Digital Film Restoration and Remastering

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Abstract

Film restoration is important for economical, cultural and artistic reasons. Different forms of digital media, such as high definition broadcasts, digital downloads and DVD and Blu-ray Disc have forced film restoration to be extremely vigilant and thorough. Compared to photochemical restoration, digital restoration offers more tools and solutions to make a damaged, faded film to look and sound as good as it did on the day it was released. However, it can be argued that modern digital restoration is mostly about making the film look better than it did when it was originally released.

This thesis attempts to answer the research question of how digital technology is used in the restoration and remastering of motion picture film and what kind of ethical implications might arise in these processes. The literature review provides the framework for the thesis. The research method chosen for the study was qualitative research where, in the span of 15 months, a total of 13 experts who work in the fields related to the research topic were interviewed. The study is constructed from the responses the experts shared in the interviews.

The first step in digital restoration is the digitization of the film. Three things determine the quality of a scan: resolution, bit depth and dynamic range. After digitization, the picture restoration begins. The handling of defects such as dust, dirt, scratches, mold, image instability, flicker, color breathing, shrinkage and dye fading are addressed. For example, several of the spatial defects can be fixed by borrowing information from adjacent frames and using the information to mask the defect area. Automated processes should be used sparingly, as they can create digital artifacts by mistaking picture elements as damage.

Sound restoration begins with research and evaluation. The next step is to be able to playback the elements and digitize them, which is often the most challenging part of the process. Once the elements have been digitized, an engineer will work at a computer workstation in a controlled listening environment to identify all the problems and removing them with little or no effect sound quality. Similar to picture restoration, automation should be used sparingly in order to ensure that sounds that belong in the film are not erroneously removed. After a full digital restoration of a title, the finished digital intermediate is recorded out to film: YCM separation masters are said to have a 100-year or longer life. The digital files are preserved too. Digital archiving is a debatable issue, as some consider it to be an oxymoron where too many unfortunate things can happen over time. On the other hand, others argue that a digital content archive can store films forever without any degradation, and that it will also be cheaper in the long run when compared to archiving on film.

This thesis also deals with the ethical side of film restoration by providing discussion on where the digital intervention should end (e.g. what should be fixed and what should be left alone). Algorithms are not presented in the thesis. The reader doesn’t need to know anything about the subject matter beforehand. Background information and most technical terms (both film and digital) are explained.

Keywords
Digital film restoration, digital image processing, sound restoration, digital archiving

Foreword

I would like to thank all the people who contributed to the research. First I'd like to thank Lecturers Raija Halonen and Eeva Leinonen for guidance and suggestions on how to shape this thesis into more scientific. Thanks to DVD Producer John Albarian, Senior Vice President Kim Aubry, Filmmaker Francis Ford Coppola, and Vice President Larry McCallister for providing the rights to use pictures from their DVD documentaries in chapter two. Last but not least I would like to give my warmest thanks to all the interviewees who participated in the study: Director of Digital Intermediate Systems Richard Antley, Vice President of Digital Services Tom Burton, Jeff Cava, Vice President Dave Cavena, Media Archivist Michael Friend, Director of Library Restoration and Preservation Theo Gluck, Film Archivist Robert A. Harris, Vice President Bob Heiber, Curator Martin Koerber, Chief Engineer John Polito, Director of Audio Restoration and Preservation Tom Regal, Vice President Jack Theakston, and Head of Technical Delivery James White. I'm very grateful that they all took time from their busy schedules to participate in the study. Without these people this thesis would have most likely never come to fruition.

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1. Introduction

Film restoration attempts to construct a specific version of a film, where all known surviving source materials are compared and pieced together into the order suggested by exhibition history and production records. Often image and sound have to be enhanced to compensate for past damage. (National Film Preservation Foundation [NFPF], 2004, p. 4.) Typically the main attempt is to create representation of the film as it originally looked (Aubry, 2008). No proper reference for the defining the term remastering was found. However, one of the experts interviewed for this study said that in the case of film, the term can mean taking an existing high definition (HD) element and applying additional digital image processing technologies (e.g. clean-up work, color tweaking, grain management), for example, but the main distinction is that the process doesn't begin with an original film element.

According Haas, Pinz and Schallauer (1999), film restoration is important because of two main reasons. All the material in the film and TV archives represents a record of history of the cultural and artistic development of all aspects of life since the early 20th century. It has to be preserved. A restoration phase is necessary in order to keep a copy as close as possible to the original. The second reason for film restoration is economic. Because of quickly developing communication media, such as multimedia, satellite and cable TV, this growth opens a new market for film and TV archives. However, without a restoration phase, these archives are only partly useable, which makes preservation as well as restoration necessary for film and TV archives. Bosley (2008) writes that Sony Pictures had its first full-4K high resolution digital restoration project carried out in 2006, and the studio would continue to do such restorations on other titles, thanks to the advent of Blu-ray Disc high definition DVD technology and the quickly grown popularity of larger display devices in homes.

While there has been previous research in the Information Systems (IS) industry, most of these studies are about presenting image processing algorithms to accelerate and automate the digital restoration process. Magazine articles and documentaries have been devoted to restoration case studies, and many are referenced in chapter two, but generally these do not give a thorough view of the entire process. Giovanna Fossati's book *From Grain to Pixel: The Archival Life of Film in Transition*, which was discovered late in the research process, is the closest thing in providing a more detailed examination of digital picture restoration, but her book does not examine sound restoration. Indeed, much less information is written on sound restoration, so one of the goals for this study was to delve more deeply into that area. Overall, the research done in the IS industry on digital film restoration has been scarce.

The main research question for this study is the following:

- How is digital technology used in the restoration and remastering of motion picture film and what kind of ethical implications might arise in the process?

The objective of this thesis is to provide a look at the many challenges faced in digital film restoration and remastering, and what the solutions are to those challenges. The goal is also to study what kind of impact digital media has had on these processes. Both picture and sound restoration are examined. As digital restoration is all about

intervention, the goal is to discuss where the line is drawn. The ethical issues arise particularly when it has to be decided whether or not a problem should be fixed with today's digital tools that could not be fixed during the production of a film with contemporary tools.

Qualitative research was chosen as the research method for this study. Thompson and Walker (1998) define the method as an examination of events or experiences in context from the perspective of the individuals experiencing the phenomena. Qualitative interview was used as the data gathering tool. 13 experts in professions related to this subject matter were interviewed.

In order to narrow the subject matter, the biggest exclusion comes from the fact that this thesis is devoted to digital restoration. This means that apart from a short comparison, photochemical restoration isn't discussed. Another major exclusion comes from the fact that image and sound processing algorithms will not be presented in this thesis. Even though the title of this thesis features the term remastering, the emphasis is in restoration, though similar tools can be applied to both processes. This thesis is also designed in a way that the reader does not need to know anything about the subject matter beforehand. This means that background information is presented and most of the technical terms are explained. Hopefully by the end of the thesis, the reader will have an understanding of all the main aspects and challenges faced in digital film restoration, and what things should not be done in the process.

This thesis is structured in the following way. Chapter two is the literature review portion, which provides the framework for this thesis. The chapter consists of referencing previous research, which was gathered from a wide variety of sources. Journals, articles, conferences, magazine articles and documentaries are referenced to tell about the digital restoration process in a chronological order. Background information is also given, such as film element related terms and reasons for the poor conditions of old films. Chapter three tells about the research method chosen for this study and how the empirical research was conducted.

Chapter four showcases the study done for this thesis. 13 experts were interviewed, and the content for the chapter is constructed from the information they shared in the interviews. The first half of the chapter deals with picture restoration and remastering. The emphasis is particularly in the handling of various picture issues; how are some of them fixed, and which should be left alone. Most of the second half of the chapter deals with sound restoration and remastering, starting from the research and evaluation process all the way to the digitization and handling of various sound issues to the completion of a project. The chapter ends with the debate concerning digital and film archiving. Chapter five provides conclusions based on the research done for this thesis and suggestions for future research.

2. Literature Review

This chapter is the literature review portion of this thesis. The goal of this chapter is to provide a framework for the study that was researched for this thesis. This chapter consists of a wide variety of sources. Conferences, journals and articles were researched from the following databases: IEEE, Google Scholar, Web of Science and Science Direct. In addition to these, several books, magazine articles (e.g. American Cinematographer) and documentaries were researched and referenced to construct the content for the literature review. All the information presented here is referenced from those various sources.

This chapter is structured in a way that it tells about the restoration process chronologically. However, background information is given first. This starts with describing the various film element related terms that will be used in later parts of this thesis. Restoration and its related terms are examined as well. Information on the reasons for the poor conditions of old films and how different versions of one title can provide challenges in the restoration. Section 2.5 and its subsidiary sections talk about the digitization of the film elements. Picture restoration and remastering is discussed from 2.6 all the way through 2.7.1. Sections 2.8 and 2.8.1 are about digital sound restoration. This chapter ends with describing what happens after the film has been digitally restored.

While several other film restoration examples are used throughout this chapter, the digital restoration project of all three *Godfather* films is used as the main example. This begins with section 2.4, which describes how that project got started. The other instances where the restoration is referenced in this chapter are sections 2.5.3, 2.6.7, 2.7.1 and 2.9.1.

2.1 Film element related terms

The film element that captures the image in the photographic process is the negative (NFPF, 2004, p. 10). The original camera negative is generally referred to as the OCN (Science and Technology Council, 2007, p. 6). In order to display the recorded image, the negative must be directly printed on to positive print film. For releasing large numbers of prints, the negative goes through intermediate photochemical processes of creating an interpositive (IP) and then multiple internegatives (INs). (Bankston, 2005.) A color interpositive is a low contrast, low density positive with an orange suffusion due to the orange integral masking (Meyer & Read, 2000, p. 64). A fine grain master positive is a black-and-white film used for making positive copies from negatives. It is an intermediate step towards the creation of a duplicate negative, which is then made into a projection print. A fine grain film has a low contrast and a very high resolution, and it produces the fine details of both the dark and light tones of the image very well. (Fossati, 2009, p. 288). When a check print is made from the internegative, the images on the OCN can finally be displayed (Bankston, 2005). Answer print refers to the first graded copy printed from a cut negative (Meyer & Read, 2000, p. 62). According to Bankston (2005), a print does not reproduce everything that was recorded on the negative.

Black-and-white separation masters are protection elements. While color negative will fade over the course of time, black-and-white will last as long as the base of the film survives. As illustrated in Figure 1, black-and-white separation masters are extracted from the original camera negative, and are created by using red, green and blue filters to split the color of the film into three records. One piece of film carries each of the three colors: red, green and blue (RGB). By using filters again, the three pieces of film can be recombined to make a duplicate negative, or dupe. (Aubry, 2008.) YCM separation masters refer to the yellow-cyan-magenta separations on black-and-white film stock (Science and Technology Council, 2007, p. 6).

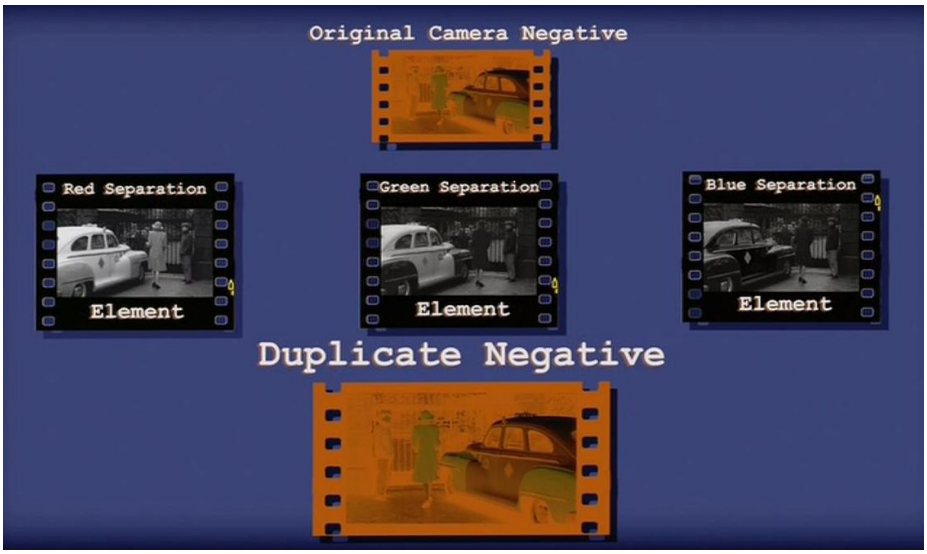

Figure 1. Black-and-white separation masters extracted from the original camera negative in order to create a duplicate negative (Aubry, 2008)[1].

