

COLOR GRADING – ON SET AND IN POST

B.S. Motion Picture Science – Senior Project

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## Introduction

One of the tools filmmakers use to achieve their vision is color correction. Color correction can be an important tool that not only makes images visually pleasing but also can change them to affect the mood and message of a film. With the expanding world of digital workflows, filmmakers are constantly trying to find new ways to better develop their vision and to do it in a more effective manner. This project will explore the aesthetic and technical sides of color correction. Two student projects will be discussed in detail including insight on workflow, color decisions, and the motivation behind those decisions. The world of on set color correction will also be explored to determine an onset workflow for the School of Film and Animation at RIT and to determine its usefulness in an on set environment.

### I. History of Color in Cinema

Ever since the existence of cinema, filmmakers have been working hard to explore different aesthetic options in order to better represent their vision for the screen. One tool that can be used by filmmakers is color. Color can be manipulated and changed to affect mood, change perspective, and even provide insight into the story and characters.

Color has actually been around since the beginning of cinema. It all started in the early 1900s when there were those dedicated people who gave 110% to go in and paint their film frame by frame. Some of those who were dedicated included Thomas Edison and George Méliès. They were so dedicated that they hired other people to do it for them, at least in the case of Méliès who in 1902 had 21 women hand color his film "A Trip to the Moon" (Figure 1). This process got old fast and it wasn't long before tinting became the more popular way to colorize your film (1). There were several different processes used to color or tint film including Pathecolor which Charles Pathe created in 1905. This process took different parts of frames that were tinted using a separate stencil to apply different colored dyes. This stencil was cut by an operator using a pantograph to trace the projected image. On the opposite end of the pantograph arm was a needle that electronically vibrated and cut away the stencil. This was done frame-by-frame, scene-by-scene. Obviously this was not a quick or easy process either. However it became quite popular and by the early 1920s around 80-90% of films had at least some scenes tinted (2).

Unfortunately for tinting enthusiasts, the introduction of sound eliminated the use of this technique. The wavelengths of radiation most sensitive to the sound reproducer cells were being absorbed by the dyes that were being used. This caused a loss in audio quality that was significant and unacceptable to filmmakers and moviegoers alike. However, color had become important to several producers and audiences so companies scrambled for solutions. One substitute was Kodak's Sonochrome series released in 1929 providing 17 differently colored film stocks that worked with sound and silent films. However, by this time, color in film was moving in a more advanced direction than just tinting or dyeing the film (2).



Figure 1 - A still from "A Trip to the Moon."

While tinting and coloring in post became somewhat popular, it was far from the solution in terms of creating color motion pictures. True, accurate, and realistic color needed to be captured in camera and on set. Enter the 2 color additive system, Kinemacolor. The Kinemacolor camera was actually modified several times starting out as a three-color process before downgrading to a two-color system due to fringing problems in projection. This two-color system used blue-green and red-orange filters contained within the opening of the shutter. The film was then exposed at 32 frames/s with alternating exposures between the filters. The frames were then projected the same way essentially merging the two images (via visual integration) into what was perceived as a color picture (2). Besides Kinemacolor there were many other systems that used a 2D color space to render color. These included Douglass Color, Gilmore Color, and Keadacolor. While many of these systems improved upon each other, none of them were able to eliminate the awful gamut created by a two-color system.

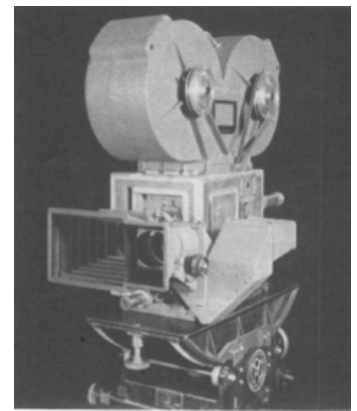
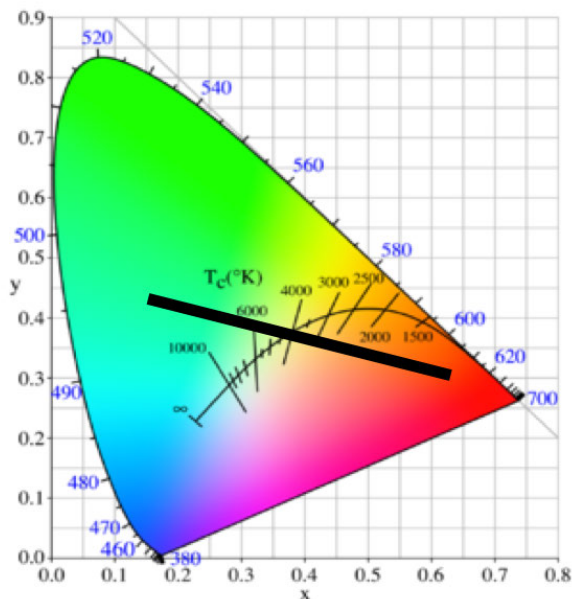


Figure 2 - Technicolor's three-strip camera (2)

The reason for this awful gamut is shown in Figure 3.

The graph is a representation of every color that is visible by the human eye. The black line in the center represents which colors a two-color system such as Kinemacolor can reproduce. Since there are only two primaries the gamut is not able to cover an area beyond what this line portrays. This figure also shows why the whites of many two colors systems appeared yellowish. It was determined that skin tones were the most important color to portray accurately so this line was placed such that skin tones would be represented correctly. However this usually resulted in the white point falling in a place with a yellow tint instead of being completely neutral. The reason a three color system is such a vast improvement over a two

color system is because with three primaries a triangle is able to be created which can cover a much larger gamut of colors. This larger triangle also allows for accurate skin tone reproduction while maintaining a neutral white point.



**Figure 3 - A two primary color gamut is outlined by the black line.**

Since the beginning of color in motion pictures, most people knew that two-color systems would not produce the best color; even the human visual system uses a tri-chromatic system. However it was the best they could do without sacrificing the quality of the picture, especially in regard to sharpness. Many three color and even four color systems were tried but it wasn't until 1932 that a three color system became functional with Technicolor's three strip camera (2).

The first feature shot with this technology (Figure 2) was *Becky Sharp* released in 1935 and while there are many other advances that happened within color, 3D color systems have forever since been the most prominent (3).

