and is easier to convert to 120 fps compared to 24 fps. Another reason why a standard frame rate and a really high frame rate was chosen was to maximize the frame rate change as much as possible.

6.3 Implementations and Approaches

In this section of the chapter, different implementations and its approaches will be discussed. Due to limitations and the time frame given for this thesis, it was decided that the accelerated approach would not be explored. The use of accelerated implementation would add complexity and by using any form of non-linear change at this stage would be more confusing than it should. Additionally, it would increase the amount of time and effort required to figure out how it can work. Therefore, the three main dynamic frame rate implementations that were explored in this thesis are Instantaneous cut, Crossfade change and Linear change.

Animation tests were created into two versions, one in 30 fps and one in 120 fps. The TimeWarp function was used within Maya to generate the same motion when comparing a 30 fps to a 120 fps. Animations that involved with dynamics and particle systems were subsampled at a frame rate of 120 fps. The subsampling enabled particles and dynamic system to move with 120 fps motion when the animation tests were TimeWarped to 120 fps content. After the two versions were set up, they were rendered using V-Ray. The motion blur for the renders were set with a 360 degrees shutter angle. However, this was later changed to a 90 degrees shutter angle for the 30 fps content and a 360 degree shutter angle for the 120 fps content. The reason for this decision will be discussed later on in this chapter.

Animation tests were all made without any audio. According to a study done by Souta Hidaka and Masakazu Ide, it was argued that sound can create an auditory suppression effect on visuals. The use of sound can degrade a person’s visual orientation and effect visual perception [Hidaka and Ide 2015]. As such, audio was disregarded for all animation tests since the goal of this thesis was focused solely on viewer’s visual perception to DFR.
6.3.1 Instantaneous Cut Implementation

![Instantaneous Cut Implementation](image)

The instantaneous cut implementation was a fairly straightforward implementation and required a little amount of effort. By instantly changing from one frame rate content to the next through the use of a video editing software, an instantaneous implementation can be achieved. Figure 6.2 provides a graphic understanding of what happens to the frame rates during an instantaneous change.

6.3.2 Crossfade Implementation

![Crossfade Implementation](image)

Crossfade implementation refers to the process of fading out a frame rate content while fading in another frame rate content over a period of time. For this thesis, an one second time-frame was first utilized for the crossfade implementation. However, to understand whether or not if different duration of the change can pose any significance to the detectability of frame rate change, it was decided that a three second crossfade change should also be included for the test. Figure 6.3 shows the graphic understanding of how a crossfade implementation would work.

6.3.3 Linear Change Implementation

The linear change implementation was the most complex out of the three implementations used for this thesis. The process required a more mathematical approach in both Maya and Nuke.
TimeWarping was a major factor to changing the frame rate correctly. TimeWarp keys had to be set in the timeline within both Maya and Nuke. In Maya, the TimeWarp function allows a change in the number of frames that would be rendered per second. Differently in Nuke, the TimeWarp function helps change the number of frames displayed per second. By finding the where the key frames should be, we can manipulate time to be extended or decreased depending on when the change should started at. To know where exactly the TimeWarp keys should go in the animation, an equation was required.

Different variables were considered in the process of creating the equation. First, the x and y axis for the equation has to be defined. Second, the length of the change will need to be known. Third, there has to be a variable for the frame rate. Fourth, the slope for the linear curve will need to be set. Last, the highest frame rate that will be used for the animated sequence has to be considered. In the following paragraphs, the step process to derive the equation will be discussed.

The y variable of the equation is defined as the keyframe of where the TimeWarp should be at with the given frame rate. The x variable of the equation refers to the frame rate which is set from 0 to 1 where 0 is 0 fps and 1 is the highest frame rate, which is 120 fps. Each 0.05 steps of x is an increase of 6 fps. A 30 fps would be 0.25 because that is the result if you add 0.05 six times and it is also the case if you divide 30 by 120. Since only 30 fps and 120 fps are used for the thesis, anything before a value of 0.25 is disregarded.

Now that the y and x are defined, a time variable is needed. The time, which is the length of the change, is defined as t. The t is set in frame rate rather than seconds since the the number of frames is needed for the end result. For a one second change, the t value would be 120. For a three second change, the t value would be 360. By multiplying the t value with x, it will give us the frame rate. However, it would not give us the keyframe for the TimeWarp.

To find the keyframe for the TimeWarp at specific frame rate, two more variables are needed. The first one is a suitable slope for the curve to suggest how many additional frames are needed to be rendered or displayed as the frame rate changes. From the previous steps, we have stated that every increment of 0.05 in the x value is equal to an increase of 6 fps. From 0.25 to 1 and vice versa,
there are a total of 15 increments. This means that for every 1/15th of a increment, there should be
a keyframe for the TimeWarp. If we set this value of 1/15 (≈0.0667) as the slope and multiply it by
the x and t value, we can get number of frames that is needed for the frame rate that it is currently
on with a duration of 1/15th of the total duration of the entire linear change. For example, for a 36
fps content in an one second change, it would be 0.0667 * 0.3 * 120 ≈ 2.4 frames. The last variable
that is necessary for the equation is a variable for the keyframe of previous frame rate. For instance,
to find where the keyframe of 36 fps is at, the 30 fps keyframe will be needed to be added to the
result of 0.0667xt. By adding the keyframe of the previous frame rate it will give us the end result
of the keyframe for the current frame rate. Thus, the full equation would look like the following:

\[ y = a + 0.0667xt \]

**Figure 6.4:** Linear Change Equation

Where . . .

y is the result of where the keyframe for the TimeWarp should be set at.

a is the keyframe for the previous frame rate

x is the current frame rate it is on with the range from 0.25 to 1

t is the time for the change in 120 fps
The above two graph shows what a linear change looks like when frame rate changes within the given period of time. The one on top is form Maya and the one at the bottom is from Nuke. The curve may look like a logarithmic curve and the reason is because the TimeWarp in both Maya and Nuke is increasing or decreasing the number of frames that are rendered or displayed per second. For an increase in frame rate, the number of frames necessary for each increment of frame rate would need to be increase. For a decrease in frame rate, the number of frames are decrease after each increment. Therefore, the end result is a non-linear curve. However, in reality as derived by the equation we found, the change is linear.
6.4 Animation Tests

Figure 6.6: Animation Tests
Different animation test consisting of a range of variables were tested throughout the production phase. This was a necessary step in order to determine what types of test would be suitable for participants to view in the test phase.