Film stock comes in different widths, which are created for different markets. The width, generally called the gauge, is measured from edge to edge and expressed in millimeters. The most common film gauges at least in American collections are 35mm, 16mm and 8mm. 35mm remains the industry standard to this day. Smaller gauges are less expensive to use. With larger gauges, the film frame has a greater area and projects a sharper image. Film format is a broader term as it takes into account the following qualities: width, height and position of the image, and sprocket hole size and placement. (NFPF, 2004, p. 6.) Traditional 35mm film cameras and projectors pull down four-perf film. The term four-perf means that each frame has four perforations along the two side edges of the film. The perforations are all spaced apart the same distance. (McLendon, 1990.)

2.2 Restoration and its related terms

The term preservation is increasingly understood as the full continuum of activities necessary to protect the film and share the content with the public. Film preservation embraces the concepts of film handling, storage, duplication and access. It is an ongoing process. As standards and techniques improve, duplication must be repeated, because film needs continuing care to extend its useful life. (NFPF, 2004, p. 4.) According to restoration expert Robert Gitt, preservation refers to taking something from an unstable medium and putting it on to a more stable medium (Champlin & Gitt, 2001). According

[1] Permission from Kim Aubry, Larry McCallister and Francis Ford Coppola, granted April, 2010

to Enticknap (2004), the object of preservation is to treat and store the original element and, when duplication becomes necessary, copy the element as faithfully as possible.

According to The Film Preservation Guide, restoration attempts to reconstruct a specific version of a film. Ideally this involves comparing all known surviving source materials, piecing together footage from these disparate sources into the order suggested by exhibition history and productions records, and in some cases, enhancing image and sound to compensate for past damage. (NFPF, 2004, p. 4.) Film archivist Robert A. Harris emphasizes that the main attempt is to create a representation of the film as it originally looked (Aubry, 2008). Gitt agrees that the idea of film restoration is to put the movie back to way it originally was and to try to recreate the filmmaker's original intention. Restoration often requires pulling in bits and pieces of film elements from all over the world and putting them together. Restoration can also involve making the movie simply look and sound as good as it originally was. Removing the blemishes of age, such as pops and clicks on the soundtrack, is commendable because they are not supposed to be there. (Champlin & Gitt, 2001.)

According to Enticknap (2004), restoration is, ethically speaking, a more controversial subject. Reconstructive restoration attempts to assemble a completed film from a number of different source components in the exact form of which can be established to a reasonable degree of accuracy from things such as cutting continuities and other written documentation. Another method of restoration is to enhance the picture and sound of the source material, but it is ultimately a subjective judgment whether the end result can really be described as an enhancement. If certain characteristics, such as sharpness, contrast and color density are changed, the question of how it is decided what constitutes an enhancement and what makes it in any given sense better rises.

Cook and Wang claim that there are three modes of digital restoration practice. The first mode adheres to the absolute integrity of the original. This includes reproducing age-specific technological deficiencies. The second mode enhances the original film to conform to contemporary expectations and tastes. The third mode consists of working with the original filmmakers to reconstruct the film in ways that respect its artistic integrity, but allow the filmmakers to take advantage of contemporary technologies to improve their work (Cook & Wang, 2004.) Gitt uses the term modernization in situations where, for example, a black-and-white film is colorized or where mono sound is remixed into stereo. It is something film archivists do not do. For studio and commercial use, however, modernization, which aims to make the movie more suitable for modern tastes, is a commercially viable and acceptable thing to do. Gitt adds that some restorations border on modernization. (Champlin & Gitt, 2001.)

2.2.1 Example of a criticized restoration: *Vertigo* (USA, 1958)

Alfred Hitchcock's *Vertigo* was photographed in VistaVision. It was a horizontal, double framed 35mm film format. During its original release *Vertigo* was never projected in VistaVision, only in standard 35mm. In the mid-1990s, the movie's photochemical restoration was led by Harris and James C. Katz. The film was transferred to 70mm, due to VistaVision being an obsolete format and because it was almost a one-to-one transfer. (Auiler, 2000, p. 197.) Originally all three separate elements of sound (dialogue, music and effects) were mixed during postproduction into one mono channel. However, in the remastering process the components the restorers had available did not allow them to simply copy an existing print of the 1958 mix without suffering considerable degradation in sound quality. (Enticknap, 2004.) The restorers made a conscious decision to digitize the dialogue tracks. According to Katz,

when dialogue tracks are digitized, the foley effects are lost. Foley effects consist of gun shots, footsteps, bird cries and other sounds added by the filmmakers in postproduction. The decision was to re-Foley the movie. Katz and Harris acknowledged it would be a controversial decision. Katz adds that the alternative for the purists would be to hear the 1958 soundtrack with all the defects. The end result of the restoration was not a version that audiences had seen in its original release, but what Hitchcock had shot. According to Katz, the fiscal aspect and the responsibility that they have to the studio has to be acknowledged too. Compromises have to be made so that it will be more commercially successful. (Auiler, 2000, p. 197-198).

Enticknap (2004) criticizes the restoration of *Vertigo*. All of the key visual and aural properties apart from aspect ratio have been changed from the properties apparent in the 1958 artifacts. The list includes such things as sharpness, contrast, color balance, the number of sound changes, and their content. Harris and Katz's objective in restoring the film was to create a commercially viable product for 1996. They explain that after working two years to make sure the work is as true as possible to Hitchcock's intentions, the entertainment value of the movie is heightened with the new sound tracks. This, according to Enticknap, encapsulates the paradoxical nature of the restoration process. Harris and Katz acknowledge the amount of material changes they have effected and justify them on the grounds of commercial prerogatives. However, they also cite authorial authenticity as a criterion by which they decided what changes to make. The restoration of *Vertigo* is used as an example to show that the decisions involved in such a project on technical processes and materials have implications for the aesthetic and authorial properties of a film in the ways that they are analyzed and discussed by historians and critics. An understanding of these properties and their ability to change over time must be placed at the core of the film studies agenda.

2.2.2 Restoration as a marketing tool

In the late 1990s, Harris stated that many entities use the term restoration as a marketing tool. He adds that it not only damages the concept of film restoration worldwide, but it also damages and shortens the lives of the films that people are saying are being restored when, in fact, they are not. (Bouzereau, 2000.) Séverine Wemaere, the head of the Thomson Foundation for Film and TV Heritage, says that film restoration is not only technical, but also creative and ethical. Nowadays many works that are just materials that have been cleaned are called restorations. Wemaere claims that some works respect the filmmaker, but some take too many liberties. The goal is to not betray the filmmaker by doing a restoration he or she would have not wanted. (Argy, 2009.) The term "restored" is an important marketing tool in situations where the film, taken as a complete textual system, may have been radically altered from previous versions regarded by many as original (Enticknap, 2004).

2.2.3 From photochemical to digital film restoration

Digital technologies have been improving the motion picture post-production process since the early 1990s. Computer graphics and compositing, digital color correction, nonlinear editing and high definition film scanning and recording have all improved the creative control filmmakers have over the final look of material originally shot in 35mm film. Computer storage has grown in capacity and declined in price, so the ability to store all the uncompressed data of a theatrical motion picture while it is being creatively modified and manipulated has become increasingly feasible. This process, in which original film-acquired images are scanned into data and then artistically processed in what is literally an intermediate step before being output to film again, is called digital

intermediate (DI). It has become a powerful creative tool. (McKernan, 2005, p. 96.) In the November 2001 issue of American Cinematographer interviews were conducted with executives of seven Hollywood studios about their preservation and restoration practices. Digital technology did not figure prominently in the discussion. At the time, digital tools were being used sparingly in film restorations, for select shots whose problems had no photochemical solution. The DI did not even come up in the interviews. For example, in 2001, five of the productions covered in American Cinematographer involved DI work; in 2007, the number was 60. Digital intermediate has proven particularly useful for film restoration, because it requires minimal handling of the original film element. (Bosley, 2008.)

Photochemical restoration is based on special copying machines to improve the quality of safekeeping copies. Only a small amount of defects can be removed with this process, because the unit of manipulation is always the physical film strip. Photochemical film restoration equipment can handle a few defects, such as limited scratch, dust and dirt removal and global color-shift reduction. In digital film restoration, the process can be adapted for each frame and even for each pixel. The amount of defects that can be handled by digital image-processing techniques is larger compared to photochemical methods. (Haas, Pinz & Schallauer, 1999.) The DI can closely approximate the looks of long-gone film processes such as Technicolor. (Bosley, 2008). Technicolor was a color additive process that exposed three separate strands of black-and-white film in one enormous camera, and then printed the three strands on top of one another to produce a full color effect. *Gone with the Wind* (USA, 1939) and *The Wizard of Oz* (USA, 1939) are examples of films shot in Technicolor. (Dixon & Foster, 2008, p. 96.) The original film element only has to be used once as it is scanned digitally. Once it is scanned, the image can be manipulated freely while the film element is returned to the vault. (Turner Entertainment Co., 2005.) Michael Inchalik from Lowry Digital told American Cinematographer in 2009 that digital restoration cannot yet be considered a mature science, and that only half of it has been invented so far (Heuring, 2009a).

In the digital restoration of *The Red Shoes* (UK, 1948), the original goal was to do a new photochemical restoration using wet-gate contact printing from the original three-strip Technicolor camera negatives. The picture negative was covered with mold. All 48 reels were cleaned by hand and then ultrasonically. This took the worst mold off but left behind stains and little cracks and crevices in the emulsion. When the first test reel was seen, the team was relieved as all of the fungus damaged had been eliminated simply with the use of diffused light and wet-gate printing. However, as the film progressed, the team discovered that a lot of the material was severely out of register; there were extreme vertical-registration problems in quite a number of the shots. It was soon realized that the only way to do a photochemical restoration would be go to back to the laborious method of optical printing, which would build up contrast and add film generations. Restoration facility Cinetech was interested in using a combination of photochemical and digital techniques. Cinetech did tests using wet-printed master positives that came out very well, but because it is theoretically best to use the OCN, the team also did tests at Warner Bros. Motion Picture Imaging (MPI) using the original negatives. Both facilities did very good work, but when the image was blown up very large, it was evident that scanning the original negatives produced a result that sharper and less grainy. So the decision was made to work with the original negatives at MPI and use digital techniques exclusively to fix all the film's problems, including mold damage. (Birchard, 2009.)

2.3 Reasons for the poor state of old films

It has been estimated that nearly 70-80 per cent of all the films released up to the early 1930s, when sound film was introduced, have been lost. Film losses from later periods are considerable, but less dramatic. (Meyer & Read, 2000, p. 2.) Almost 90 per cent of all silent movies and half of all films produced before 1950 have been irreparably harmed (Kuiper & Sigmund, 2005). Even the original negatives of many films from recent decades have been lost, or are in bad condition (Meyer & Read, 2000, p. 2).