While color has been around since the beginning of cinema, and many technological advances have been made since, it was not as widely used after its conception like other developments such as sound and widescreen were. Color was implemented slowly over time and in different ways. Many filmmakers used color for different reasons especially due to the psychological effects color would and does have on audiences. In the early days of color, the color was not very realistic and was therefore used for specific purposes. For example, sometimes films would use color in just one or two scenes for symbolic effect such as in Erich Von Stroheim's film *Greed* (1924) where a yellow tone (Figure 4) was used in the final sequence to symbolize gold (2). Others like Sergei Eisenstein used it only for dramatic effect and were even worried that color would just be another element that would alienate film from artistic purposes. Eisenstein whose *Ivan the Terrible* (1944) only had sequences in color, said,

*"Color is good when it is necessary. That means that color [is] good where and when [it] can most fully express or explain what must be conveyed, said, or elucidated at the given moment of the development of action"*(5).

Douglas Fairbanks, the director of *The Black Pirate* (1927) created with a 2-color Technicolor system, stated that color was

*"always met with overwhelming objections. Not only has the process of color motion picture photography never been perfected, but there has been a grave doubt whether, even if properly developed, it could be applied, without detracting more than it added to motion picture technic. The argument has been that it would tire and distract the eye, take attention from acting, and facial expression, blur, and confuse the action. In short it has been felt that it would militate against the simplicity and directness which motion pictures derive from the unobtrusive black and white."* (4)

The technology however moved forward and eventually color became more natural, with expanded color gamuts, more accurate skin tones, and truer neutrals. However it was some time before audiences adjusted to the different feel of color in cinema. In the 30s and 40s color was used for things that were much more imaginative such as cartoons, musicals, and fantasies while black and white was still used for things that were deemed more realistic such as dramas, documentaries,



**Figure 4 - The final scene in Greed (1924)**

and newsreels (4). Even now when we think about the time of black and white film we sometimes think of the world then as being in black and white. Edward Buscombe sums it up nicely stating, "the colors we accept as real are therefore a compromise between what we are accustomed to and what used to be." (4)

While color became more widely used as time went along, the artistic choices on how to manipulate that color remained limited. Colorists could change the settings on their printer

lights but otherwise were limited to the color reproduction that Kodak (or Fuji) chose to incorporate into their film stocks. That all changed in the late 1990s with the revolution of Digital Intermediate. In 1993 *Snow White and the Seven Dwarfs* became the first film that was entirely scanned to digital files, changed and manipulated (for restoration purposes) and then recorded back out to film. In 2000 the Coen Brothers released their film “*O Brother Where Art Thou?*” It was the first full feature film to go through the Digital Intermediate process. Essentially they scanned the film at a high resolution (2k), created data files in order to edit and manipulate the color digitally, and then printed it back out to film for distribution. The color was adjusted with a Pandora MegaDef and a Kodak Lightning II recorder was used to print out to film (7). An example of how the color was changed can be seen in Figure 5.



**Figure 5 – “O Brother Where Art Thou?” before and after grading.**

Digital color correction continued to expand with the introduction of Digital Cinema cameras. George Lucas’ *Star Wars: Episode II* (2002) was one of the first feature films shot entirely on digital and helped pave the way for digital cinema cameras to be seen as legitimate options for filmmakers. Today cameras such as the Arri Alexa, Sony F65, and Red Epic are commonly used for big budget features. Many of these cameras have RAW modes, which capture images in an “unfinished” state in order to give the artist more freedom to reproduce the color as they choose. This however has created a greater need for colorists both on set and in post who are knowledgeable in the world of color science, color management, and digital workflows. Much of what RAW is and how it applies to this project will be discussed below.

Over time, color, which started out as a way to convey more imaginative things, evolved into something that was considered more realistic. Now with the world of digital color correction it has come into a state where it can be manipulated and changed in so many ways it seems it can help convey almost anything the artist desires. Color is still evolving through different artistic techniques and through advances in cameras and display devices. As we look forward into the world of color correction, I think it is important to look behind and to note those that doubted in color and argued that it would take away from the artistic side of film. Many would say the same about new advances in color correction as well as the new technologies of digital cinema, high frame rates, 3D, and special effects. However, I would argue that it is exactly the opposite. Anytime a technology is developed that gives a filmmaker more options while making a film, it can only

increase the creative possibilities and therefore paves the path for more creative and artistic films to be made. The following is a discussion of how some of these creative possibilities were utilized for two student projects at the Rochester Institute of Technology.

## II. James Nevada’s “From the Hard Coal”

**SYNOPSIS:** *A miner named Jack and his breaker boy son Francis live and work in a small coal-mining town in the Coal Region of Pennsylvania. In the wake of a murder by the town guards, the mining families rally together to decide how to respond. While most of the miners are in favor of violent action, Jack believes there is another way. Conflicted between the beliefs of his father and those of the town, Francis must ensue on a moral journey to realize what is right and what is wrong.*



**Figure 6 - Promotional poster for “From the Hard Coal”**

My involvement with “From the Hard Coal” (FTHC) actually started back in the spring of 2013. James Nevada, whom I had previously worked with on his film “*Assumption of the Virgin Manny*,” approached me about being his colorist for his senior thesis. Having had a great experience working with him on the previous project I immediately agreed.

In the beginning stages of pre-production I was thankful to be able to be involved in many of the discussions and meetings involving the look of the film. The original plan was to shoot on 35mm film, which got pushed to 16mm film, which eventually got booted for the Sony F5. James wanted a dirty, gritty, and cool look for his film and felt that film offered the best aesthetic with which to achieve that look because of film’s deep blacks and grittiness gained from film grain. Early on the dream was to shoot on Fuji film since it had a cooler look to it than Kodak’s film. As pre-production went along it was determined Fuji film was impossible to get and that Kodak would be the best option. We met with Kyle Alvut (senior colorist at Eastman Kodak Company in Rochester, NY) in May 2013 to discuss the possibilities of obtaining a good deal on film stocks, processing fees, and the possibility of me doing the digital transfers over at Kodak Building 205. Test shoots were also performed to determine the performance of Vision3 500T film specifically in low light situations. A still from these tests can be seen in Figure 7.