A total of seven animation test were explored. The variables tested ranged from simple to complex. Simple variables involved with a limited amount of objects, limited movements in the xyz axis and a defined movement throughout the whole animation. Complex variables included medium to large amount of objects within a scene, a range of object speed and erratic movements. Most animation tests were done with a still camera. Only the Jet Fly Through test utilized a camera movement. Animation test were mostly kept with a still camera to limit the number of variables and to provide consistency between each test.

![Figure 6.7: 30 fps with 180 degrees shutter](image)

The shutter angle for each of the animation test were kept at 360 degrees for both 30 fps and 120 fps. The main reason for keeping all frame rate at 360 degrees shutter angle was to replicate what it would look like using a real camera. If a 180 degree shutter angle was to be used instead for all the frames, then the 30 fps content and the 360 content will not match correctly. Referring to the figure above, the shutter angle for the 30 fps content that is converted into 120 fps would be different than the 120 fps content. Since a 180 degree shutter angle means that half of the frame is covered, a 30 fps with a 180 degrees shutter will look different when converted into 120 fps and may cause discrepancies. Thus, it was decided that the shutter angle should be kept at 360 degrees for all frame rates so the variable of shutter angle can be eliminated.

Each animation test were rendered and compiled into five different conditions. Two of them were
constant 30 fps and 120 fps. The other three were the instantaneous change, crossfade change and linear change implementations. The duration of change for the crossfade change and linear change were kept at one second.

6.5 Observations From the Animation Tests

Motion blur contributed significantly to the detectability of dynamic frame rate. In a 30 fps content with a 360 degree shutter angle, the motion blur was a lot wider and visible than the motion blur from the 120 fps content with 360 degree shutter angle. The wide gap of motion blur made changes in frame rate very detectable for each of the animation tests. The change was the most perceivable with the instantaneous change implementation. The effect sometimes look like a computer glitch and in most cases, it felt unnatural to view.

Speed of object movements was another factor. Objects moving at faster speed has a higher chance to be perceived when the frame rate changes compared to objects moving at slower speed. Additionally, as the frame rate changes from 30 fps to 120 fps while objects are moving at the constant speed, there was an illusion that moving objects were slowing down. The opposite happens when the frame rate changes from 120 fps to 30 fps, objects seem to speed up. This illusion was most apparent in the Jet Fly Through and Falling Balls test. The illusion of changing speed created an interesting visual effect that could be used as a technique in DFR movie production.

The distance from the object to the camera also contributes to the apparentness of frame rate changes. The closer the object is to the camera, the more detectable it is to see a change in the frame rate. From the Cube Movement test, the green block farthest away from the camera has a limited difference in motion blur compared to the green block in the front. At the same time, the fact that it is farther away means that its speed would look slower compared to the one in front. Due to these two factors, it is harder to detect a change in frame rate when the focus is on the farther green block.

Comparing the three dynamic frame rate implementations, instantaneous change has the most apparent change while crossfade change and linear change is relatively the same. All three implementations were easily detected but the crossfade and linear change has a more smoother effect and
were more appealing to the eyes. When comparing between the crossfade and linear change, both of them look alike when the animation is playing. This may be because the motion blur from the 30 fps helps hide the overlapping effect of the two frame rate contents.

6.6 Changes and Decisions for Test Phase

Since motion blur was a major factor to the detectability, it was decided that the motion blur of animation tests for the test phase should be the same throughout the entire animation. To match the motion blur of 30 fps to 120 fps with a 360 degree shutter, the shutter angle of the 30 fps would have to be 90 degrees. By keeping the motion blur the same for each frame rate, it eliminates the motion blur variable and the data would be more focused on detecting the actual change of frame rates and not whether or not the motion blur within the animation has changed. One interesting observation from changing the 30 fps shutter angle to 90 degrees was that your eyes will try to create a motion blur effect itself as you are watching it. But in reality, the motion blur of the object movement is exactly the same as the motion blur in 120 fps if the sequence is paused.

The variables that were decided to be included for the test phase were limited to object movement in the xyz axis, object movement speed, defined vs erratic movement and number of objects within the scene. The decision was made to prevent using multiple complex variables which can add unwanted complications and confusion for the analysis phase. By limiting variables and keeping similar variables together, the test will have more focused set of variables while enhancing the

![Figure 6.8: Motion Blur Comparison](image-url)
complexity of the animation with the given variables. The data collected from the animation test would allow us to understand how the specific set of variables used would affect viewers perception. Additionally, it will allow easier and more solid comparisons between the different animation test groups.

From the animation tests, two animation test was chosen to be used for the test phase. The first one was the Cube Movement test. This test was selected because it provides a simple animation while maintaining enough variables to be tested. The second one was the Pachinko Machine test. This test provided another level of complexity compared to the Cube Movement. At the same time, another set of variables were tested which would be suitable for the testing phase.

A third animation test was decided to be made for the test phase which encompasses both variables from Cube Movement and Pachinko Machine tests. The concept was to see whether or not the complexity of animation has any affect on viewers perception towards a change in frame rate.
Chapter 7: Test Phase

This chapter goes over the test concept, how the test was set up and what were the goals and expected outcomes from the test. The purpose of the testing phase was to obtain information of viewers noticeability to the different DFR implementations and to observe whether if the complexity of animation test has any affect on the detection of DFR.