There are several reasons for the bad condition or total loss of films. The first reason is economic: films were neglected or destroyed when no longer considered profitable. The second reason is practical: people would throw films away so they could make use of the storage space. The third reason is aesthetic: old films were considered 'primitive' as the language of film became more "sophisticated". When sound films became popular, silent films were destroyed, and inflammable nitrate films were destroyed when nitrate film stock became prohibited. (Meyer & Read, 2000, p. 2.)

Human intervention and negligence excluded, films also destroy themselves. Until the early 1950s, films were shot on a nitrate cellulose base. That type of film is notoriously chemically unstable. Acetate cellulose or safety film stock was considered sufficient to preserve the films for the centuries to come. However, it is a well-known fact today that safety film is almost as unstable as nitrate. Acetate film decomposition, which is labeled as vinegar syndrome because of the typical vinegar smell, cannot be stopped. This means a film from 1990 may need a thorough restoration, just as much as a film from 1910. (Meyer & Read, 2000, p. 2.) In the earlier stages of vinegar syndrome the main problem is the deformation of the support which causes a variable local blurring effect (Chambah, 2008). Polyester is considered to be the most stable and resistant film base. Compared to cellulose triacetate film polyester film has many advantages and its expected life span is much longer. Today it is used for some release prints, some archival films and Super 8 films. However, it has to be noted that the life expectancy of the emulsion that holds the photographic image could be much shorter than the base. (Meyer & Read, 2000, p. 249-250.)

One aspect of classic films is that the more popular and better the films are, the worse condition the original film and sound elements generally are. For example, when Universal Studios bought five of Alfred Hitchcock's films from the Alfred Hitchcock Foundation in 1984, Katz and Harris discovered that all five films were in poor condition and that they would have been lost if nothing had been done to preserve them. Two of these five films were *Rear Window* (USA, 1954) and *Vertigo*. According to Harris, the original camera negative of *Rear Window* was used to create a total of 389 prints. (Bouzereau, 2000.) When an original negative is constantly running and coming into contact with printing stock, and the sprockets in the negative going into sprocket holes, it simply wears out (Aubry, 2008).

Another example would be the digital restoration of Akira Kurosawa's film *Rashomon* (Japan, 1950). When the Academy of Motion Picture Arts and Sciences (AMPAS) Film Archive began to plan the restoration in the fall of 2007, they were expecting to get a long list of archives that had 35mm elements of the film in their collections, because the film was very popular and influential and continues to be taught at film schools. However, the result was that only 16mm elements and dupes of dupes of dupes were found. This goes to show that even widely acknowledged classics are very close to being lost for good. (Bosley, 2008.) When a restoration is started, it is necessary to first do a lot of research. Film elements are brought from all over the world to a place where

their picture and sound quality can be evaluated. In the end, it is decided whether the film can be restored or not. There are a lot of films that cannot be restored. (Engle, 1997.)

2.3.1 Different versions of one title

David Lean's epic *Lawrence of Arabia*, which was shot on 65mm film, had its premiere in December 1962. The film's length was 222 minutes. After the premiere Lean was forced to shorten the film by 12 minutes because distributors were beginning to make 35mm prints. Soon after that, the film's producer, Sam Spiegel, cut another eight minutes out of the film. Lean had not approved of those edits. (Morris & Raskin, 1992, p. 203.) After a long photochemical restoration in the late 1980s, the film was finally restored to its director's cut length (Morris & Raskin, 1992, p. 207-208).

Another example of a title, which has more than one version, is *Mr. Hulot's Holiday* (*Les Vacances de Monsieur Hulot*, France, 1953), directed by Jacques Tati. The film was originally shot in 1951 and 1952. In 1962, the director re-edited parts of the film and reworked the score and the sound mix. In 1977, as the movie began to attract a new following, Tati shot additional footage and incorporated it into the movie. When it came time to restore the film, the first question was which version should be treated as the definitive one. Because all the changes to the movie had been made by the director himself, it was decided that the third and final version should be the basis of the restoration. (Argy, 2009.)

The third example is Fritz Lang's *M*, which originally premiered in Berlin, Germany, in 1931. The running time of the longest known print is 110 minutes. An early sound film, *M* produced a difficulty in selling the movie in foreign countries. Silent films could easily replace inter-titles with ones in the new language, but with the coming of sound film distributors had to come up with new ways to bridge linguistic barriers. For example, the French version of the movie is mostly just dubbed into French, but some scenes were actually completely reshot in French. When the movie was re-released in the early 1950s, a number of changes were made to the film. For example, an all-new opening credits sequence was created, the running time was cut to 99 minutes, and a number of foley effects were added to the often-silent sound track. In the early 1960s, a script of the film was published as a book. The book showed that the prints that were in circulation at the time were incomplete and edited against Fritz Lang's intentions. Later, a reference print was created based on various archives. The print, while in poor audiovisual quality, showed the original continuity and served as the guide for later restorations. (Criterion Collection, 2004.)

2.4 Starting the *Godfather* restoration project

Paramount Pictures' *The Godfather* (USA, 1972), is widely regarded as an American classic and a landmark achievement in cinematography. Like many other films of its era, it was not properly preserved. Paramount, like most Hollywood studios, did not create a preservation program until the success of home video in the 1980s proved that film libraries could have indefinite and profitable lives. However, before the 1980s original negatives were typically used as printing negatives, so successful films took a lot of abuse. *The Godfather* was no exception. The film was not only popular, it was also Hollywood's first blockbuster. (Argy, 2008b.) Francis Ford Coppola, the director of all three *Godfather* films, mentions that the success of *The Godfather* was such that it led to making many more prints that anyone had expected (Aubry, 2008).

When Paramount purchased film studio DreamWorks, Coppola sent a congratulatory letter to filmmaker Steven Spielberg in which he asked if Spielberg could do something for the poor condition of the negatives on the first two *Godfather* films and perhaps the third one as well. Spielberg then called the head of Paramount, Brad Grey, and told him about the letter Coppola had sent and asked if Grey could write a cheque to restore the first two *Godfathers*. According to Spielberg, Grey immediately said yes. (Aubry, 2008.)

The Film Preserve, which is best known for restorations of titles such as *Vertigo* and *Lawrence of Arabia*, began work on *The Godfather* with Warner Bros. Motion Picture MPI in the fall of 2006. The film's surviving elements, such as the original camera negative, separation masters and thousands of feet of miscellaneous elements, were delivered to Pro-Tek Preservation services, where an inspection confirmed that a lot of work was required. The original negative, which was held with tape, was filthy and full of scratches, rips and tears, some of which broke into the image area. Parts of the image had even been torn away in some sections. One reel had at some point been removed and replaced with a dupe. Some scenes were missing from the final separation masters, because they had been made before the final cut was done. It was determined that a photochemical restoration would be out of the question. According to Harris, the original negative of *The Godfather* should never be run through a pin-registered mechanism, because it could crack up. One year was spent digitally restoring the first two films. After that, the team turned to the much more recent *Part III* (USA, 1990), which required no restoration at all; a DI was made to create the director's cut, which had previously existed only on home video. (Argy, 2008b.)

2.5 Preparing the film elements for digitization

Getting all the information from film into the data world is a challenge. The greatest concern in scanning the film elements is that nobody would like to eventually have to contact the client and inform how several feet of the original negative was destroyed in the digital scanning process. To avoid such a thing happening, all the physical, architectural crevices of the film elements are inspected, and all the splices are looked at to make sure the film holds together. Once it has been determined that the physical structure of the film could go through some kind of machine, the film is digitally scanned. (Aubry, 2008.) When a term called telecine is mentioned, it refers to a machine, which transforms film images into a video signal (Lukicic & Grgic, 2005).

2.5.1 Digitization of film elements

The digitization of film elements is carried out by a device called a film scanner, which is the first hardware used in the digital restoration process where the information of every single frame of cinematographic film is translated into digits. In digital restoration, the earliest film element, possibly the original camera negative, should be digitized. An important aspect of the digitization process is resolution. Resolution refers to the capacity of a means of reproduction to describe detail, which can be specified by measuring the amount of smallest distinguishable elements in the image. In photography and film these elements are grain, whereas in digital imagery they are pixels. The more there are pixels or grain in the image, the higher the resolution will be. (Fossati, 2009, p. 75-79.) Harris adds that in the case of film, resolution is not necessarily sharpness of elements within the frame. When a film is shot, the director of photography can have certain things in the foreground of background, and the focus can be sharp or soft. (Aubry, 2008).

An image can be scanned and mathematically encoded into any number of lines both horizontally and vertically. This is known as spatial resolution. Because a film frame is wider than it is tall, there are typically more lines of resolution horizontally than vertically. This means that more information is found in a scan line from side to side than one from top to bottom. Each line in a frame consists of individual pixels, and each pixel contains one red, one green and one blue component. Depending on the encoded values for that pixel, the components will dictate what color the pixel will be along with the characteristics of the specific display device. (Bankston, 2005.)

When resolution is mentioned as K, it refers to the number of individual pixels that are across a 35mm frame. One K is 1,024 pixels. 4K is 4,096. This means that in a 4K image across a frame of film there are 4,096 individual pixels or dots that make up one line of an image. A 4K image has 3,112 lines so the overall resolution is 4,096 x 3,112. Figure 2 presents a comparison between the resolution of a standard definition broadcast TV (640 x 480) and a 4K film scan. 4K has over 40 times the resolving power. (Aubry, 2008.) The exact resolution of a 2K image is 2,048 x 1,556 (Fossati, 2009, p. 285).

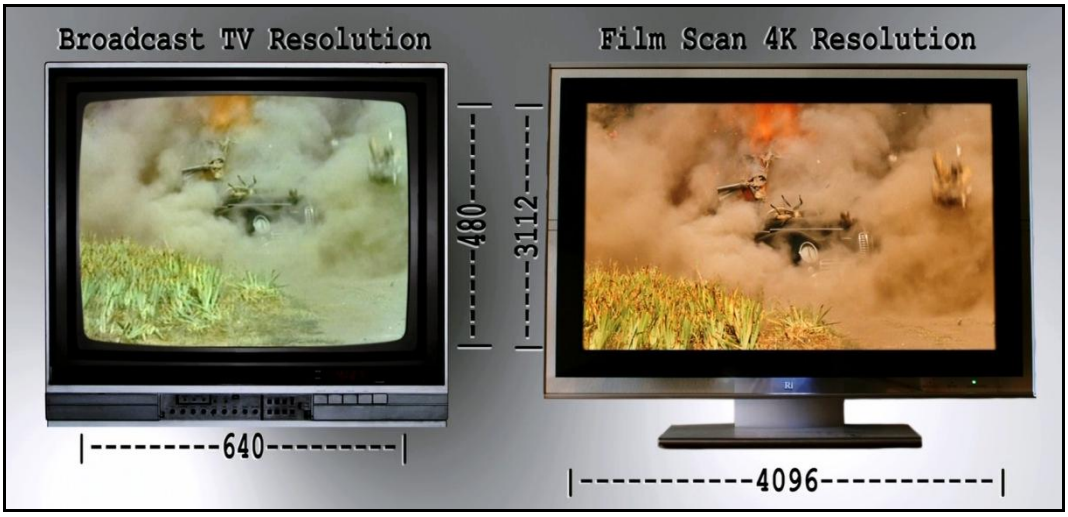

Figure 2. Comparison between TV broadcast resolution and 4K (Aubry, 2008)[2].

In addition to resolution, two other factors that determine the quality of a scan are bit depth, also referred to as color depth, and dynamic range. Bit depth refers to capacity of a pixel to describe gray and color tones. A bit is the smallest unit of data in a computer and consists of a single binary value, either 0 or 1. A pixel that is able to depict only black and white has a bit depth equal to 1, whereas a pixel capable to describe gray tones (256 tones) has a bit depth of 8. To be able to describe tones for independent colors (red, green and blue), the bit depth is typically 24, which corresponds to 16,777,216 tones. However, when compared to photography or graphic design, the 24-bit depth is referred to as 8-bit depth in cinema. The term dynamic range describes the range of tonal difference between the lightest light and the darkest dark of the image, and it depends on factors such as bit depth and the overall performance of the scanner used for the digitization. (Fossati, 2009, p. 79-80.)