As summer went along many fundraising endeavors fell short of expectations and by the time fall came the dream of shooting on film died. The decision was made to shoot on the Sony F5. It was determined that its high dynamic range, low noise output, and capabilities to shoot 4K gamma encoded slog2 would allow for enough freedom to create the desired look and feel for the film. Sony cameras also tend to have a more “cool” look to them, which matched our original desire

to shoot on Fuji Film. It should be noted that while we originally were hoping to incorporate the gritty look of film, it was decided that a noisy output from a digital camera did not achieve the effect we wanted and therefore a camera with a low noise output was seen as ideal.



Figure 7 – A still of test footage taken with Vision3 500T film

The setting of this film is in a dark, gray and dismal mining town. The citizens of this town are being oppressed by a company and are therefore tired and depressed. The goal of the look of this film was to bring the audience into this environment and connect with the citizens of this town. As stated above, this tone was accomplished by giving the film a cool, gritty and dirty look. Colors such as gray, blacks, browns, deep greens and blues were focused on. Most light sources tried to match the color temperature of oil lamps that many times were included in the scene. Contrast and saturation have been adjusted accordingly to accomplish the feel of grittiness and discouragement.

A couple stills from films that were used as inspiration for the look of this film can be seen in Figures 8-10. Sherlock Holmes (Figure 9) especially resonated with me as I liked how it added a bit of green into the shadows to help give it that dirty and gritty look.



Figure 8 – There Will Be Blood (2007) directed by Paul Thomas Anderson, color by Gregg Garvin

For the first weekend of shooting, the F5 was rented out a couple days in advance to ensure time to do a test shoot. The night of September 18, 2013 this test shoot commenced in Studio A of SOFA (School of Film and Animation) at RIT. Images from this test shoot can be seen in Figures 11-12. Through testing it was determined that the camera provided

enough dynamic range to allow us to shoot one stop over and bring it down in post. This would enable us to get a cleaner image with less noise artifacts especially in low light situations. It was also determined that we would be shooting in slog2 4K RAW for the Sony F5. The F5 records in a MXF file wrapper.



Figure 9 – Sherlock Holmes (2009) directed by Guy Ritchie, color by Adam Inglis



Figure 10 – October Sky (1999) directed by Joe Johnston, color by Mike Stanwick



Figure 11 - Sony F5 Test Shoot



Figure 12 - Sony F5 Test Shoot

The first weekend of principal photography took place from September 20-22. I was able to have the opportunity to join the crew on set for the first weekend of shooting and not only was it a great experience, it proved to be useful as well. On set my role was primarily an advisor. Michael Harper handled most of the DIT and Assistant Camera duties and I was able spend most of my time giving my advice to James and his DP Andreas Roalsvig. There were two specific situations where I feel like I was especially helpful. One scene was being shot in the coalmines with low light. Andreas was having trouble getting enough light without having his aperture open too far (which would cause to shallow of Depth of Field). I simply suggested he move his lights closer and the problem was solved giving him enough light for the scene (enough to shoot 1 stop over) and enough Depth of Field to grab his subject. Another moment came when shooting in a Bed and Breakfast. The scene was being lit very warmly with red gels. While the light sources of the film's time period would have come from a flame, the look of the film had been discussed as cool and desaturated. Before shooting commenced I brought it up and a discussion was held and the shot was changed. Rather than looking like it was on the fire, the room was lit much more neutrally. Unrelated to color I also was given the opportunity to be an extra in a couple scenes, which was a lot of fun for someone who doesn't usually get to be on set. See Figures 13-17 for several stills from the production of FTHC.



Figure 13 – Shooting the gallows scene



Figure 14 – Chris Brands preparing to be an extra



Figure 15 – Director James Nevada on the set of FTHC



Figure 16 – Shooting in the coal mines



Figure 17 – Video village

When working with a digital cinema camera it is very important to have an understanding of the workflow to ensure your images are managed correctly. For this project almost all scenes were shot on the F5 capturing through an AXS Recorder that records 4K 16-bit gamma encoded slog2 in an MXF container. This footage was then backed up onto a master drive and a secondary backup drive for data protection using a program called ShotPut Pro 5. The footage was then imported into DaVinci Resolve and exported into 1920x1080 ProRes 422 HQ with a quick technical grade for editing in Avid Media Composer. VFX worked with the low-resolution files for preliminary design and then for the final export used the un-graded high-resolution MXF files to export for color correction. I as the colorist received an ALE file of the final cut from Avid Media Composer and then re-conformed the timeline to the high-resolution MXF files. The final video was exported from resolve and then joined together with the final sound mix in Adobe Premiere. A 1920x1080 version was exported for screenings. The possibility of creating a 4K DCP is still being discussed.

It is also important to note a few pickup shots were shot on the Arri D-21. These were shot at a resolution of 2880 x 2160 in ArriRAW LogC and were run through s2View and ArriRawConverter to create 16-bit DPX files. This workflow can be read about in detail in the “Arriflex D21 Operation and Production Guidelines” document written by Alexander Pagliaro. Since the final output will be 1920x1080 the smaller resolution will not be an issue. If the 4K DCP is to be created, this conform issue will have to be addressed.

As of December 2013 all principal photography was wrapped for this film. In the winter I had the opportunity to play with some of the footage and even work with James to develop a preliminary look that was used for the poster. One of the things that needed to be determined before grading was how to take the slog2 footage and change it into something that is presentable. Davinci Resolve, which is the chosen grading program for this project has a 1D LUT called “Sony slog2 to Rec 709.” I chose to not use this option as I felt it allowed me more freedom in my grade to start with the flat look. However if a time crunch were to have happened it would have been a

viable option to help get my slog2 footage to a more “normal” starting point. Another thing to consider is that the F5 does not bake in exposure index or color temperature. All of these things can be adjusted in Resolve after shooting by right clicking on your footage in the media pool and clicking “Edit Sony Codec Settings.” A box comes up with different settings including color space, gamma, white balance, exposure, and sharpness. For this project the chosen color space is Rec. 709 since that was the final output for screenings. Gamma was set to slog2 and the Decode Using setting was set to clip. White balance and exposure varies for each shot; however since most shots were shot one stop overexposed most exposure values will be set quite low. A screenshot of this settings box can be seen in Figure 18.