7.1 Test Concept

The thesis has an experimental approach similar to that of other researchers who have tested the use of high frame rates in television systems [Banitalebi-Dehkordi et al. 2014][Emoto et al. 2014][Kuroki et al. 2012][Salmon et al. 2011]. While these studies evaluated sequences with one constant frame rate during playback, this study will vary the frame rate during sequence playback. The main goal for this study was to learn viewers sensitivity towards DFR with animations that has different levels of complexity and whether viewers perceive a change in frame rate using the different DFR implementations set up for this research. A short survey were given at the end of the test session to collect feedback of what they felt as they are watching the test conditions. Please refer to Appendix B for the survey.

7.1.1 Recruiting Subjects

Participants were 18 or older and were mainly college students, both undergraduate and graduate, within Drexel University. For the purpose of this thesis, variables such as age, gender and their background of study were disregarded to limit the complexity and to avoid assumptions. To have a greater variety of subjects and a random sample of people, student from different college departments were contacted. Flyers and brochures were placed on bulletin boards with permission. Emails were sent out to students and faculty members as a mean for recruitment. Psychology department’s SONA system was also utilized for recruiting students who attend psychology classes.
7.1.2 The Concept

The test was composed of three groups: Simple group, Normal group and Complex group. Simple group were to look at a simple animation that involves with a few objects moving along the x axis and z axis of the scene in a defined pattern. Normal group takes a look at a more complex animation that utilizes dynamics and physics collision to generate erratic object movements in the x and y axis. Object movement speed were also varied throughout the scene. The number of objects in the scene were also increased by a large amount compared to the Simple group. A combination of these variables in the Normal group resulted in a more erratic and random movement for participants to watch. Participants in the Complex group looked at a complex animation that includes all the variables from the Simple group and the Normal group. The main goal for having these the complexity of animations separated into different groups was to identify whether or not complexity in a scene can affect the perception and noticeability of dynamic frame rate contents.

The test took place indoors in the High Frame Rate Lab of UBRN Center in Drexel University. Each test session had only one subject at a time. Before the test, subjects were given a brief explanation of what frame rate is, what a dynamic frame rate is, and instructions for the test. During the test, subjects were assigned a test group to view on a Acer XB270H monitor. The monitor was 27 inch wide and can handle frame rates up to 120 fps. Subjects were seated at 4 feet away from the monitor for an optimal viewing distance [Collins]. Test animations were played through Tweak Software’s RV media player. The lights were turned off during the test to simulate a cinema environment and to prevent distractions from the surrounding environment. A button system was set up and the subjects were to press the button whenever they felt that they saw a change in frame rate. A camera was set up during the test which only captured the button press and the monitor screen for data collection. Subjects’ facial features were not captured by the camera. After the test session, a short survey was given to the subjects to answer which consist of questions about their thoughts of the test conditions and their habits of watching movies or playing games.

The goal was to get at least 30 subjects with 10 subjects for each group. However, due to the limit of time and discrepancy in subject data, data from a total of 21 subjects were recorded with 7
subjects per test group. Some data were disregarded due to subjects falling asleep during the test.

Within each test group, there were seven different test conditions. Two conditions were constant 30 fps and 120 fps that act as the control test and the other five condition were five different implementations of dynamic frame rate that serves as experimental conditions.

*Control Test Conditions*

- Constant 30 fps
- Constant 120 fps

*Experimental Test Conditions*

- Instantaneous Cut
- Crossfade over 1 second
- Crossfade over 3 seconds
- Linear change over 1 second
- Linear change over 3 seconds

For each of the experimental test conditions, there were multiple places within the animation where the frame rate changes. Instantaneous cut had four changes in the animation. Crossfade over 1 second had three and the rest of the implementations has two each. The idea for applying multiple changes in the implementations was to gather was much data as possible. However, this method was not the best approach since it did not provide consist data and prevented accurate comparison of results between the different implementations.

Each test session had only one subject at a time. The subject in the test session were given the specific animation test to watch accordingly to which group he or she is in. The test started out with either the constant 30 fps test condition or the 120 fps test condition. After a play through of the specific control test condition, the rest of the test conditions were followed in a randomized
order. Each control test condition have 25 trails. Each experimental test conditions have 10 trials. 
The total number of the control trials were 50 and the total number of the experimental trails were 50. This gave a total of 100 trials for a full test session. For each of the experimental test conditions, 5 of the trials started out with 30 fps while the other 5 begun with 120 fps. The goal for this was to randomize the content a bit more and to prevent the subjects from identifying which test condition was playing.

7.2 Button System

The button system utilized a spacebar from the keyboard. A external keyboard was connected to a laptop. The keyboard was placed in front of the participant. An application was created where a red sphere and red light would appear on the laptop screen whenever the spacebar was pressed. A video of the frame rate change was placed beside the button application and was synced with the animation test playing on the monitor that the participant was watching. The frame rate change video suggests the exact time when the frame rate changed within the test animation while the button application suggests the reaction of the participant to the frame rate change. Throughout the whole process, a camera is placed behind the laptop and the monitor to record the data.

7.3 Testing Goals

The main goals for the test was to understand viewers sensitivity to different DFR implementations and viewers level of noticeability towards animation tests with various level of complexity. By understanding viewers sensitivity to different DFR implementations and animation tests, it can help us learn what works and what does not work. It can provide us with information on how DFR should be approached in the future as well.