Depending on the scanning resolution, each frame of a color film contains up to 45 megabytes of information. Given a film speed of 24 frames per second, an hour-long film consists of 86,400 frames, or 3.9 terabytes of information. (Saito, Komatsu, Hoshi

[2] Permission from Kim Aubry, Larry McCallister and Francis Ford Coppola, granted April, 2010

& Ohuchi, 1999.) A 4K, 16-bit scan of one frame of film takes about 50 megabytes of storage. 16-bit means that there are 65,536 colors available to each pixel. For example, when the scanning speed is six frames per second, 300 megabytes of information is stored every second. (Turner Entertainment Co., 2005.) Fossati (2009, p. 80) says there are scanners capable to scan 24 frames per second, but with heavily damaged films it is necessary to feed the scanner frame by frame. According to Argy (2008b), 4K data files of a 100-minute film will take about eight terabytes of storage.

Sony Pictures Entertainment's first full-4K restoration was carried out in 2006, on *Dr. Strangelove or: How I Learned to Stop Worrying and Love the Bomb* (UK, 1964). According to Sony's Grover Crisp, every studio will eventually have to do 4K in order to create the best-quality material for Blu-ray and the best-quality material to lock away in the vault. 6K scan tests were done for a restoration of *A Star is Born* (USA, 1954). Ned Price from Warner Bros. noted that while he couldn't quantify how much more information he is seeing in a 6K scan as opposed to a 4K scan, the more information can be captured, the more the picture residing within the emulsion can be manipulated later on. (Bosley, 2008.)

2.5.2 Workflow resolution

Even if the film elements are scanned at 4K, it does not necessarily mean that the entire restoration process will have a 4K workflow. For example, the restoration of *Rashomon* had a 4K-2K-4K workflow. This means that the elements were scanned at 4K, the image processing was done at 2K, and the work was recorded out at 4K. The image processing was done at 2K because 4K would have almost doubled the time and budget. If the team had had the OCN, an all-4K workflow might have been worth it. A slightly different example is the restoration of *Leave Her to Heaven* (USA, 1945), which had a 2K-2K-2K workflow. The film would have been scanned at 4K if the restoration team had had the original three-strip negatives. 2K/4K comparison tests are done on a constant basis, and the difference is rarely significant when the team is not working from a good original element. (Bosley, 2008.) When films are reproduced by optical duplication mechanisms, the operation can result in deterioration in resolution even when conducted with special care (Chambah, 2008). According to Harris, no one knows for sure what the resolution of film is, but he estimates it is somewhere between 4K and 5K for four-perf 35mm film. (Aubry, 2008.) According to Fossati (2009, p. 78), all films do not have the same grain resolution to begin with and that pixel resolution lower than 4K might be enough for the larger part of archival film. In most cases they are not original negatives, but just two or more original generations down the line, as the negatives have been lost. This is why it can be estimated that most archival films have a resolution lower than 4K.

2.5.3 Digitization of the *Godfather* films

The scanning process of the *Godfather* films was successful. The film elements were scanned with a Spirit 4K scanner at Warner Bros. Motion Picture Imaging facility, which is one of the few places in the world that can provide a full-4K image from start to finish. Considering the condition of the first *Godfather* film, the Spirit 4K scanner was a suitable choice because it is gentle on the film, and the team did not want to risk the film by putting it in any kind of jeopardy. (Aubry, 2008.) The restoration project had a 4K-4K-4K workflow. According to Harris, it was necessary to work in true 4K resolution, and anything that the studio might have tried to do with digital technology before that would have been a waste of time. (Argy, 2008b.)

2.6 Digital image clean-up and repair

Some scanners are equipped with a wet gate. This means that the film is scanned while immersed in a fluid. With this technique it is possible to remove the most superficial scratches already during the scanning process. (Fossati, 2009, p. 220). Once the film elements have been digitally scanned into the file system, digital artists and engineers will go through the scanned film frames one by one, and fix them to the best of their ability. (Aubry, 2008). DPX, which stands for Digital Picture Exchange, is an uncompressed file format typically used for digitized film frames (Fossati, 2009, p. 288). In high resolution, any of the little imperfections that are in the picture become much more apparent to the human eye. That is why it is really important to focus on fixing the defects. (Albarian, 2003.) Fossati (2009, p. 82-83) explains that most software for digital restoration allows the operator to set a number of parameters for each different tool, which generally range from conservative to aggressive. Conservative means that fewer problems are solved in a single rendering session. The manufacturer's default settings can be used as well. Although digital restoration allows more manipulation than photochemical restoration, the aim remains to restore the original look of the film. If the operator doing the clean-up and repair work has no expertise in restoration, he or she could easily make the film look like a new one. Another concern is that too little human supervision can create digital artifacts, which are new image elements erroneously created by the software, or existing elements erroneously removed.

2.6.1 Defects overview

Dust and dirt are the most common defects in historical films. They usually appear as dark or bright spots in the picture. Dust and dirt are usually caused by improper storage environments or pollution during the duplication process. One important characteristic of all these defects is that the pollution is local on the film material. This means that they occur in only one frame of the image sequence. (Haas, Pinz & Schallauer, 1999.) Dirt can stick on films. This means as soon as a film is copied without correctly removing all the dirt is copied to the new film-substrate (Kuiper & Sigmund, 2005).

Scratches appear in the direction of the film strip over more than one frame of the film. They are generally caused by film transport or by the developing process, when there are particles in the developer's machine. (Haas, Pinz & Schallauer, 1999.) Kim and Kim (2009) claim that film line scratches are visible as vertical lines of bright or dark intensity. A scratch is defined by three different characteristics: it has a lower or higher brightness than the neighboring pixels, it usually appears as a vertically long thin line, and it has a temporal continuity, which means it appears in successive frames. According to Kuiper and Sigmund (2005), vertical line scratches are a common problem in archived film.

Mold, mildew and fungus are caused by humid storage environment. Generally these biological agents start the attack from the outside edge and make their way into the film roll. Mold, mildew and fungus can cause significant damage to the emulsion. The growth initially appears in the form of matte-white spots before growing into a lacy, web-like pattern. (NFPF, 2004, p. 13-14.)

Image vibrations originate in the limited mechanical accuracy of film-transporting systems in movie cameras or duplication equipment. It can also originate in the unstable camera attachment during filming. Image vibrations are superimposed on regular camera motions like tilt, pan, zoom, or rotation. (Haas, Pinz & Schallauer, 1999.)

According to Chambah (2008), image vibrations or jitter is caused by repeated loading, unloading, winding and rewinding of the film strips. This damages the film holes that are supposed to guarantee a stable repeated positioning of the images during projection.

Flicker is visible color variation or global brightness from one frame to the next. The term global means that the variation is homogenous inside a frame. (Haas, Pinz & Schallauer, 1999). Zhang, Wu, Ding and Hao (2009) define flicker as unnatural fluctuations in perceived image intensity that do not originate from the original scene. Flicker is typical for old black-and-white film where it is caused by irregular exposure time of early movie cameras. In modern cameras, flicker can be caused by interferences between the exposure and the lighting during filming. (Haas, Pinz & Schallauer, 1999.) According to Ohuchi, Seto, Komatsu and Saito (2000), factors such as unstable chemical processing, copying, aging of film and imprecise telecine conversion cause image flickers. Van Roosmalen, Lagendijk and Biemond (1999) add dust and aliasing to the list of causes.

Shrinkage is a major symptom of acetate decay. It also affects nitrate film and can be aggravated by overly dry storage environments. If the relative humidity falls below 15 per cent for extended periods, the film loses moisture, contracts and may become brittle. (NFPF, 2004, p. 14.) When separation masters need to be recombined, they usually don't align properly at first due to warping and shrinkage. They tend to shrink more at the edges than they do in the middle, because the edges are where they lose their moisture. (Heuring, 2009a.)

2.6.2 Manual damage repair

The most common way to digitally repair a damaged frame of film is to capture information from earlier or later in the image sequence and fill it in by matting out the area that moves, and extracting the area that doesn't move, and simply replace it (Aubry, 2008). Fossati (2009, p. 84-85) argues that badly damaged frames require manual repair instead of automated processes. The operator can use a paint tool to manually paint over the bigger damage using cloned pixels, which can be cloned from adjacent areas or painted through the neighboring frames. A quicker but less precise way to manually repair severe damage is by interpolating frames, generally the one preceding and the one following the damaged frame. Fossati suggests that an area of region should be defined rather than having the software interpolate the entire frame. This would not only cost more processing time but would also replace pixels where there is no damage. In the case of film line scratches, the damage is often in the same location throughout a length of a film. This makes it difficult for the software to detect the scratch as there is almost no relative difference between adjacent frames. As the neighboring frames are partly damaged too, pixels that are next to the scratch have to be cloned to cover up the missing information.

Figure 3 (see attachment B on page 68 for a larger size version), which is from the 2003 digital restoration of *The Who: The Kids Are Alright* (UK, 1979), showcases the manual process of damage repair. What the software does it basically looks one frame ahead and one frame behind, interpolates the information and puts the information from those two frames on to the area that is window boxed. The small window box can be seen in the upper left corner of the left frame in Figure 3 where the added black arrow is pointing at. By making these small window boxes on the area of the defect in the damaged frame, the operator can remove the scratch seen in the left frame. The middle frame in Figure 3 showcases the process as part of the scratch has been removed. Fixing the damage took a long time, especially when it got to the area where the person is in

the image sequence. There was also some dirt, a bounce, and the film shifted. The frame count was five or six frames and it took four to five hours to clean and repair the section. However, it has to be noted that this is by 2003 standards, so it raises the question whether today's tools could fix this sequence faster. Ultimately, nearly 100 hours were spent in the overall restoration of the film to fix sections like the one illustrated in Figure 3. Thousands more hours would have been required to clean every single frame of the film. This would have made the restoration far too cost prohibitive. (Albarian, 2003.)

Figure 3. Manual damage repair in the restoration of *The Who: The Kids Are Alright* (Albarian, 2003)[3].

Usually the larger defects are removed first. Once they have been removed, the smaller defects tend to look bigger, so it creates a snowball effect. (Aubry, 2008.) The processing time is the most time consuming part of the process. This depends on the following variables: the resolution of the scanned frames, the available processing power and the amount of tools applied at one time. For a single frame, the processing time can take up to several minutes. (Fossati, 2009, p. 82.) In the 2005 restoration of *The Wizard of Oz*, the dirt cleaning took 250-300 hours, or one and a half months. The first ten minutes alone took almost 91 hours. According to Ned Price from Warner Brothers, it is a very tedious job. (Turner Entertainment Co., 2005.)

2.6.3 Automatic detection and removal of one-frame defects

A significant characteristic for defects such as dust and dirt is that the pollution is local on the film material. This means that they only occur in one frame of the image sequence. That is why they can be labeled as one-frame defects. These defects can be detected automatically by observing the brightness along motion paths. Object characters like brightness or color are rather constant from frame to frame. However, when a motion path intersects a one-frame defect, the object characteristics change significantly. This property is the basis for the automatic detection of one-frame defects. The detection plan is based on a three-frame algorithm that uses two neighbors of the center frame, for which the one-frame defects are detected. The necessary information is then copied from the neighbor frames and painted into the area in the center frame that has the defects. (Haas, Pinz & Schallauer, 1999.) As Fossati (2009, p. 83-86) explains, a software tool called dust removal can be very effective for addressing spatial defects such as scratches, small chemical damage, dust and dirt. Before the tool is utilized, the software needs to perform several pre-calculations, shot detection and motion analyses. The software begins the process by marking the first and last frame of every different shot. Once that is done, the movement of all objects within the same shot can be analyzed and tracked. The software detects both moving objects as well as camera

[3] Permission from John Albarian, granted March, 2010

movements. This process is necessary in order to detect and remove all and only those elements extraneous to the image.