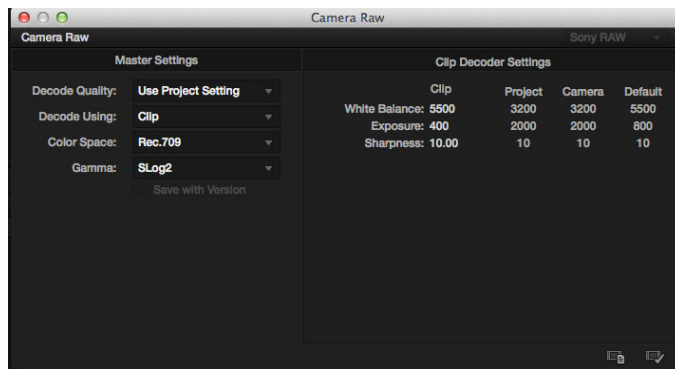


Figure 18 – DaVinci Resolve “Edit Sony Codec Settings”

Figures 19-24 show examples of two grades completed for this project. One of the things I learned was helpful as a colorist was to choose “hero” shots for each scene that I could base the look of the scene off of. I also chose a “hero” shot for the film. Figures 19-21 show the “hero” shot we chose for this film of the two main characters walking down a road in the mining town. Several things were done to this image. Obviously contrast was increased and saturation was decreased. More specifically magenta was added to the keyed out green portions of the scene such as the grass and leaves. This helped it appear more dead but not colorless altogether. The brightness of the sky was brought down as well. Lastly green was added to the shadows and a little to the mid-tones. It should be noted that these stills have not been properly color-managed to be viewed within this paper.

The second shot showed here (Figures 22-24) is a shot of the gallows scene. Again contrast was increased and saturation decreased. The greens were once again keyed out and given a golden hue. This was done by first adding magenta and then adding yellow to the keyed out area. Another thing that had to happen with this shot is that the main characters white shirt had blown out portions but also was very blue. I ended up using a luma key to grab his shirt and completely desaturated it to make it as neutral as possible.



Figure 19 – Sample still from FTHC before grading (slog2)



Figure 20 – Sample still graded to a “normal” look



Figure 21 – Sample still from FTHC after grading

“Hero” shots were graded for each scene. This not only allowed us to establish a look for each scene but also allowed me as a colorist to have a head start before picture lock. Two of the main corrections that we kept fairly consistent throughout the movie was to add a touch of green to the shadows and desaturating the shadows and highlights more so than the midtones. We also did our best to keep the entire film as dark as possible while maintaining a desired amount of contrast.

Reflecting on grading this film, I really enjoyed grading slog2. After adding contrast back into the image, hardly any color had to be added and it gave out accurate color reproduction. This allowed for a lot of flexibility in color decisions.

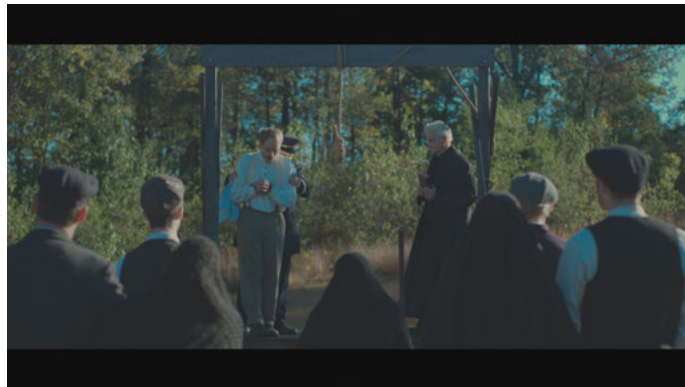


Figure 22 - Sample still from FTHC before grading (slog2)

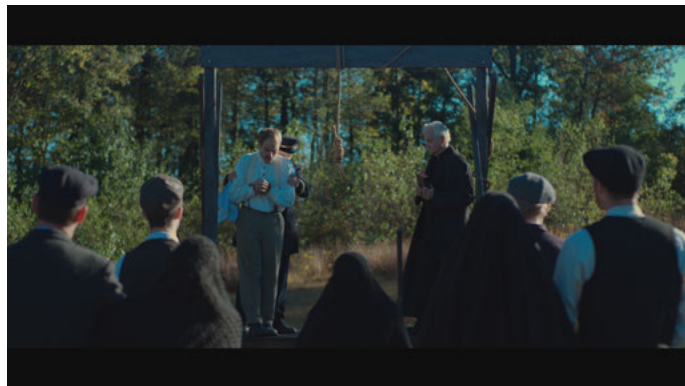


Figure 23 – Sample still graded to a “normal” look



Figure 24 - Sample still from FTHC after grading

Upon finishing this film we had a couple issues. The main issue we had was that when exporting from Resolve an incredible amount of banding was being applied to the image. In order to fix this a very light random noise/grain filter was applied to the entire film to confuse the compression algorithms creating the banding effect. The other issue we had was that when applying this filter, some of the framing got resized, particular the D21 footage, which had a 4:3 aspect ratio. These images got cropped and stretched and unfortunately were not correct in the screening of the film here at SoFA. However this is an easy fix for future screenings.



### III. Austin Williams' "Preis"



**SYNOPSIS:** *For over a year Dean has been playing an "imaginary friend" for his younger brother Scott. After realizing that his brother confides too much in the creature, Dean decides that he may have to break off the fantasy sooner than expected.*

The process of Austin's film has been very different from that of James' film. Back in the spring of 2013 Austin asked me to be his colorist and I agreed. Having seen some of his past films and enjoying them, I was excited to get to work with him. His proposal was accepted in the spring. However he decided to change his story and his script and resubmitted in the fall. Unfortunately unlike James' film I have not had much of a chance to be involved with pre-production.

The choice of camera changed every time I talked to him. Austin originally planned to shoot BlackMagic, then he was going to shoot Canon C300; the Panasonic GH2 got brought up, then he decided to go with the RED One MX Camera before finally settling back on the BlackMagic Pocket Cinema Camera. As far as I am aware this choice was made solely on the basis of cost. I do not think this was the correct camera for this production, at least not in the way it was shot. One issue with it was that the dynamic range of the camera could not handle many of the outdoor scenes that it was used for. This isn't entirely on fault of the camera as they could have done a better job of using flags on set to avoid clipping highlights. Another issue was its color reproduction. BlackMagic cameras are well known to have IR spill onto their sensors. This was the case in many shots and resulted in inconsistent and inaccurate color reproduction.