Another goal was to identify whether or not the average amount of people understand the concept of frame rates. For example, if a subject was to press the button most of the time while a control condition was being presented, then it would suggest that the subject does not understand what he or she was looking for. This information would allow us to learn that if we directly let people watch a DFR content without telling them anything, there would be a chance that they would not even
notice that the frame rate has changed.
Chapter 8: Analysis Phase

A total of 21 subjects were recruited for the test with 7 subjects in each group. Data collected from the testing phase were analyzed with Signal Detection Theory. Signal detection theory provides a way of measuring performance and people’s response to a stimuli [Wickens 2002][Macillan and Creelman 2005]. As such, this method would be the most suitable for analyzing viewer noticeability and sensitivity towards a change in frame rate within a movie sequence. The test data consist of a series of yes and no response from the control condition and experimental condition. The figure below provides a graphical information of how it works. The number of hits and misses would suggest how many times the subject recognized the DFR conditions. The number of false alarm and correct rejection conveys the subject’s understanding toward constant frame rates.

![Signal Detection Box](image)

**Figure 8.1:** Signal Detection Box

\[ d' = \text{normsinv(Hit Rate)} - \text{normsinv(False Alarm Rate)} \]

![d’ prime equation](image)

**Figure 8.2:** d’ prime equation

To calculate the sensitivity of dynamic frame rate implementations in each test group, the d’ (dee-prime) function derived from Signal Detection Theory was used [Wickens 2002][Macillan and Creelman 2005]. The d’ takes the difference of the norms-inverse of the hit rate and the norms-
inverse of the false alarm rate. The hit rate is calculated by dividing the number of yes responses in the experimental condition to the total number of experimental conditions. Similarly, the false alarm rate is calculated by dividing the number of yes response in the control conditions to the total number of control condition. The higher value the $d'$ is, the more sensitive the test group is.

The following sections in this chapter will cover the general data for each group and data comparison between the groups. In the general data, if the subject pressed the button once at any point during a test condition, it was counted as either a hit or false alarm depending on the condition that was displayed. In the data comparison, a comparison of the general data will be discussed. Additionally, a more in-depth data of the relationships between the different DFR implementations in each group will also be covered. The data for the DFR implementations were found by observing if subjects pressed the button when the frame rate changed during a test condition. Any button reactions that were a second late was considered while button reactions that were later than a second was not considered. Due to the more in-depth analysis for DFR implementations and the fact that each implementation have multiple frame rate changes, the result may differ from the general data.
8.1 General Data

8.1.1 Simple Group Data

Table 8.1: Simple Group Subject Detection Rates

<table>
<thead>
<tr>
<th>Subject</th>
<th>Hit Rate</th>
<th>False Alarm Rate</th>
<th>d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.558</td>
<td>0.058</td>
<td>1.72</td>
</tr>
<tr>
<td>2</td>
<td>0.981</td>
<td>0.173</td>
<td>3.012</td>
</tr>
<tr>
<td>3</td>
<td>0.596</td>
<td>0.635</td>
<td>-0.101</td>
</tr>
<tr>
<td>4</td>
<td>0.808</td>
<td>0.288</td>
<td>1.427</td>
</tr>
<tr>
<td>5</td>
<td>0.769</td>
<td>0.058</td>
<td>2.311</td>
</tr>
<tr>
<td>6</td>
<td>0.904</td>
<td>0.885</td>
<td>0.105</td>
</tr>
<tr>
<td>7</td>
<td>0.865</td>
<td>0.173</td>
<td>2.047</td>
</tr>
</tbody>
</table>

Table 8.2: Control Condition Average

<table>
<thead>
<tr>
<th>Control Condition Average</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>30FPS</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>120FPS</td>
<td>16</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 8.3: Average Rates

<table>
<thead>
<tr>
<th>Average Hit Rate</th>
<th>Average False Alarm Rate</th>
<th>Average d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.783</td>
<td>0.324</td>
<td>1.503</td>
</tr>
</tbody>
</table>

The table above represents the hit rate, false alarm rate and the $d'$ for each subject in Simple group. The hit rate for this group is leaning relatively high while the false alarm rate is relatively low. This suggest that a majority of the subjects are detecting the changes in frame rate and for some subjects, the sensitivity is high as suggested by the $d'$. The average of the hit rate and false alarm rate is what was expected where the hit is a lot higher than the false alarm rate. The average $d'$ came to be at 1.503 which means it was generally easy to detect DFR in the simple group.
8.1.2 Normal Group Data

Table 8.4: Normal Group Subject Detection Rates

<table>
<thead>
<tr>
<th>Subject</th>
<th>Hit Rate</th>
<th>False Alarm Rate</th>
<th>d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.962</td>
<td>0.346</td>
<td>2.165</td>
</tr>
<tr>
<td>2</td>
<td>0.885</td>
<td>0.385</td>
<td>1.492</td>
</tr>
<tr>
<td>3</td>
<td>0.981</td>
<td>0.865</td>
<td>0.965</td>
</tr>
<tr>
<td>4</td>
<td>0.981</td>
<td>0.962</td>
<td>0.301</td>
</tr>
<tr>
<td>5</td>
<td>0.942</td>
<td>0.269</td>
<td>2.189</td>
</tr>
<tr>
<td>6</td>
<td>0.808</td>
<td>0.885</td>
<td>-0.329</td>
</tr>
<tr>
<td>7</td>
<td>0.981</td>
<td>0.981</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 8.5: Control Condition Average

<table>
<thead>
<tr>
<th>Control Condition Average</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>30FPS</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>120FPS</td>
<td>8</td>
<td>17</td>
</tr>
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</table>

Table 8.6: Average Rates

<table>
<thead>
<tr>
<th>Average Hit Rate</th>
<th>Average False Alarm Rate</th>
<th>Average d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.934</td>
<td>0.67</td>
<td>0.969</td>
</tr>
</tbody>
</table>

The hit rate for Normal group was a lot higher than what was anticipated. What was expected was that the use of multiple objects and erratic movements would divert viewers attention and make the change in frame rate less noticeable. However, the false alarm rate was also fairly high. This suggested that the erratic movements and the change in speed of the objects may have deceived subjects into pressing the button. While half of the subjects had a higher levels of d', the other half had low levels of d'. What this implies is that there are more possibilities of people not being able to detect a change in frame rate in this group. Instead, they are guessing and being tricked by the object movements as suggested by their high false alarm rate.
8.1.3 Complex Group Data