However, when methods of computer vision are used for the recognition of image defects, the main problem is to find algorithms which are able to separate image structures into two distinct classes: image defects and image features (Rosenthaler & Gschwind, 2001). In 2008, Michael Pogorzelski from the Academy Film Archive told American Cinematographer that current algorithms still have difficulties distinguishing some pictorial elements from defects. For example, the film *Rashomon* has a lot of scenes featuring rain, or smoke, or trees and bushes blowing in the breeze. These picture elements can confuse the algorithms that are designed to detect one-frame defects. When the software sees a raindrop in one frame and doesn't see it in the neighbor frames, it may interpret it as dirt. This means that the only solution is to clean those frames manually. (Bosley, 2008.)

Whereas Fossati (2009, p. 84-85) argued in the previous section that badly damaged frames require manual repair instead of automated processes, Heuring (2009b) on the other hand suggests that automated damage repair becomes particularly useful when the film is very flawed. The restoration of the 1920 film *Manhatta* is an example of a situation where the film was damaged to an extent where it became difficult for artists to repair it manually without leaving a digital artifact. A human being can create the necessary pixels to make a seamless repair over the course of five frames, but when the frame count reaches 100, for example, and other problems, such as flicker, warping and inconsistent luminance appear, the work gets extremely difficult. In situations like this, automation has to be used because the software will repair defects in precisely the same way, frame after frame, without leaving a digital artifact. This allows the artist to go in and find usable image areas from which to borrow to repair the damage. Over 900 hours were spent restoring the 12-minute *Manhatta*'s 11,223 frames, and this includes both the automated and the manual work.

Automated dirt and scratch removal software was used in the 2005 restoration of *The Wizard of Oz*. As it was previously mentioned, the film was shot in Technicolor. The software detects defects by examining all three records of film. If the software detects an element in one of the records, which does not appear in the two other records, it classifies it as a defect and removes it. The software worked well in the beginning, but it also removed things from the frames that should not be removed. For example, the software mistook the main character's sparkly red shoes as red film dirt, because they have bright pinpoint instances of color in them that flash on and off. This is why it is important to bring the process back to the supervision of a professional with a skilled eye. (Turner Entertainment Co., 2005.)

2.6.4 Missing frames

Haas, Pinz and Schalleur (1999) claim that heavily disturbed frames or missing frames are caused by long storage time or improper storage environment of the film elements. According to Chambah (2008), when a film strip is severely mistreated or repeatedly manipulated carelessly, entire frames or even whole parts of the scene can be lost. Fossati (2009, p. 87) declares that there is no automated software tool to address the issue of missing frames. Only special software for computer-generated imagery (CGI) and compositing can be used to reconstruct the missing information. When frames are lost, a compositing tool is needed to create lost image elements. However, this kind of intervention should be carefully considered first as the line between restoration and forgery is hard to draw. In any case, it should be properly documented.

2.6.5 Film grain

Film contains tiny crystals of silver halide salt. These crystals are the light sensitive component. When the film is developed, the crystals are turned into tiny threads of metallic silver. In a black-and-white negative the image is made up entirely of these microscopic filaments. They curl up and clump together, which is commonly called grain. (Kuiper & Sigmund, 2005.) Film grain is unavoidable in analog film due to the physical process (Byung, Shaw-min & Kuo, 2009). Bailer, Fürntratt, Mörzinger, Schallauer and Thalinger (2007) label film grain as an inherent artifact of analog film stock, which has a significant impact on the effectiveness of digital film processing. Film grain characteristics depend on the film stock, the non-linear relation between film exposure and density, the film lighting conditions, and on the non-linear operations possibly applied within the digitization process. According to Byung et al. (2009), when high resolution movie contents obtained by scanning the analog film are digitized and compressed, such randomly distributed film grain noise is a major burden to typical video coding methods.

Three restoration examples of the use of grain reduction tools are referenced here. The first example is the restoration of *The Robe* (USA, 1953) where grain reduction tools were used only slightly in order to maintain the original look of the film. The image of *The Robe* would not resemble at all what it originally looked like if the majority of the grain had been taken out. A test was made in which a non-manipulated scan of the film was compared to a scan where the grain was reduced to the limit. The differences were very noticeable; the grain-free image resembled edgy high definition video instead of film. (Heuring, 2009a.) The second example is the restoration of *Lola Montés* (France, West Germany & Luxembourg, 1955) in which there was only one scene in which some work was done on the film grain. The scene looked washed out because the film elements were in poor condition. Overall, the goal of the restoration of *Lola Montés* was to preserve the film grain that was already part of the picture. (Argy, 2008a.) The third example is the the restoration of *The Red Shoes*, grain reduction was done only for some of the optical effects. The reason for doing so was that the film grain structure would change and become very obvious. Baselight's degraining tool was used here and there, but the main goal of the restoration was to keep the look of the original film as much as possible. (Birchard, 2009.)

In one of his articles for The Digital Bits[4] website, Harris (2008) wrote about the overuse of DNR in the remastering process for home video release. By DNR Harris not only refers to Digital Noise Reduction, but to any way of taking the image originally captured on film and modifying it for home video release. This includes all digital means of changing, maneuvering, cleaning and de-graining the image. Harris says he is aware that grain reduction of a certain amount is sometimes needed for acceptable compression in standard-definition DVDs, where grain can be digitally manipulated to produce a more coherent image, especially when a quality master is made from numerous elements that might be old or damaged. However, the situation is different on Blu-ray. Initially one of the major selling points for Blu-ray was a higher capacity disc; more data can be encoded to a disc, compression rates can be lowered, and the bitrate can be much higher. As examples of well-produced Blu-ray releases of catalog titles Harris mentions titles such as *Bullitt* (USA, 1968), *The Professionals* (USA, 1966), *Reds* (USA, 1981) and more problematic productions like *The Adventures of Baron*

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[4] http://www.thedigitalbits.com

Munchausen (UK & West Germany, 1988) and *Bram Stoker's Dracula* (USA, 1992), which have a courser grain structure and a slightly softer image. Harris writes about critics, reviewers and bloggers who might have a preference toward a clean, glossy image where the look of the picture resembles that of high definition nature channels and high definition sports. It is this preference that has had an effect on studio executives to have the film grain taken out of the picture.

The main example Harris (2008) uses in his article is the 2008 Blu-ray release of *Patton* (USA, 1970). Photographed on 65mm 5-perf, the film has approximately 40 per cent grain structure of that of a normal 35mm 4-perf production, and it should not be manipulated for the home video release on Blu-ray. Harris states that the image looked good on a 30-inch high definition monitor, but the situation was different when viewed on a larger screen. Waxy faces, missing background detail and high frequency information made the image looked more like a video game instead of film. Harris suggests that studio executives and reviewers need to be educated about grain and as to what film and video can and should look like.

2.6.6 The handling of production nuances

According to Fossati (2009, p. 223), problems or defects that have always been in the film should not be removed in digital restoration but where the line is drawn is subjective. For example, if the negative got scratched in the camera while shooting, film restorers would be divided between those who would have the scratch removed and those who would not. A scratch like that was never intended to be there, but it has become part of the film's history, and the audiences saw it in prints, as photochemical tools were not capable of removing it. Today's digital tools can easily remove a scratch like that. A compromise would be to digitally remove the scratch from the restoration but preserving the film element with the scratch and documenting its existence. Sony's Grover Crisp says that people, especially broadcasters, are less willing to accept damage on the image even when they were used to it in a photochemical restoration.

In the restoration of *The Robe*, the film restorers were determined to leave in as many nuances of the original production as possible. This included such things as distortion at the edges of the frame created by the prototype CinemaScope lenses and visible matte lines throughout the film. The film ends with a big process shot, which is not up to today's standards, but it was left as is because it speaks to the technology of the time. (Heuring, 2009a.)

In the restoration of *Mr. Hulot's Holiday*, a large part of the existing opticals and effects presented the question of which to restore and which to leave untouched. For example, there was a sequence created using a split-screen composite where a horse kicks a car rumble seat and traps a man inside. In the existing footage, the two sides of the composite shift noticeably against one another. Deciding whether to fix something like that is problematic, but in this case, they decided to fix it. (Argy, 2009.)

Fossati (2009, p. 219-223) reports that in the restoration of *Dr. Strangelove*, the wires holding the miniature planes were not removed because they are to be considered the state of the art special effects at the time the film was made. Removing the wires digitally would mean improving the film by means of modern technology. For most restorers, this kind of digital intervention would not be ethically acceptable as it would modify the film's original aesthetic appearance and means of production. Fossati also argues that there have been restorations where the removal of wires has been justified as something the director himself would have done if he had the chance. Even Crisp, who

led the restoration, has been criticized for not removing the wires from *Dr. Strangelove*. The film elements used for the restoration were a 35mm fine grain positive, a 35mm duplicate negative and a 35mm print. Since the 1980s, Stanley Kubrick had several dupes made from two surviving fine grain positives from 1964 in an attempt to trying to get a perfect print made. Fossati does not specify which of the elements used for the restoration showed the wires.

2.6.7 Picture clean-up and repair on the *Godfather* films

As it was mentioned in section 2.4, the OCN of the first *Godfather* film was in poor condition. It was estimated that the first film would require 4-5 times more work than its sequels. The method used to digitally clean and repair the images resembles the method as described in section 2.6.2. Figure 4 illustrates two comparison sets of the software in use. The picture in the upper left corner shows the dirty, unprocessed frame, and the right side shows as it is being cleaned by painting over with information from neighboring frames. The lower left picture shows an example of a smaller damage, a white speck, which the software can identify quickly. The right side shows the area after the clean-up process. (Aubry, 2008.)

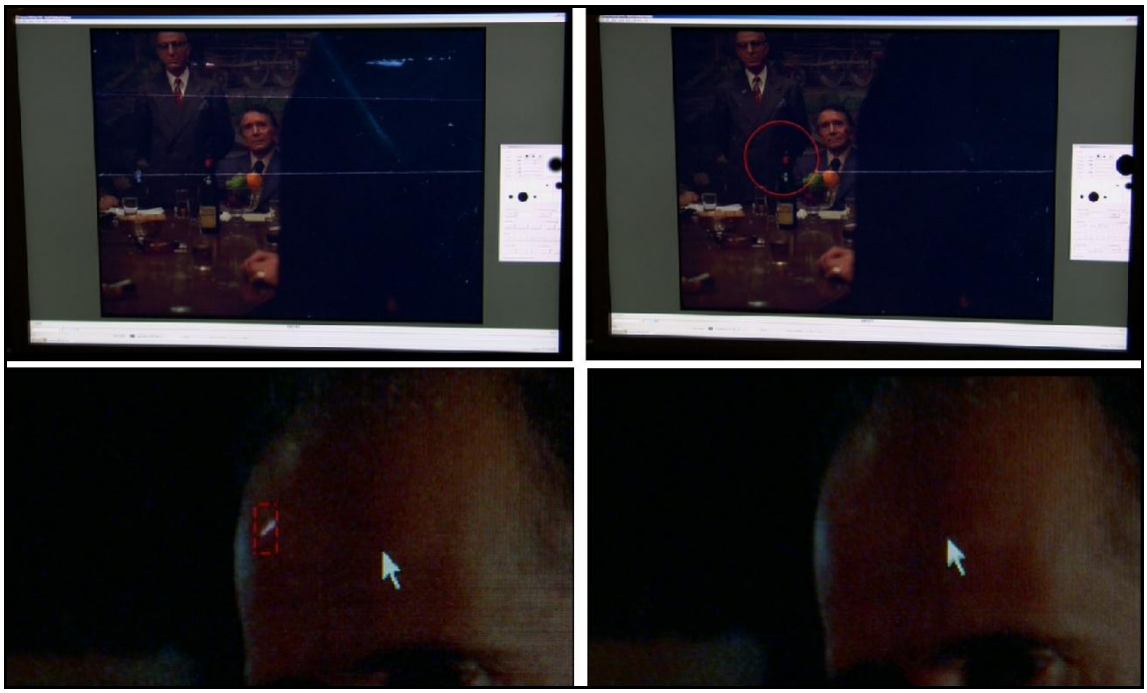

Figure 4. Clean-up work on *The Godfather* films (Aubry, 2008)[5].