"Preis" was shot in the Atlanta, GA area from January 14-20<sup>th</sup>. It was shot in 1920x1080 in the CinemaDNG RAW format. Another issue that occurred was that the cold weather caused the storage media to malfunction, which resulted in corrupted frames. This issue was fixed in post by Michael Harper who was able to duplicate existing frames to fill in the gaps, but because of this error I ended up grading ProRes files as opposed to the original CinemaDNG files. I do however believe that all of these issues could have been avoided with better pre-production planning and camera testing.

The look of Austin's film was much less stylized than that of James'. With "Preis" we went for a high contrast "golden"

look. We wanted to give the forest scenes of the boys playing almost a dream world type look. Therefore we made these a golden hue. We kept the rest of the film warm to generally match that style however it was scaled back a bit in order to keep a distinction between the real world and the dream world.

Originally we actually wanted it to have a very subtle cool/cyan look. Austin wanted to set a serious yet playful mood. One of our inspirations for this look can be seen in some stills from The Shins' music video "It's Only Life" in Figures 25-27. The video can also be viewed at <https://vimeo.com/56004497>. However once we got to post production it was determined that this look was not going to be possible. Since shooting took place in January, many of the shots had no color to pull from and much of the grass and plant life was dead. Therefore the golden look was opted for instead.



Figure 25 – Still from "It's Only Life" – The Shins



Figure 26 – Still from "It's Only Life" – The Shins



Figure 27 – Still from "It's Only Life" – The Shins

Similar to James' film, once shooting was completed I asked for "hero" shots from each scene. These "hero" shots became the base look for each scene. The shot below (Figures 28-29) was our "hero" shot for the film. Achieving the look for this film was much simpler than it was for James' film. I basically graded the scene back to normal, which involved adding some contrast and adding color back in by boosting the saturation, and then I added some warmth to the scene mainly in the highlights and midtones.



Figure 28 - Still from Preis before grading (RAW)



Figure 29 - Still from Preis after grading

The scene that gave me the most trouble was the scene of the soccer game. As stated above the grass was very dead so it took a bit of effort to add some green back into it. There was also an issue with the IR spill. I couldn't just add saturation to the whole shot in order to get color into the grass because doing so caused the jerseys the boys were wearing to glow this weird orange color. These jerseys were actually a darker red in real life but reproduced as a glowing orange in post-production. Therefore not only did I have to key out the grass but I had to key out the jerseys in every shot as well (Figures 30-33).



Figure 30 - Still from Preis before grading (RAW)



Figure 31 - Sample still graded to a "normal" look



Figure 32 - Sample still with green added to the grass



Figure 33 - Sample still with the final grade

Despite not enjoying the feel of BlackMagic RAW and how it graded, I did value the experience of working on this film. While not everything went smoothly, I learned a lot about how to handle different situations and shots. It was also my first opportunity to work with BlackMagic footage, and while I didn't enjoy grading it like I did slog2, I did value the experience of getting to work with it.

#### IV. Introduction to On Set Color Correction

Filmmakers have always desired to see their images as quickly as possible. Quickly identifying and fixing mistakes on set is a very important part of the movie making process. On the other end of the workflow process, those in the industry are constantly trying to find ways to increase efficiency and speed in the post-production process. While dailies have typically been the best way to identify mistakes during production, times are changing. With the switch to digital, images can be viewed not just through the viewfinder but also on monitors and screens that the director, producer and even crewmembers can look at. These images, however, are not always that accurate to the final look of the film. Those shooting on new digital cinema cameras typically shoot in RAW formats that are flat, desaturated and require color grading to create a satisfactory and pleasant image. While dailies are still a successful tactic, many are expanding on this by adding on set color correction into their workflow. On set color correction allows quick color adjustments to be made to the image by the cinematographer or colorist allowing them and others to see the image in a way much closer to how it will actually look on the silver screen. Another advantage to on set color correction is that the color decisions made on set are able to be saved and kept as a starting point for the colorist in post-production. While on set color correction brings great possibilities, many choose to avoid it. Adding another on set task can slow up production, especially when everyone can see the image and wants to play colorist. In this project I will explore the world of on set color correction by building an on set suite for the Arri D21 Digital Cinema Camera. This suite will be built with SOFA students and a SOFA workflow in mind with the hopes of future students being able to utilize its features.

#### V. Why RAW

Before continuing on it is important to take a minute to understand what RAW really is and what are its benefits in color correction. RAW in its truest definition means that no image processing has been done to the image after it has been captured by the camera's sensor. This results in an image file that has a linear relationship of exposure to code value. The benefits of this from a color correction stand point is that it allows the colorist to make many of the image processing decisions as opposed to the camera manufacturer doing it for them. While this can be more work and is much more time consuming, it allows for much more flexibility and creative space in the color correction process. Many cameras offer RAW modes (such as Sony's slog2). These modes are not true linear RAW but instead offer minimal image processing. Usually this image processing is something determined by the manufacture to allow the user a better starting point than full RAW but still enough flexibility to be creative in the color correction process.

#### VI. What Already Exists

There are currently several on set color correction systems already out there. Technicolor's On Location Services department has a system that uses Colorfont's On Set Dailies

software to set looks. These looks are baked in for deliverables like DVDs and QuickTimes for at home viewing. They also save the ASC CDL (this is described below in the section Saving the Grade) information of the grade in an Avid ALE, which along with the MXF media gets sent to the editorial team. An ALE is a list of metadata for each shot in the camera and it includes varies information such as the camera roll and shoot date. Essentially Technicolor puts the ASC CDL information into the Avid metadata. They are then able to export an EDL (Edit Decision List), ALE, or XML from Avid and then use a program such as Resolve or Baselight to import that data.

Another system out there is FilmLight's FLIP (Figure 34). The FLIP is an on-set color visualization system. It uses a system that can be battery powered and saves the color decisions in a Baselight Grade File (BLG) so these decisions can be the foundation for the final grade.

*"FLIP is a real-time image processor which applies lookup tables, grades and filter effects to the live output of your camera while you are shooting on set. Inserted directly in the single or dual-link HD-SDI feed between camera and monitor, it utilises GPU accelerated hardware combined with Baselight grading and Truelight 3D LUT technology to apply looks to your raw footage so you can see exactly what the final grade is going to look like in post."* –FilmLight

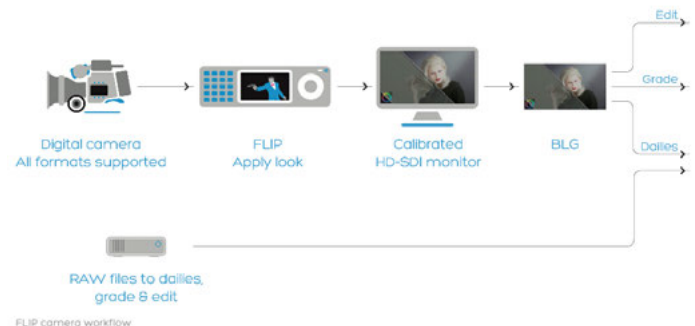


Figure 35 – FLIP Workflow

Gamma & Density also has an on set system they released at NAB 2011. Their system is a product called Image Control. The idea is similar to the FLIP system except it is entirely integrated into an iPad app.