Table 8.7: Complex Group

<table>
<thead>
<tr>
<th>Subject</th>
<th>Hit Rate</th>
<th>False Alarm Rate</th>
<th>d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.981</td>
<td>0.519</td>
<td>2.022</td>
</tr>
<tr>
<td>2</td>
<td>0.942</td>
<td>0.365</td>
<td>1.919</td>
</tr>
<tr>
<td>3</td>
<td>0.962</td>
<td>0.538</td>
<td>1.672</td>
</tr>
<tr>
<td>4</td>
<td>0.981</td>
<td>0.981</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.692</td>
<td>0.558</td>
<td>0.357</td>
</tr>
<tr>
<td>6</td>
<td>0.962</td>
<td>0.558</td>
<td>1.624</td>
</tr>
<tr>
<td>7</td>
<td>0.962</td>
<td>0.942</td>
<td>0.194</td>
</tr>
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</table>

Table 8.8: Control Condition Average

<table>
<thead>
<tr>
<th>Control Condition Average</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>30FPS</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>120FPS</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 8.9: Average Rates

<table>
<thead>
<tr>
<th>Average Hit Rate</th>
<th>Average False Alarm Rate</th>
<th>Average d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.926</td>
<td>0.637</td>
<td>1.113</td>
</tr>
</tbody>
</table>

The hit rate for Complex group was higher than expected as well. The false alarm rate was also leaning towards mid-high levels. Overall, subjects in the Complex group performed similarly to the Normal group. The data hints to us that complexity in a sequence does in fact help with lowering the detection rate of DFR.

An interesting information that was observed in this group was the average of false alarms of the constant 30 fps control condition was higher than the constant 120 fps condition by a large amount (Figure 8.8). The difference between the two was doubled for some of the subjects. This may suggest that with complex sequences, lower frame rates are more prone to tricking viewers into thinking that frame rate was changed. If we consider the changes in object speed from high speed to low speed, movement direction, speed of rotation and the number of objects in the scene, viewers may be tricked into thinking that the deceleration of an object was the change in frame rate. However, in reality, the frame rate did not change at all. This affect would be more apparent in a lower frame rate than a higher frame rate where object motion are smooth.
8.2 Comparison of Data

8.2.1 General Data Comparison

<table>
<thead>
<tr>
<th></th>
<th>Average Hit Rate</th>
<th>Average False Alarm</th>
<th>Average d'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Group</td>
<td>0.783</td>
<td>0.324</td>
<td>1.503</td>
</tr>
<tr>
<td>Normal Group</td>
<td>0.934</td>
<td>0.67</td>
<td>0.969</td>
</tr>
<tr>
<td>Complex Group</td>
<td>0.926</td>
<td>0.637</td>
<td>1.113</td>
</tr>
</tbody>
</table>

Of the three test groups, the sensitivity of the Simple group was the highest. This was predicted since we expected that it would be easier to detect a change in frame rate with a simple animation while more complex animation would have lower detection rate due to its complexity. Both the average false alarm rate from the Normal Group and Complex group was one times higher than the false alarm rate from the Simple group. The high false alarm rate in Normal and Complex group suggest that viewers had a harder time differentiating between constant frame rate and dynamic frame rate.

The interesting result from comparing the d’ of these three groups was that the Normal group had the lowest level of sensitivity. What was expected was Complex group would have a lower sensitivity level due to its additional variables that were considered to enhance another layer of complexity. However, this was not the case according to the data result. If we compare the animation test between the Normal group and the Complex group, the Normal group had more variance of object speed and object erratic movements. As a result, we can infer that the speed of the object and its movements are the major factors to changing the sensitivity of changes in frame rate while the addition of variables does not necessary imply that the sensitivity will be lower.
8.2.2 DFR Implementation Comparison

Table 8.11: DFR Implementation Hit Rate Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Instantaneous</th>
<th>Crossfade 1 second</th>
<th>Crossfade 3 second</th>
<th>Linear 1 second</th>
<th>Linear 3 second</th>
<th>Experimental Trial Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Group</td>
<td>0.589</td>
<td>0.501</td>
<td>0.650</td>
<td>0.714</td>
<td>0.664</td>
<td>0.624</td>
</tr>
<tr>
<td>Normal Group</td>
<td>0.811</td>
<td>0.832</td>
<td>0.829</td>
<td>0.857</td>
<td>0.821</td>
<td>0.830</td>
</tr>
<tr>
<td>Complex Group</td>
<td>0.750</td>
<td>0.671</td>
<td>0.736</td>
<td>0.814</td>
<td>0.779</td>
<td>0.750</td>
</tr>
<tr>
<td>Across Group</td>
<td>0.717</td>
<td>0.668</td>
<td>0.738</td>
<td>0.795</td>
<td>0.755</td>
<td>0.735</td>
</tr>
</tbody>
</table>

Table 8.12: False Alarm Comparison

<table>
<thead>
<tr>
<th></th>
<th>False Alarm Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Group</td>
<td>0.324</td>
</tr>
<tr>
<td>Normal Group</td>
<td>0.670</td>
</tr>
<tr>
<td>Complex Group</td>
<td>0.637</td>
</tr>
</tbody>
</table>