The cleaning, repairing and color-correction was mostly done on a Baselight system, but there was also a team doing cleanup work with MTI's Digital Restoration System. According to Harris, bits and pieces of different film elements were scanned in order to capture the highest quality image. One element would be sharp but wouldn't have the correct color and vice versa. This meant that the occasional use of sharpening and noise reduction tools was necessary to even out differences between the various film elements that were scanned. The project raised ethical questions concerning the handling of production nuances. A question concerned a photographic problem that happened during production: if it could not be fixed then but can be fixed now, should it be fixed.

[5] Permission from Kim Aubry, Larry McCallister and Francis Ford Coppola, granted April, 2010

According to Gordon Willis, the director of photography on all three films, the answer is yes, as long as it doesn't have an impact on the overall restoration. (Argy, 2008b.)

2.7 Digital color restoration

Color fading happens to all types and brands of color motion picture over time. While varying in stability, the process is inevitable. The main culprits in color fading are heat and high relative humidity. The three different dye layers lose their original color at different rates. Depending on the film stock, either yellow or cyan is often the first to go. Color balance changes as the dyes break down. Contrast is lost, and the film begins to take in a pinkish brown cast. Eventually the film tends to have a washed-out monochromatic look. Negatives and prints can experience fading at different rates. (NFPF, 2004, p. 15-16.) In the case of black-and-white films, the fine-distributed silver particles oxidize and hence discolor (Rosenthaler & Gschwind, 2001). Strong saturation of the black and of the white areas with a severe loss of middle tones is a common problem seen in old black-and-white films (Chambah, 2008). Since the 1950s, monopack color film became the standard on which the majority of cinematographic works were recorded. A few decades later, it was discovered that this process was chemically unstable which caused the fading of whole film stocks with time. When a bleached color release print is the only available record of a film, photochemical restoration of faded prints is not possible due to the irreversibility of the bleaching phenomenon. In this instance, digital color restoration is incontestable. (Chambah, Rizzi, Gatta, Besserer & Marini, 2003.)

Traditional motion picture color timing or grading is a laborious photochemical procedure. Digital color-timing is far more efficient in terms of speed and exactitude. Modern day digital tools provide a wealth of new creative abilities, such as the ability to isolate specific areas of an image and change its brightness or color while leaving surrounding areas unaffected. (McKernan, 2005.) The most important and well-known color filters are brightness-contrast modification, color balance, hue-saturation correction, gamma-expose, color levels adjustment, and curves which are histogram transformations specified manually or by special pre-defined functions. (Czúni, Császár, Hanis, Kovács, Licsár & Szirányi, 2004). Telecine colorist Janet Wilson says the first step for her in the digital color grading process is going through the film in its entirety and giving it basic settings and look. The next step is adjusting contrast and brightness. At this point the image is generally too saturated compared to what it was originally. The saturation is then lowered until the right color is found. (Turner Entertainment Co., 2005).

The biggest challenge in a color restoration is usually the lack of reference for restoring the original colors because in most cases all the original elements of a film have suffered the same type of color deterioration. Because of this film restorers often need to make a well-educated guess what colors are to be restored. (Fossati, 2009, p. 90-91.) The word color manipulation has to be sometimes used so that the look that the client had in mind can be achieved. There are artistic liberties and the original vision, which should not be ruined. For example, Marlon Brando's eyes in *The Godfather* can be painted green, brown or orange, but just because it can be done doesn't necessarily mean it should be done. A director uses a lot of time to make a film, so the ability to go back to the roots and change the look of the movie entirely is nerve-wracking. (Aubry, 2008.) According Harris, it is necessary to have a cinematographer involved in the process (Argy, 2008b).

Figure 5 presents an image from a European, video based source material transferred to 35mm film for theatrical projection. On the left side, a mix of oversaturated yellow and green flare can be seen near and on top of the white shirt collar. Once it is determined what the overall color of the shot should be, one of the things the restoration team was able to do was isolate the colors and implement color changes to the problem area. The right side of Figure 4 presents the same section of the corrected frame. This kind of manipulation was done on a shot-by-shot basis in scenes that were from video based source materials. (Albarian, 2003.)

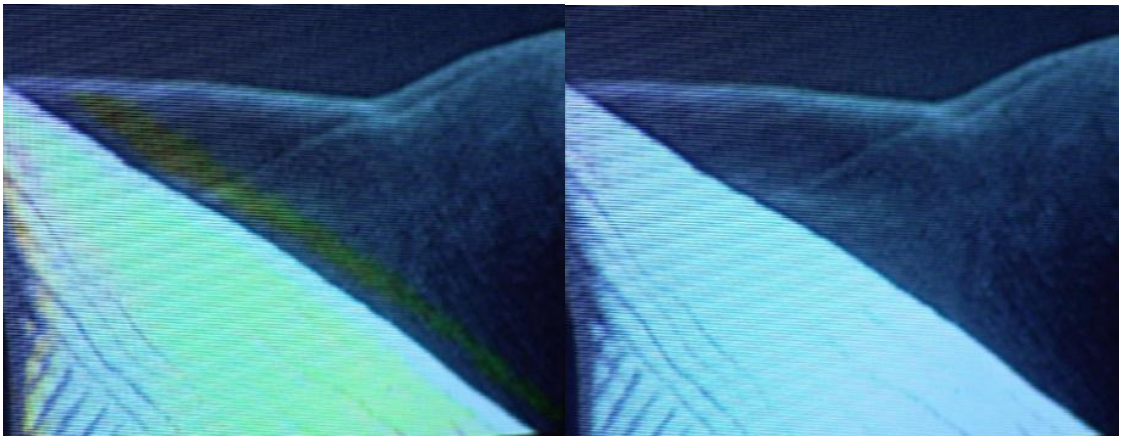

Figure 5. Before and after comparison of removing a yellow flare (Albarian, 2003)[6].

Automatic Color Equalization (ACE) is a color equalization algorithm, based on a perceptual approach. ACE is unsupervised and needs little involvement from the user. To restore the vividness of the colors, the saturation of the real colors of the image is enhanced before using ACE. A non-uniform saturation enhancement technique is used to avoid increasing the color cast. Once the colors of the image have been restored, the next step consists of removing the color cast, balancing the colors and correcting the contrast of the picture using ACE. The algorithm's inner parameters have to be properly tuned and new functions have to be added to meet the requirements of the naturalness of the image. The study claims that while the algorithm provides good results, the biggest drawback is its slowness. There is no information whether this algorithm has been used in any restoration project. (Chambah et al., 2003.)

2.7.1 Color-timing the *Godfather* films

In the restoration of the *Godfather* films, the biggest challenge in terms of the cinematographer's work was figuring out what black is in the films. Since Gordon Willis, who shot all three films, wasn't able to actively participate in the project, cinematographer Allen Daviau gave his advice several times. (Argy, 2008b.)

[6] Permission from John Albarian, granted March, 2010

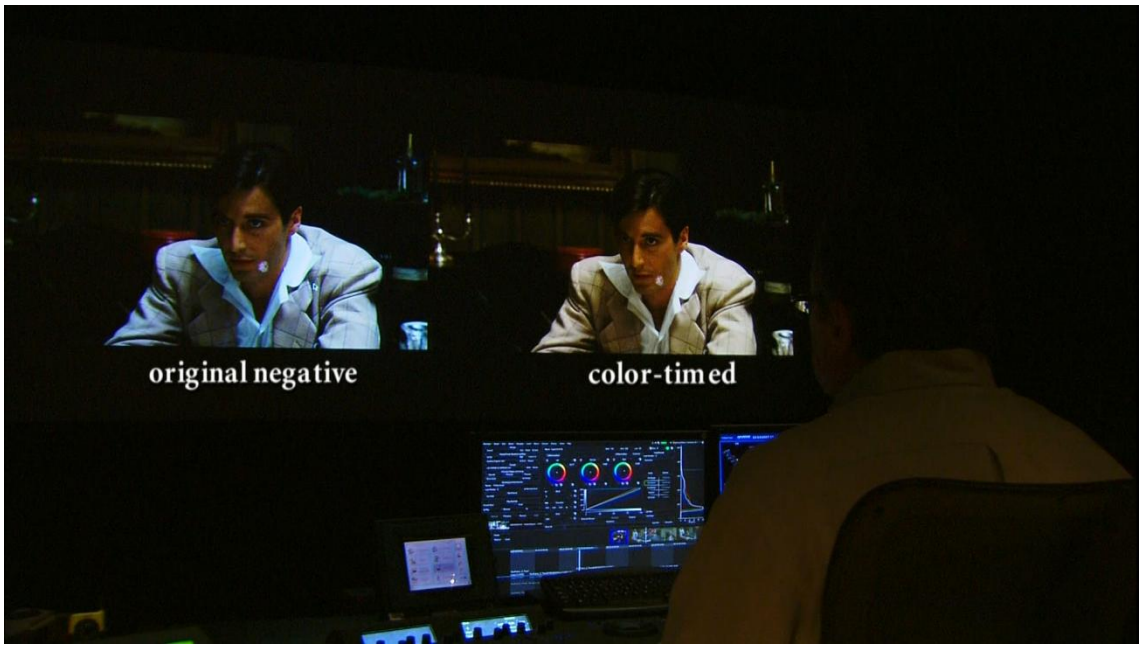

Figure 6. Color-timing *The Godfather: Part II* (Aubry, 2008)[7].

Figure 6 shows the difference between the original negative and the digitally color-timed version. Harris states that the films were shot in normal color with fully exposed negatives, and the look was achieved in the laboratory with precise color-timing. The correct color for all three films consists of four points yellow and one point red. (Aubry, 2008.)

2.8 Digital sound restoration

A large share of the films made since the 1930s use an optical soundtrack to record the sound. The Academy of Motion Picture Arts and Sciences introduced the standard Academy Optical Mono track where the optical track is located in a space of 3mm between the images and the perforations. This allows the duplication of a film to automatically copy its soundtrack. The optical soundtrack undergoes the same type of degradations as the image of the film, such as dust and scratches. As the track is close to the film edge and perforations, it is sometimes degraded by abrasion or impaired over a large surface due to moisture. (Brun, Hassaine, Besserer & Decenciere, 2007.) As sound tracks deteriorate, the original recording suffers in quality, thus resulting in such defects as hums, hiss, clicks and pops heard during the screening of older sound films. In digital sound restoration, the sound is transferred to a digital file, where the defects can be corrected at a digital audio workstation. (NFPF, 2004.)

Digital signal processing (DSP) is a technique for implementing operations such as signal filtering and spectrum analysis in digital form. One of the many advantages of digital processing over analog is flexibility and repeatability. The flexibility comes from the fact that system parameters are simply numbers stored in the processor. For example, it is a trivial matter to change the cut-off frequency of a digital filter whereas a lumped element analog filter would require a different set of passive components. DSP enables very complex linear and non-linear processes to be implemented, which would not be possible with analog processing. (Godsill & Rayner, 1998.) Once the restoration

[7] Permission from Kim Aubry, Larry McCallister and Francis Ford Coppola, granted April, 2010

is done, the sound is then output to film, often directly from the computer hard drive to soundtrack elements. The digital data is archived for future use. (NFPF, 2004.)