Figure 34 – FilmLight FLIP System



Figure 36 - Image Control iPad Screenshot



Figure 37 – Image Control iPad Screenshot

*“Image Control works by grading still frames of motion footage on the iPad in a calibrated screen environment, and then exporting those color corrections to post using our effective and industry accepted 3cP Reports. The Reports include a file of the actual LUT or CDL that was created in Image Control.” –Gamma & Density*

## VII. SOFA System – The Goal

The goal for my system was quite simple. I wanted to have a working system that allowed SOFA students to color correct on set using the Arri D21 and Sony FS700 cameras while shooting in their RAW modes. I wanted to be able to give the user basic color wheel functionality including lift, gamma, gain, hue shift, and saturation controls. It needed to be able to work fast enough to be useful on an on set situation and these corrections needed to be able to be saved for later use in post-production. While this goal was not reached for the Sony FS700 (mostly due to a lack of equipment) the sections below outlines how I was able to satisfy these goals for the Arri D21.

## VIII. The Arriflex D21

The first step in developing this system is understanding the workflow for a digital cinema camera like the Arri D21. Normally when shooting with the D21, a laptop will interface

with the DMAG Recorder via an Ethernet network in order to control the DMAGREMOTE GUI. This is a useful tool not only to hit record on, but also to apply metadata to your shots. While interfaced with the DMAGREMOTE a laptop can also mount the drive via a Samba connection. More on each of these can be read about in the “Arriflex D21 Operation and Production Guidelines” document written by Alexander Pagliaro. Being able to connect to both of these tools at once allows for the quick transfer of a D21 file onto a laptop. After shooting and applying metadata the mounted drive can be accessed and one or more frames can be simply dragged off the DMAG and into a folder of the user’s choice.

When shooting the D21 in its gamma-encoded logC ArriRAW format, the files do not come off the camera ready to go. If you shoot ARRIRAW on the D21 and record to an S.Two DFR2K DMAG the files are wrapped in a proprietary S.Two DPX file. Therefore these files must be converted its original DPX wrapping using the S.TwoView utility. This results in an .ari file, which must then be processed using a program provided by Arri called ArriRawConverter (ARC). Much like the previously discussed F5, decisions must be made about exposure index, white balance, and color encoding when processing these images. ARC gives you the option of exporting your files as TIF, 10-bit or 16-bit DPX, or JPEG. There are also two versions of ARC, the user-friendly program with a built in interface as well as a command line program. A visual representation of this workflow can be seen in Figure 38.

While this is the normal workflow for the D21, it is not very efficient on set. Early tests showed that this took at minimum 5 minutes to run and to have a graded image. The goal therefore was to find another way to have a gradable file that would replicate that which would be graded in post. This file however, needed to be created in a user friendly way as quickly as possible.

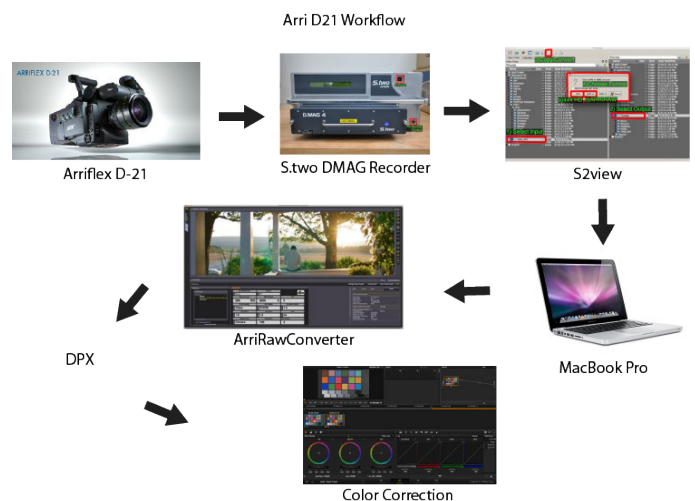


Figure 38 – D21 Traditional Workflow

## IX. The Sony FS700

One of the more popular cameras in SOFA Cage right now is the Sony FS700. As stated above an on set workflow was not developed for this camera as part of this project. The Cage updated one of these cameras in January 2014 to be able to shoot 4k RAW (slog). However a recorder is not available for it at the cage. If one wishes to develop an on set workflow for this camera in the future, a recorder will have to be obtained.



Figure 39 – Sony FS700

## X. Early Attempts and Failed Possibilities

One possible solution that was explored early on in the project was the option of using DaVinci Resolve 10's live grade feature. This is a great option because it allows the user to connect the camera to the computer via a decklink or video interface. Then within Resolve you can see the live feed of the camera, make corrections, and even save these corrections to an ASC CDL. Unfortunately the Decklink or Video interface required to make this work costs upwards of \$500 and is not a reasonable solution for students in SOFA.



Figure 40 – Blackmagic design video interface



Figure 41 – Decklink

## XI. The On Set Workflow

After much trial and error a workflow was developed for the system. This workflow can be seen in Figure 42. The central part of this finalized workflow is a program called D21Convert. This is a program that has been created as a substitute of both S2view and ARC. The ins and outs of this program are detailed in the next section. In essence the finalized workflow requires a frame to be extracted from the Dmag, run through D21Convert, and then inputted into Resolve. An ASC CDL can be exported from Resolve once an on set session is complete to save corrections for later use. This process is outlined in detail in the section titled Saving the Grade. If the on set colorist is well organized and learned in the system the time from capture to having a graded image should be able to be kept to about two minutes.