Table 8.13: DFR Implementation $d'$ Comparison

<table>
<thead>
<tr>
<th></th>
<th>Instantaneous</th>
<th>Crossfade 1 second</th>
<th>Crossfade 3 second</th>
<th>Linear 1 second</th>
<th>Linear 3 second</th>
<th>Experimental Trial Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Group</td>
<td>0.682</td>
<td>0.460</td>
<td>0.841</td>
<td>1.022</td>
<td>0.880</td>
<td>0.777</td>
</tr>
<tr>
<td>Normal Group</td>
<td>0.440</td>
<td>0.523</td>
<td>0.508</td>
<td>0.627</td>
<td>0.480</td>
<td>0.515</td>
</tr>
<tr>
<td>Complex Group</td>
<td>0.323</td>
<td>0.090</td>
<td>0.279</td>
<td>0.542</td>
<td>0.416</td>
<td>0.330</td>
</tr>
<tr>
<td>Across Group</td>
<td>0.482</td>
<td>0.358</td>
<td>0.543</td>
<td>0.730</td>
<td>0.592</td>
<td>0.541</td>
</tr>
</tbody>
</table>

Regarding to the hit rate for the DFR implementations in each group (Table 8.11), the data shows that Simple group had the lowest hit rates for every DFR implementations. On the other hand, Normal group had the highest hit rates for every DFR implementations. Though it may look as if the Normal group has the most detectability for changes in frame rate, the false alarm rate helps counteract the sensitivity for each DFR implementation.

Referring to Table 8.13, the $d'$ data gave us a couple of information. First, Crossfade over 1 second experimental condition had the lowest $d'$ average while the Linear change over 1 second had the highest $d'$ average. The two conditions look similar to each other, yet it was interesting to see that there was a great difference in the sensitivity. Second, Instantaneous condition generally had a lower sensitivity than most of the other DFR implementations for all the groups. The expectation was that Instantaneous condition would have the highest level of detection however the result does not suggest that at all. With the data collected, there were not enough information to understand...
why that was the case. Third, while the conditions with a 1 second frame rate change had a wide
gap between each other, the conditions with 3 second frame rate change did not have a significant
differences in sensitivity. Last, considering all the possible times the frame rate changes within each
implementation, the result of the average d' from each group suggests that the sensitivity was a lot
lower than the average d' found in the general data.

While the general data suggests that Normal group had the lowest sensitivity, the DFR imple-
mentation comparison data shows us that the Complex group was the one with the lowest sensitivity.
This is the case because the general data did not consider the places where frame rates were changing
in each of the implementation. Rather, it was only focused on detecting if subjects has pressed the
button once during a condition. Differently, the DFR implementation comparison data was taking
in account of when the subjects saw each and every one of the frame rate changes in each implemen-
tation. As a result, the sensitivity for the two data sets were different. However, both data shows
us that Simple group had the highest sensitivity which suggests that DFR sequences with simple
object movements can be spotted more easily.
8.3 Results from Post-Test Survey

Post-test survey act as a method to gather information on subject’s experience throughout the test session. At the same time, data on subject’s movie watching and gaming habits are noted. However, due to a lack of subjects, their movie watching and gaming habits were omitted due to the lack of data to prove anything significant. As a result, only the subject’s experience throughout the test will be discussed in this section. There are a total of 21 subjects who participated in this thesis with 7 subjects in each group.

![Simple Group Survey Results](image)

**Figure 8.3:** Simple Group Survey Results

From the question on subject’s thoughts of DFR, most subjects in the Simple group are unsure if they felt the experience was positive or negative. While some expressed that it was a positive experience when they saw the frame rate go from a lower to higher frame rate, they also felt the change was negative when the change went from higher to lower frame rate. A few subjects indicated that the change in frame rate broke their feeling of immersion and expressed that they would rather look at the constant higher frame rate instead.

When asked if they would like to see DFR in movies, 3 expressed an uncertainty, 2 mentioned they would be interested in watching such content and 2 commented that they would rather see a consistent frame rate.
Subjects in the Normal group were overall positive about DFR. A few subjects commented that they enjoyed the subtle changes in frame rate and it gave a sense of differentiation. Most subjects who were unsure mentioned that they liked the high frame rate content but they felt it was a jarring change when the frame rate went from high to low. One of the unsure subject indicated that the lower frame rate was a better experience.

Most subjects in this group would like to see some form of attempts of DFR in movies. Some subjects added that they are oblivious to the changes in frame rate and would probably not notice the change in frame rate at all. Other subjects mentioned that DFR can be used to for artistic choices to achieve different effects if implemented correctly. The most interesting fact was that this was the group that had the highest false alarm rate despite the high hit rate.
Chapter 8: Analysis Phase

8.3 Results from Post-Test Survey

Subjects in the Complex group had 4 unsure, 2 positive and 1 negative. Similar to the subjects who were unsure in both Simple and Normal groups, they felt a positive experience when the frame rate went from low to high and negative experience when the it when from high to low. Both of the subject who said positive liked the sudden change and felt that there was a sense of excitement. The subject who said negative did not give a reason.

Most subjects in this group expressed that they would want to see DFR in movies. They believe it may help enhance movies in the future and are interested and curious about what it would look like. Comparing the survey results of all three groups, it seems that with more complex sequences, viewers are more acceptable to DFR. However, the number of participants in this study was small. As such, we cannot be certain that this is the case.

Figure 8.5: Complex Group Survey Results
Chapter 9: Expectations VS Reality

9.1 Expected Results

The expectation was that it would be harder to notice a change if the frame rate change is to happen over a period of three seconds compared to one second or the instantaneous change version. The reason is that given more time for a transition, the change of frame rate would not be as apparent. On the other hand, the instantaneous cut would be the most disturbing for the viewers since there is a very short amount of time that the frame rate would change. Furthermore, jumping from 30 fps directly to 120 fps is a big change. Another expectation from the subjects is that there will be a few subjects that would think there is a change in frame rate in the control tests. The result of this may be significant since it can tell us that subjects are always perceiving changes to what they see. More complex animation will have a lower DFR detection rate while simple animation will have the highest detection rate.

9.2 Reality

One main difference between the expected result and reality was that a majority of subjects did not understand what a frame rate was when they walked into the test session. This statement is suggested by the high false alarm rate in Normal and Complex group. If most subjects could tell the difference between DFR and constant frame rates, then the d’ of each group would be a lot higher. It was not expected that the false alarm rate would be this high for the tests.