2.8.1 Wow and flutter artifacts

Wow refers to irregular cyclical motion, which creates variations in the pitch of a soundtrack. Flutter is attributable to similar deviations in the transport at a higher rate of occurrence. Regardless of the quality of the equipment, all analog recordings suffer from wow and flutter. (Heiber & Howarth, 2005.) The various irregularities can originate from various mechanisms, depending on medium types, production techniques, random damages of a signal's conveyor and other factors. The resulting parasitic FM distortions can range from periodic to accidental, having different instantaneous values. (Czywewski & Maziewski, 2007.) Godsill and Raynel (1998) state that wow and flutter results in a disturbing modulation of all frequency components.

According to Heiber and Howarth (2005), there are also other types of flutter such as scrape flutter and sprocket-cogging. Scrape flutter occurs as the film or audiotape is pulled across the recording head, creating a micro-stiction noise modulation. This higher frequency flutter can also cause a very fine mechanical vibration in the tape path that can also impact the purity of the audio signal. Sprocket-cogging is a function of the sprocket drive of 35mm film, and while it is at a fairly low signal level, it creates an intermodulation distortion component that also affects the purity of the sound, and creates listener fatigue. Mechanical instabilities caused by the bearings, capstan, rollers and reel motors create an ever-shifting pattern of beat frequencies that intermodulate with the audio, resulting in artifacts from bass cancellation, to lower midrange mud, up through grainy sidetones in the midrange, and on up into the clouding of the high frequency with interstitial haze and transient blurring.

One solution to correct wow and flutter artifacts is a technology called Clarity Audio Restoration by Plangeant Processes, which is a combination of proprietary DSP and hardware for the playback of 35mm magnetic sound film and audiotape. Clarity utilizes a novel method of re-timing the audio signal. To re-time the audio signal, the Clarity transfer equipment recovers signals in the ultrasonic region that can be found on film or tape along with the audio of the original recording. By ascribing to these ultrasonic components the properties of a moving clock, and mathematically re-timing these signals, the DSP now knows the speed fluctuations of the original machine occurring at the moment it made the recording. When the error signal is inverted and the corresponding audio conformed to it, Clarity's DSP re-times the audio to a fixed and stable time base, thus resulting in perfectly pitched audio with no wow or flutter. In addition to correcting gross errors, the process also makes a significant contribution to the overall audio quality by improving the transparency, depth and intelligibility of the overall soundtrack. (Heiber & Howarth, 2005.)

2.9 Archiving the DI

Allen Daviau states that once it is decided that the DI is done, the movie is recorded back to film (Aubry, 2008). The digital master, which is created in the DI process, is recorded to stable yellow-cyan-magenta (YCM) separation masters on black-and-white film with an expected 100-year or longer life. Since the late 1960s, and in some cases longer than that, Hollywood film studios and other content owners have stored all motion picture film records, including elements like the original camera negative and final release prints. This method of saving everything was possible due to the low cost

of storage and long-term life of film and its supporting photochemical technology. (Science and Technology Council, 2007, p. 1-2.) In the restoration of *The Robe*, which had a 4K-2K-4K workflow, the studio preserved a mix of analog and digital elements. In addition to 4K-resolution 35mm film elements, both the color-corrected data files and the original, unprocessed 4K scans were archived. (Argy, 2009a.)

According to Cavena, Wood, Bonwick, Steele and Selway (2007), movies are currently archived on film. In its century-plus long history, the movie industry has tried over 100 different formats, standards and media types, but finally standardizing on a 35mm film format. The goal of the standardization of 35mm film is such that any properly archived theatrical movie photographed on 35mm film can be retrieved from that archive and played in any theater projecting feature films. However, the lifecycle of filmed entertainment has changed. Cavena et al. say that both capture and exhibition are becoming digital, and post-production, libraries and repurpose are already digital. This raises some major questions. One of them concerns whether it is possible in 2107 to retrieve a movie from a film-based archive placed there in 2007, and project in any theater in the world. Projectors and scanners can be rebuilt because they are only electromechanical devices, but it might not be the desired future of the highly valuable motion picture industry.

Digital data practices generate much larger amounts of materials, and currently very little of it is preserved. The annual cost of preserving film archival master material is $1,059 per title. This calculation is based on a monthly cost of 40 cents per 1,000 foot film reel in preservation conditions and the amortized cost of film archive element manufacture. The annual cost of preserving a 4K digital master is $12,514, making an 11-fold difference. The calculation is based on a yearly cost of $500 per terabyte of fully managed storage of three copies of an 8.3 terabyte 4K digital master. (Science and Technology Council, 2007, p. 1-2.) The calculations made by Cavena et al. (2007) claim that the total cost to archive a movie for 100 years using current film-based practices and costs is approximately $130,000. If the movie is repurposed only once during the 100 years, re-scanning all the three YCM separations would cost $65,000, and if any restoration work is required, that is an additional cost. The cost of archiving a 100 terabyte digital archive object in a 2000-movie archive would be approximately $73,000 per archived movie per century. This is based on a single-studio contribution of 20 movies per year added over the century. The cost of repurposing that digital archive object is approximately $2,000.

Grover Crisp stated in 2008 that there are no standards for archiving digital media and that Sony Pictures takes a conservative approach to preserving data. MGM's Scott Grossman asks the question whether it is worth spending six figures to create preservation elements that might not be the desired preservation elements five years from now, especially considering that there already are 8K and 16K scanners available. Due to the quickly developing digital technology, Grossman says any preservation decision has been uncertain in the early 21st century. (Bosley, 2008.)

2.9.1 After the DI of the *Godfather* trilogy

The finished DI work on all three *Godfather* movies can be transferred to any format that is needed in the future (Aubry, 2008). It was estimated that the data files for the entire trilogy required 160 terabytes of storage space. The finished work was recorded out to 35mm film. The restored versions of the first two movies were screened for selected audiences in Los Angeles, the first via 2K digital projection and the second via 35mm print. The whole trilogy was released on home video in September, 2008.

According to Willis, *The Godfather* is a very good-looking movie now due to the restoration that was done, including repairing all the damage done to the negative and also because nothing was added to the film that wasn't there before. An essential issue was to keep the restoration process as disciplined as possible because of the unusual look of the film. Willis states that because the film has already been made, the goal of the project was to restore, not to remake. (Argy, 2008b.) Cinematographer John Toll wrote a letter to American Cinematographer magazine, in which he used the restoration of the *Godfather* movies as a great example of how digital technology and existing film technology can work together to ensure that the work of the cinematographer is preserved and even enhanced (Toll, 2008).

This chapter has provided the framework for this thesis. 48 references were used to showcase the previous research in this subject matter. Some of the information presented in this chapter will be referenced in chapter four. For example, most of the film element related terms were explained in section 2.1, and some of them will be mentioned in the fourth chapter. The same goes for section 2.6.1, which gave an overview of image defects; the solutions on how to fix some of them will be given in the fourth chapter. The next chapter talks about the research method used to construct the study for this thesis.

3. Research Method

This chapter discusses qualitative research, which is the research method chosen for this study. According to Batista (2003), quantitative and qualitative are the two main currents in scientific research. Whereas quantitative research methods are characterized by using procedures such as statistical procedures to test hypotheses that are formulated on a set of measureable variables from a sample which is chosen randomly, qualitative research's data primarily emerges from fieldwork, observation, interviews, questionnaires, documents, texts and the investigator's own ideas and reactions. Despite all the qualities of quantitative research methods, the scientific community is nowadays increasingly interested in qualitative research methods. Thompson and Walker (1998) define qualitative research as an examination of events or experiences in context from the perspective of the individuals experiencing the phenomena.

3.1 Qualitative interview as a data gathering tool

The data for this study was gathered by performing qualitative interviews. Myers and Newman (2006) feel the method is the most common and one of the most important data gathering tools in qualitative research. While it is an excellent means of gathering data, it also has several difficulties, problems and pitfalls. One of these is the artificiality of the interview where the researcher is interrogating someone who is a complete stranger is required to give or to create opinions under time pressure. Lack of trust is another problem. Because the interviewer is a complete stranger, the interviewee may choose not to divulge information that he or she considers to be sensitive. This might result in the data gathering being incomplete if the information is potentially crucial for the research. Another reason for the data gathering being incomplete is the lack of time for the interview. It can also lead to an opposite problem, where the interviewee is creating opinions under time pressure, thus leading to the gathered data not being entirely reliable.

The interviews conducted for this study were either structured or semi-structured. Myers and Newman (2006) divide qualitative interview methods into three categories: structured, unstructured or semi-structured, and group interviews. A structured interview doesn't leave room for improvisation. Instead there is a complete script that is prepared beforehand. An unstructured or semi-structured interview has an incomplete script. Some interview questions may be prepared beforehand, but there is room for improvisation. A group interview can be structured or interviewed in which two or more people are interviewed at once by one or more interviewers. As the interview subjects were experts in the fields related to this study, Flick (2009) introduces the term expert interview. People who are particularly competent as authorities on a certain matter of facts can be labeled as experts. The target groups in expert interviews are generally staff members of an organization with a specific function and a specific professional experience and knowledge.

The majority of the interviews conducted for this study were done by email. Selwyn and Robson (1998) argue that the speed and immediacy of using email as a research tool is its principal feature. The need for proximity between the interviewer and interviewee is not an issue. It also reduces the problem of interviewer effect, whether resulting from visual and non-verbal cues or status differences between interviewee and interviewer.

Another benefit is that this type of interview method requires no additional transcription, as the data that is eventually analyzed is exactly what the interviewee wrote. However, email's lack of verbal interaction is an obvious limitation to its use as an interviewing tool.

3.2 The research conducted for this study

The inspiration for choosing qualitative research for this study started at a web message board in the spring of 2010. A topic was posted to a forum related to Blu-ray Disc media asking for tips and references. The second person to reply to that topic was a well-known film historian and preservationist who gave advice and mentioned that if any additional information was needed, he could be contacted privately. A short time later a private message was sent by another film restoration expert who offered his assistance. A list of questions was sent, and they were answered in a matter of days, so it can be said that the first interview for this study was done in April, 2010.

Since May of 2010 interview requests by email have been sent to several experts and facilities. Some of the references used in chapter 2 were constructed from interviews with film restoration experts. Some of those people were searched on the Internet through business networking sites, for example. One of the interviewees was reached through Facebook. In addition to this, several restoration facilities were contacted through their websites. In August, 2010, membership at the Association of Moving Image Archivists (AMIA) was acquired. Twice a year AMIA releases a Membership Directory list, which consists of a list of people who are associated with film archiving. The list includes each person's name, facility and contact information. Interview requests were sent to several people.

The general approach that was taken when contacting people and facilities was to first quickly introduce what the study was about and where it was being made and by whom. Then a question was presented that would the person or facility who was being contacted be interested in answering questions related to digital film restoration and remastering. If a positive response to the interview request came back, interview questions were then sent to that interviewee. Because the interviews were, with the exception of one, conducted via email, the questions were quite specific, thus making the interviews structured.

Each time an interview was completed, the responses were added to a single Microsoft Word document. Once all the interviews were gathered to one file, the responses were then analyzed. After this, more documents were created. First picture restoration and sound restoration were divided into their own documents. Then these were divided into smaller categories. For example, the topic of digital noise reduction tools was a common question in the interviews, so a document was created where all the responses concerning the use of those tools were compiled together. This kind of categorizing helped the process of constructing the content for the next chapter.