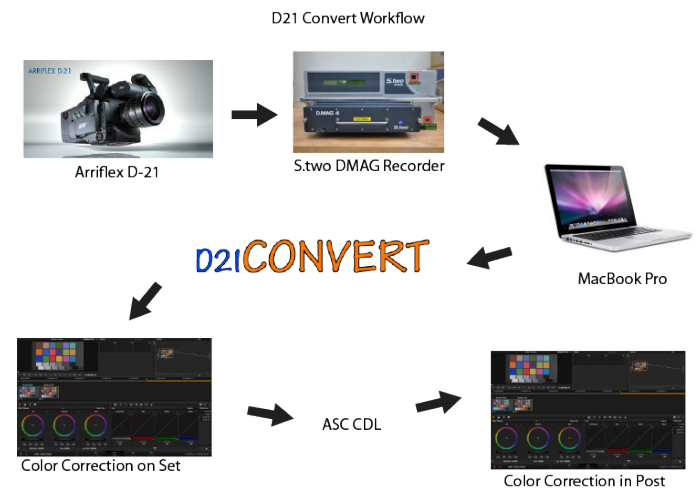


Figure 42 – On Set Color Correction Workflow

## XII. D21Convert

As stated above a solution was needed to be able to have a gradable file that will replicate that which will be graded in post. This file however, needed to be created as quickly and in the most user friendly way possible. D21Convert is a combination of several different steps combined into one user-friendly software that solves this problem. The overall workflow of the program can be seen in Figure 43.

The first step in D21Convert is to run a program called DPX Convert created by former RIT student Glenn Sweeney. DPX Convert is a command line program that writes a TIFF from the original DPX encoded logC file. The TIFF that it writes out contains the raw data off of the camera sensor. Even though the D21 shoots in RAW, the camera still contains some onboard processing that affects the image after it is captured by the sensor. This includes noise correction and white balance that is baked into the digital counts. More specifically Arri adds a floor of 16 to help with its noise statistics. These images are also created much like those on any camera, in a mosaic pattern. Each pixel represents a red, green, or blue Bayer filtered pixel. These are then white balanced to be equal for a white point. For the D21 the resulting digital counts are directly proportional to the sensor's response to the

photons multiplied by the white balance coefficients. Since the D21 contains a CMOS sensor these are linear responses. In other words what DPX Convert is spitting out is a mosaiced 12-bit linear image with a black level offset included. This is a 12-bit image that is upper packed into a 16-bit image.

Once this image is calculated, the logC curve is then applied to the image. This curve varies based on exposure index, which is one of the reasons D21Convert asks the user for an input of EI. These LUT's are available for public use and can be found on Arri's website.

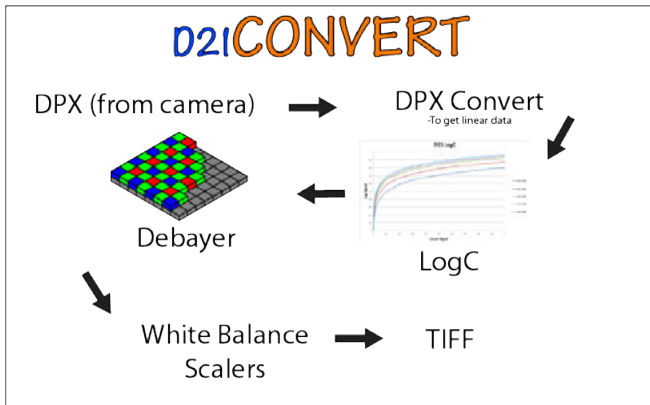


Figure 43 – D21Convert Workflow

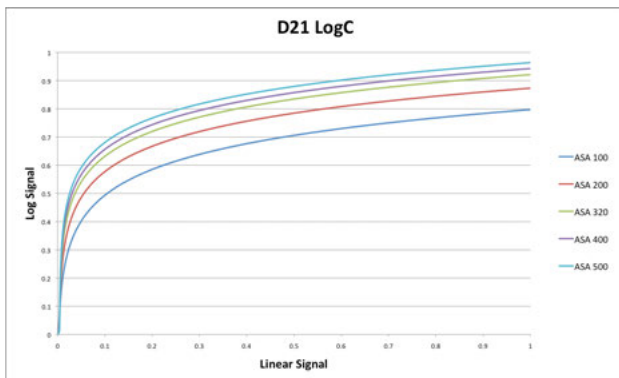


Figure 44 – D21 LogC Curve

The next step was to interpolate the image. This was done using a method based on what is outlined by Dan Su and Philip Willis in their paper “Demosaicing of Colour Images Using Pixel Level Data-Dependent Triangulation.” More can be read about it in their paper or in the paper “Demosaicing of Colour Images Using Pixel Level Data- Dependent Triangulation (September 2012)” by Chris Brands and Michael Richos.

The last step before outputting the final image was to apply white balance scalars. These white balance scalars were determined using an optimization step in order to match the output of ARC as closely as possible. In order to do this Macbeth Charts were shot on the D21 at every color temperature and every exposure index. It should be noted here that the D21 bakes in color temperature but does not bake in exposure index. However each Macbeth chart was properly exposed depending on which EI was to be applied later on in post-production. These images were then run through ARC

and compared to the images being spit out by DPX Convert. It was at this point in the process that it became clear that the newest and only available version of ARC has a flaw when working with D21 footage. While the D21 footage bakes in its color temperature, Arri's newer camera the Alexa does not. ARC has been built for the Alexa and therefore gives no option to not apply a color temperature change. A series of guess and check tests were run to determine the color temperature and tint setting that would yield the least amount of additional image processing done by ARC. These tests showed that the color temperature must be set to 5675k with a tint of +5.5 (along with the same EI as selected for D21Convert) to ensure minimal white balance effects in ARC and to match the look of the file run through D21Convert. It should be noted it does not matter whether TIFF or DPX files (10 or 16 bit) are outputted from ARC. With these settings the differences in the images did not disappear altogether but did result in a dE00 average value of .65 as seen in Table 1. These dE00 values were taken from an average of dE00 values from a standard 24 patch Macbeth color checker. Each section of each patch was selected and averaged. These average values were then compared to the average values from the patches from the other image and compared to result in a dE00 value for each patch. These were then averaged to obtain a dE00 value for each image listed in the table below.