The DFR implementation with the highest sensitivity ended up with the Linear change over 1 second rather than the Instantaneous cut. Furthermore, the Instantaneous implementation had lower sensitivity levels than other implementations as well. This was an interesting information yet we don’t have any data to suggest why it may have ended up this way.

From this thesis, we found that adding complexity to a sequence does in fact lower the sensitivity level towards DFR. The complexity of a sequence is deeply affected by object movement, object
movement speed and a number of objects within the scene. The more erratic the object movement, the more it can confuse viewers of what is happening within the scene.
Chapter 10: CONCLUSION

In this thesis, the production and implementation of dynamic frame rate was explored to understand the methods to create DFR contents. In addition, a test concept was set up and implemented to learn viewers perception toward different DFR implementations. The thesis was broken down into three major phases: production phase, test phase and analysis phase. Production phase involved with figuring out the process of DFR creation as well as observing the end product and revising the process. Test phase consist of three different groups where animations with different levels of complexity were shown to subjects. In analysis phase, data collected were scrutinized and the sensitivity and hit rates are calculated through the use of Signal Detection Theory.

Overall, this study provides a clear answer to our question: no matter which implementation of dynamic frame rate, it will be perceivable by viewers given the fact that they were giving the information on dynamic frame rate prior to the start of the test. The levels of perception for each DFR implementation varied. Some had a higher sensitivity while the others had similar or lower sensitivity. Yet, there was a lack of information to prove why that was the case. However, we can say for sure that the complexity of a sequence can change the perception of DFR by a good amount.

10.1 Significance from Production Phase

In the production phase, we figured out a way to emulate what a dynamic frame rate content would look like. This knowledge allowed us to make use of the different implementations necessary for this research. Through the various test animations, we also found that changing frame rate can create an illusion of the objects changing speed. The study on the relationship between different variables and how it affect the perception of DFR also helped with making decisions for the testing method for test phase. It allowed for a more focused variables to be tested while giving space for future studies.

One major finding that was observed during the production phase was the motion blur con-
tributed a lot to the detection of DFR. We first kept all frame rate contents with a shutter angle of 360 degrees. What was found was that the motion blur made it very easy to detect a change in frame rate due to the difference of the blur length between a 30 fps content and 120 fps content. It was then changed to have all frame rate content to have the same amount of motion blur throughout the entire animation sequence. That meant the 30 fps content had to have a 90 degree shutter angle in order to match the motion blur of a 120 fps content with a 360 degree shutter angle. By matching the motion blur, it took away the motion blur variable. However, our eyes still attempts to see the 30 fps with motion blur which made it an interesting factor to the test.

10.2 Significance from Data Results

The general data showed us that the Simple group had the highest sensitivity while Normal group had the lowest sensitivity and the Complex group had a slightly higher sensitivity than the Normal group. The sensitivity levels implied how detectable DFR was to the subjects in the different testing groups. It provided us with hints where movie sequences with simplistic object movements would be more easily detected than a movie sequence with complex object movements. However, the complexity of movie sequence can be affected by the complexity of object movement and speed. The false alarm in both Normal and Complex groups were relatively high, which suggest that with more complicated sequences, subjects have a higher chance of pressing the button while the control conditions were playing. The changes in object speed and object movement complexity may have tricked them to thinking that a frame rate has changed. Furthermore, the higher $d'$ from the Complex group suggests that the addition of variables may not be a main factor to decrease the level of sensitivity towards a change in frame rate. Rather, it was the object speed and erratic movement.

The DFR implementation data comparison provided us with another set of data to understand. Through the data, we learned that the Linear change implementation had the highest sensitivity. The Instantaneous implementation had one of the lowest sensitivity. Though the result shows us that this is the case, there are no solid interpretations of why this is the case. The case of the Instantaneous implementation having the most exposure to changes in frame rates may have cause
data inconsistency, but we can’t be sure. The sensitivity for Crossfade over 3 second and Linear change over 3 second had no major differences. On the other hand, the 1 second implementations was significantly different from each other. While the general data and DFR implementation data had different takes on which group had the lowest sensitivity, both data do show us that sequence with more complexity has a lower sensitivity than a sequence with simple movements.

The results from the post-test survey suggest that most participants were unsure dynamic frame rate. Many of the subjects had a positive experience when the frame rate changed from a low frame rate to a high frame rate. On the contrary, they had a negative experience when the frame rate changed from high to low. Some of the subjects would prefer watching the contents at a constant high frame rate. Additionally, most of them were curious and positive about the potential use of DFR in future movies.

Although the data provided us with interesting result and was able to guide us towards a direction, we were unable to prove any results or conclude with a solid outcome. There were a small sample size of subjects in each group which gave us limited data to work with. At the same time, there were flaws in the test methodology that prevented us from obtaining a consistent data result. Subjects were also given a brief explanation of frame rates and DFR which may have affected the end result. If subjects were not told about DFR in the beginning, then the result would have been very different. The complexity of the animation in Normal group and Complex group was debatable. Complex group had additional layers of variables that Normal group did not have. However, Normal group had a more erratic object movement and more diverse object speed. The variables in both groups were also hard to control. Therefore, the data itself is not definitive.

There are still answers that are needed to be found which the data itself does not fully show in this thesis. We still need a better understanding of the relationships between complexity and object movements in order to see how exactly it affects the perception of DFR. We also do not fully understand whether or not the different DFR implementation have any affect on viewers perception. Moreover, the signal detection theory data did not fully depict when exactly subjects saw the change in frame rate within the given test condition, which, that information itself could provide us with
interesting data. Due to the limitations and flaws of the testing method, the result of the data left us with things that can’t be clearly defined.

10.3 Possible Improvements

Overall, the thesis achieved the production process of dynamic frame rate and was partially successful with the test and data collection. The test concept had a few flaws and there are approaches that could be done to make the data collection better.

Although the use of Signal Detection Theory was the most appropriate method for this type of research, the methodology of the test could be better. One major flaw was the number of times the frame rate changes were different for some DFR implementations. Instantaneous change had four different places within the animation where frame rate changed and Crossfade over one second had three different places. The other implementations had two. This gave the subjects more chances to spot a change in frame rate within the Instantaneous and Crossfade over one second implementations. A better approach would be to have all implementations have the same number of times where the frame rate would change in order to keep the data consistent with each other. This can also allow a better comparison between the hit rates for each implementation.

Having 100 trials for each test session group might have been a bit too much for participants. There were times when subjects were bored after a few minutes into the test. In the extreme cases, a few subjects fell asleep during the test which their data had to be disregarded. The combination of repeated process in viewing the same animation test for 100 times and the fatigue from trying to detect a change in frame rate may have affect the results of the test. It would have been better if the number of trials was cut in half while the number of subject increases. However, due to the limit of time, the concept was remained unchanged.

The button system was set up in a way which only flashes a red sphere and red light when the subject presses the button. It did not record the time of when the button was pressed in relation to the time of the sequence that was playing on the display screen. Rather, a camera system was set up to capture the button press system and the display screen instead to see when exactly subjects saw the change in frame rate in relation to the test condition displayed. As such, all the data were
analyzed manually. Unfortunately, this type of data was not recorded during the analysis phase
due to complications and a limit of time for the thesis. However, if a script was created that can
automatically collect data on subject’s reaction time and button presses while generating a graph,
then this type of data can be easily analyzed and may produce more interesting results.

The result would have been different if subjects were not told about dynamic frame rate before
the test session. If we wanted to simulate a case where viewers does not know about a change in frame
rate within a movie, then the subjects should not have been given a explanation on frame rates and
dynamic frame rates. Instead, a better approach would have been to ask subjects to press the button
when they saw an increase or decrease in image sharpness of the movie sequence. Another approach
would be to implement a similar method to the awareness test created by DoTheTest [DoTheTest
2008]. By taking the concentration away from attempting to spot a change in frame rate, it could
have yield to a better and more accurate result.
Chapter 11: Ideas for Future Studies

A numerous aspect of dynamic frame rate can still be explored. This thesis only touches the basics of how it works and provides an introduction on viewers perception to three possible dynamic frame rate implementations. More advanced dynamic frame rate implementations can be explored such as utilizing more than two different frame rates in one sequence. Camera movements and its relationship with DFR was slightly touched in this thesis but it could be explored more in-depth. Additionally, we have very limit information on changing frame rates while the camera cuts into different shots. A 30 fps change to 120 fps might be a big jump in frame rates. Thus another approach might be to explore lower frame rate jumps and see how that would affect viewers perception. The relationship between sound and DFR can also be explored. In conclusion, there are numerous aspects of DFR that can still be researched. By diving into more complex concepts of DFR, we can open up new possibilities in the creation of digital cinema.
Bibliography


Appendix A: Terms

This section provides concise definitions of terms used throughout the thesis that the reader might be unfamiliar with.

**Frame Rate:** The frequency at which an imaging device displays consecutive images.

**Sequence:** A clip or multiple clips of a movie or animation in a specific order.

**Standard Frame Rate:** The worldwide standard of frame rate for cinema projectors. Frame rate is kept at 24 frames per second for films, and 30 frames per second for TV.

**High Frame Rate:** Frame rates that are higher than 30 frames per second.

**Dynamic Frame Rate:** The change of frame rates in real time as a movie sequence is playing.

**Keyframe:** A single still image that occurs at an important point of the animation.

**Keyframe Animation:** The process of using a keyframe methodology to create an animation.

**Apparent Motion:** When a sequence of images appear to the eyes as moving objects rather than a succession of still photographs.

**Judder:** When moving objects in the scene appear as two or three overlapping images or appear to jump backwards and forwards while they moves.

**Resolution:** The width by height pixel count of a digital image.

**Spatial Resolution:** The number of independent pixel values per unit length. The most common metric is pixels per inch (ppi). The higher the spatial resolution of the digital image, the clearer the image is.

**Temporal Resolution:** Resolution based on time of how fast images change from one to the next. Can be related to the use of Hertz (Hz) in TV screens.
High Definition Television: Television that has a resolution of 1080p HD or 720p HD

Ultra High Definition Television: Television that has a resolution of 4K Ultra HD or 8K Ultra HD

Synthetic Images: Pictures or movies that are made digitally using computers. Also known as Computer Generated Graphics.
Appendix B: Post-Test Survey

**Dynamic Frame Rate Post-Test Survey**

What are your thoughts on when you felt something was changing within the animated sequence? Was it a negative or positive experience?

Why?

Would you like to see dynamic frame rate contents shown in movies in the future?

---

**How often do you watch a movie? (circle one of them)**

<table>
<thead>
<tr>
<th>Never</th>
<th>1 - 3 per year</th>
<th>1 per month</th>
<th>2 - 3 per month</th>
<th>All the time</th>
</tr>
</thead>
</table>

**Where/On what devices do you watch them on? (circle the one you use most often)**

<table>
<thead>
<tr>
<th>Movie Theaters</th>
<th>Tablet devices</th>
<th>Home Television</th>
<th>Computers</th>
</tr>
</thead>
</table>

**How often do you play video games? (circle one of them)**

<table>
<thead>
<tr>
<th>Never</th>
<th>1 - 3 hours per week</th>
<th>4 - 10 hours per week</th>
<th>11 - 20 hours per week</th>
<th>20+ per week</th>
</tr>
</thead>
</table>

**On which devices do you play your games? (Circle one you use most often)**

<table>
<thead>
<tr>
<th>Phone/Tablets</th>
<th>PC</th>
<th>Consoles</th>
<th>Hand-held Consoles</th>
</tr>
</thead>
</table>