Table 1 – dE00 values comparing ARC Macbeth Patches to DPX Convert (with logC but without white balance scalars) Macbeth Patches

	100	200	320	400	500
3200	0.572064127	0.628686269	0.634395849	0.713041741	0.706937942
4300	0.580063506	0.624598452	0.634502277	0.716364829	0.726720307
5600	0.569550726	0.616498859	0.611535588	0.715260353	0.739222149
7000	0.557873478	0.610583332	0.626001459	0.725278319	0.732885851
Max	0.74	Min	0.56	Average	0.65

In order to lower these values even further, white balance scalars were applied. As stated above an optimization was run in Matlab to determine red, green, and blue scalar values that would best match each image. This was tested by optimizing a set of images together according to color temperature and according to EI. It was determined that optimizing according to EI yielded the best results. The following tables outline the optimized values for each EI and the resulting dE00 values.

Table 2

EI 100	R	G	B
	0.999851772	1.008964364	1.017267834
<b>Produces dE00</b>	0.116470307		

Table 3

EI 200	R	G	B
	0.999841734	1.009149355	1.017551685
<b>Produces dE00</b>	0.148919642		

Table 4

<b>EI 320</b>		
<b>R</b>	<b>G</b>	<b>B</b>
0.999983434	1.008105098	1.015805128
<b>Produces dE00</b>	0.174878639	

Table 5

<b>EI 400</b>		
<b>R</b>	<b>G</b>	<b>B</b>
0.999858961	1.009420449	1.019137822
<b>Produces dE00</b>	0.2382	

Table 6

<b>EI 500</b>		
<b>R</b>	<b>G</b>	<b>B</b>
0.999914791	1.008820254	1.018377323
<b>Produces dE00</b>	0.248	

All the results together resulted in a dE00 average value of 0.185, which is virtually indistinguishable to the human eye. Once the white balance scalars are applied to an image, D21Convert writes out a TIFF file with the final image. An example of an outputted image compared to an outputted image from ARC can be seen in Figures 45-47.



Figure 45 – Outputted ARC Image – 3200k EI 100



Figure 46 – Outputted D21Convert Image – 3200k EI 100



Figure 47 – This image combines the outputted images of ARC and D21Convert. The right side of each patch is from the outputted D21Convert image while the left side of each patch is from the outputted ARC image. This particular Macbeth chart was shot at 3200k and EI of 100.

I want to end this section with a thank you to Glenn Sweeney and Jacob DeBoer. Glenn gave me a great starting point with DPX Convert while Jake was able to take everything I have described in this section and combine it into one user-friendly program with an interface. Without both of them this program would not have been possible.

### XIII. Grading the File

Color correction can be done with a variety of different software and tools. For the purpose of this workflow DaVinci Resolve was chosen. It is the most commonly color correction software used in SoFA and the Lite version is free to download online which makes it accessible to all students. For those unfamiliar with how to use DaVinci Resolve a user manual can be found on the DaVinci website. For the purposes of this workflow only basic knowledge is needed to work the system. To gain a better understanding of how to import a file into Resolve and grade it on set, check out the “On Set Color Correction Guidelines” document.

### XIV. Saving the Grade

Once the grade has been added on set it needs to be saved in such a way that it can be accessed in post-production. One such tool that has been developed specifically for this purpose is the American Society of Cinematographer’s Color Decision List (ASC CDL). The ASC came up with the CDL in order to have a tool to allow “basic color correction data to be interchangeable between color correction systems made by different manufacturers.” It was created to be able to be communicated via ALE, FLEx, CMX EDL, and XML files.

It is important to understand the ASC CDL was not created with complex color decisions in mind but only those necessary for basic corrections that are able to be understood by all systems. The main functions of an ASC CDL are *Offset*, *Slope*, and *Power*. Saturation has also recently been added.

*Offset, Slope, and Power* have been named such in order to differentiate from the traditional *Lift, Gamma, and Gain* operations. The mathematical equations for *Offset, Slope, and Power* can be seen in Figure 48. These can be applied to each color channel red, green, and blue separately. Saturation uses common Rec. 709 weightings and is applied after *Offset, Slope, and Power* and is applied to all three color channels in combination.

*Slope*

$$S = in * slope$$

*Offset*

$$O = S + offset \\ = (in * slope) + offset$$

*Power*

$$out = Clamp(O) ^ power \\ = Clamp((in * slope) + offset) ^ power$$

**Figure 48 – Mathematical equations for slope, offset, and power**

As outlined in the “On Set Color Correction Guidelines” document DaVinci Resolve is able to save grades to an ASC CDL and to read them back in.

## XV. The Physical System

The system itself can be consolidated to run on a single laptop. This could be the same laptop that is used for DIT work with the D21, or it could be a separate laptop set up at a different station specifically for the colorist. Originally the thought was to have a calibrated monitor to be able to connect to the system, however if this is not available to the user a x-rite calibration device on rent from the cage could be used for the on set colorist to calibrate their laptop screen. This would not be a perfect grading set up but would be sufficient enough for the quick and dirty grading that would be performed on set. The laptop of course will need the required software in order to run correctly. Everything needed for the system to run properly has been put onto a flash drive and can be inserted into any laptop running a Mac OS to copy the needed files. This flash drive is obtainable from David Long.



**Figure 49 – DIT Station for the D21**

## XVI. User Manual

A detailed user manual has been written for this system. It is in a separate document titled “On Set Color Correction Guidelines.” It includes things such as how to set up and operate the on set color correction unit as well as a description of the workflow on set and in post.

## XVII. Next Steps

There are many things that can yet be improved on this system. One of the main things I would have liked to see is to have D21Convert be able to batch import frames. Tests could then be done to see if this program is a viable option not just on set but also in post-production. I would also have liked to develop a workflow for more cameras in SoFA beyond the Arri D21. Lastly, it would be useful to conduct experiments in which Directors, DPs, DIT’s, and colorists can test out the system and provide feedback as to its usefulness on set.

## XVIII. Conclusion

Color correction has and will continue to be a useful tool in the arsenal of any filmmaker. If utilized in the right way a film can be complimented and improved in such a way that is impossible to achieve with camera and lighting alone. This tool can also be utilized on set. As shown here, quick and efficient workflows can be developed in order to provide graded images that can be shown as references on set. Specifically, the on set color correction workflow developed here is fast, efficient, and gets the job done for users of the Arri D21. For an experienced user the time between shooting and having a grade shouldn’t be much longer than a couple minutes, which can be largely owed to D21Convert’s fast average running time of about 10 seconds. While improvements can always be made, the steps outlined here are a great start to having an on set color correction workflow here at the RIT School of Film and Animation.

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