4. The Study & Results

The study for this thesis was mainly done by conducting structured email interviews with various professionals in such fields as film preservation, restoration and archiving, digital scanning, digital intermediate, sound preservation, restoration and mastering. The first interview took place in April, 2010 and the last one in July, 2011. The questions represented to the interviewees were generally quite specific and the emphasis for each person tended to be in the profession they are working in. For example, sound restoration experts were naturally asked questions related to sound restoration, not picture restoration. The questions ranged from technical to ethical to general. In some instances, a question was asked by referencing what someone else had claimed before. The information presented in this study is done by referencing what the experts answered in the interviews.

The structure of this chapter, just like the literature review chapter, follows a chronological structure. First all the informants are briefly introduced. Reasons are given what kind of films generally go through a thorough digital restoration process. Scan resolution factors are discussed more thoroughly in section 4.3, and a technology that can remove surface defects in the scanning process is presented in 4.4. 4.5 and its subsidiary sections provide discussion about the handling of various picture issues. This includes the correction of various defects and also issues which have caused debate in digital restoration and remastering. Sections 4.6 all the way through 4.6.7 are about sound restoration and remastering. This begins with research and evaluation before moving into playback and digitization. After digitization, the handling of various sound issues is discussed. Section 4.7 describes the process of recording the finished work back to film, and the study ends with discussion about the ongoing debate between digital and film archiving.

4.1 The informants

Typically in a scientific thesis, the identities of the interviewees are not revealed. However, none of the interviewees objected to having their names shown, but some requested validation to make sure that none of their responses were used incorrectly or out of context. A total of 13 people were interviewed for this study. With the exception of one, all of the interviews were done by email. The quantity of questions per interviewee ranged from three to over 15. The response time varied greatly: the quickest answers were received in less than 30 minutes after the questions had been sent. The longest time between sending the interview questions and receiving the answers was nearly six months. The total amount of material from the email interviews was over 50 pages.

A quick introduction to the people who participated in this study is in place. Richard Antley, who is the Director of Digital Intermediate Systems (DIS) for Arri Inc., the US subsidiary of Arnold & Richter Cinetechnik GmBH, shared a great deal of knowledge about picture restoration tools. This means the majority of the information written about the various image processing tools was provided by Antley. Tom Burton, the Vice President of Digital Services at Technicolor Digital Intermediates, has worked on restorations of such titles as *Lola Montés* and *The Red Shoes*. Jeff Cava from Paramount Pictures provided detailed information on the restoration and remastering of the

soundtracks on *The Godfather* films. Dave Cavena was the senior Systems Engineer at Sun Microsystems dealing with Digital Cinema issues when his referenced paper titled Archiving Movies in a Digital World was written and published. Cavena lent his expertise on digital scanning and archiving. Section 4.4 is based on the interviews conducted with Cavena. Currently he is the Vice President of Sales and Marketing at Image Trends, Inc. It is important to note that there is no relation to a company called Cavena, which specializes in manufacturing subtitling systems.

Michael Friend is a media archivist and currently works as a technical specialist at Sony Pictures Asset Management, though his responses provided for this study are entirely personal and completely independent of Sony. Theo Gluck has served as the Director of Library Restoration and Preservation at Walt Disney Studios since 2004 and has worked on the preservation of many of the classic animated Disney features such as *Dumbo* (USA, 1941), *Bambi* (USA, 1942), *Cinderella* (USA, 1950), and *Pinocchio* (USA, 1940). Film archivist Robert A. Harris from The Film Preserve has worked on restorations of *Spartacus* (USA, 1950), *Rear Window*, *My Fair Lady* (USA, 1964), among many others. Martin Koerber is the Curator at Deutsche Kinemathek and has worked on projects such as the most recent restoration of *Metropolis* (Germany, 1927). John Polito is the owner and chief engineer of Audio Mechanics, and has worked on sound restoration projects of titles the likes of *Alien* (USA & UK, 1979), *The African Queen* (UK, 1951) and *The Robe*. Tom Regal is the Director of Audio Restoration and Preservation at NBC Universal. Jack Theakston is the Vice President of the 3-D Film Preservation Foundation, and some of the restorations he has been involved with include *The Phantom of the Opera* (USA, 1925), *Dragonfly Squadron* (USA, 1954) and *Wings of the Hawk* (USA, 1953). At the time of the interview, James White was the Head of Technical Delivery at British Film Institution (BFI).

The most substantial interview took place in Helsinki, Finland, in July, 2010, where an interview was conducted with Bob Heiber, the Vice President of Audio at Chace Audio by Deluxe. The company is well-known in the field of sound preservation, restoration, as well as 5.1 and 7.1 mixing. For example, out of the American Film Institute's (AFI) 100 Greatest Movies list, Chace has worked on 92 of them. Heiber has personally supervised several restorations, including such titles as *Lawrence of Arabia*, *The Bridge on the River Kwai* (UK & USA, 1957), *Close Encounters of the Third Kind* (USA, 1977) and *The Wizard of Oz*. The interview with Heiber was semi-constructed in which the interview questions were sent well beforehand, but other areas of sound restoration were also talked about. This provided a vast amount of relevant information for the study, which most likely wouldn't have otherwise been addressed. The transcript from the interview took approximately 36 pages to write. Overall, a major portion of the information presented between sections 4.6 and 4.6.5 is referenced from the interview with Heiber.

4.2 Which films to restore digitally

According to Theakston, it is usually the films that are most successful or important that need restoration the most. Digital film restoration still has a glass ceiling of production versus profit. The titles that generally get the digital treatment are usually top-shelf titles that will make the money back put into them. This is convenient, because it is the most popular titles that have the most wear. A major studio might preserve an unknown title simply because it is an asset. Currently many of the major film studios' titles have been preserved to safety stocks, so the preservation stage is finished. The upside is that the more unknown a film is, the less restoration work it usually needs, because the film was not revisited in printing that much. The film elements of unknown titles are generally in

good enough condition that photochemical restorations will suffice. Both photochemical and digital restorations have their strong and weak points. Digital restoration is more thorough in clean-up and easy to use. It is possible to restore things with a greater amount ease than in the photochemical realm. Photochemical restoration is largely downplayed, because it is thought of as an old process, but there is a wide selection of things that can be done even in that realm. It is also generally less expensive than digital restoration, and for purists, the process stays in the format of which the film was created.

Theakston added that even with digital restoration, little has changed so far as protocol is concerned. It is a common misconception that digital has revolutionized film restoration, when it actually has not. Digital restoration is merely a new tool that many are learning to or have learned to use. There is still room for both photochemical and digital restoration. It's impossible to evaluate how many restorations are photochemical and how many are digital. Most film archives still do photochemical restorations because it is cost-effective. However, due to the availability of scanning and restoration facilities outside the United States, digital restoration has come down in price and more companies are using it as an effective tool. Doing things with digital methods these days may be more cost-effective, because the most efficient way of making money back on any given project is in the digital realm, such as digital downloads, television, DVD and Blu-ray. These forms of digital media have enforced forced film restoration to be extremely vigilant and thorough. The public has become quality conscious and the bar has been set high as to what is acceptable.

At Technicolor, a detailed graphic schedule is always created when a restoration project is started. The graphic schedule indicates tasks and associated timelines. If there is an unusual or special circumstance or procedure to be accounted for, a workflow chart is also created.

4.3 Scan resolution factors

Cavena told about a study he was involved with in the late 1990s where the goal was to establish the real resolution of film although there is no actual comparison. With gathered information on color and published charts on Modulation Transfer Function (MTF) curves for a specific film stock in the varying uses (negative, interpositive, internegative, distribution), the calculations were run to establish the line-pairs visible in multiple generations. The company that contracted the study wanted to know if 4K resolution really was necessary to provide the movie-goer with an experience similar to film. Assuming there was no optical resolution loss in multiple prints (no distortion from printing, a perfectly clean lens), the best that could be delivered from a fourth-generation print was slightly under 2K. This was the result when the focus was only on the resolution, i.e. the lens, glass, screen and light issues were ignored. Cavena added that 35mm film, at best, contains only 4K of information, and even though some are marketing 8K capability, there simply is not that much information on the film.

Harris said that the major factor in deciding on the scanning resolution is to oversample by enough that the full resolution of the film element is captured. Gluck explained that some might argue that a 4K scan of 75-year-old nitrate negatives is overkill, but they know they are getting all the information that is on the film. However, he would never advocate a 6K or 8K scan for the animated feature *Steamboat Willie* (USA, 1928), for example, because the inherent resolution on that negative is admittedly low. Out of all the titles at Disney, the only elements that have been scanned at 6K resolution so far include the VistaVision and 65mm interpositives (IPs) on *Tron* (USA, 1982), the

Eastman Kodak (EK) negative on *The Little Mermaid* (USA, 1989), and the left-eye and right-eye 65mm IPs for the *Muppet*vision 3-D* (USA, 1991) attraction.

Burton added that budget and schedule have to be considered, as well as destination and output requirements of the restoration, i.e. film projection or home video. Cavena stated that if the film is only for TV, DVD or Blu-ray or other digital downloads and will not be repurposed higher than HD (1920 x 1080 resolution), then 2K is arguably enough. 2K is acceptable also if the film is old and faded enough that 4K of information is no longer on the film. At Image Trends, the preference is 4K to create archive masters and anything that may be repurposed theatrically, but ultimately it is the client who makes the decision. Burton said that there is generally debate about the issue of determining the right scanning resolution for various film elements and formats. He suggested that 2K can generally capture all the information that 16mm and 8mm film have to offer, and larger formats, such as 65mm, can benefit from 8K resolution. At Technicolor, titles shot on the 8-perf 35mm VistaVision format are most often scanned in 6K (4K x 6K).

According to Harris, all film restoration should begin with 4K or 6K. However, if the OCN does not exist anymore and one is working from a dupe, then 2K is sufficient enough, but having performed numerous tests at different facilities in regard to 2K vs. 4K scans, 4K clearly provided better results. Also, the film's aspect ratio makes no difference, because the film is scanned perforation to perforation, not vertically.

It was referenced in section 2.5.2 that *Rashomon* had a 4K-2K-4K workflow. According to Antley, the process of dropping to a lower resolution after scanning is done by downsampling. It depends on the workflow, but usually this is done in the scanner where 4K media is actually not saved to disk, even though the film was scanned at 4K. Downsampling should not lead to artifacting, other than the detail that is lost by definition. Harris noted that once the data has been down-converted, it cannot be fully brought back to the original resolution. A major point for film archivists is to consider whether the post-production facility can be trusted or not. For example, the 6K-4K-2K words are used so openly and sometimes without meaning that even new film productions, that think they were going to end up with a true 4K image, did not. They were told that the OCN would be scanned at 4K, and that the printing negatives would be recorded at 4K, but that was not the case.

4.4 Removing surface defects in the scanning process

The wet gate process, which was referenced in section 2.6, allows for the removal of the most superficial scratches already during the scanning process. However, another technology called Digital ICE, developed by Image Trends, Inc., can identify and remove surface defects from 16 and 35mm film as a post-processing operation following the scanning of the film element in the scanner, the scan being in RGB and infrared (IR). The location and magnitude of surface dirt and light scratches are determined through the RGB and IR scans. The defect record of the particular defect is then removed from the digital image and the underlying image is restored. The technology only operates on defects seen by the IR channel. Non-defect areas are not seen so ICE has no ability to do anything about them. This ensures that there are no false positives or any un-intended removal.

The technology has its limitations. ICE does not correct defects on traditional silver-halide black-and-white film, but it does work on processed C41 black-and-white film. All the silver-halide crystals in black-and-white film are opaqued in IR; they look like defect. ICE can remove the defects, but the entire image is removed in the process. The

technology works best on Ektachrome film, but is less effective on Kodachrome and poorly bleached color film. ICE also works better on an original camera negative than a positive, simply because a surface defect on an OCN becomes a baked-in defect when printed. ICE does not currently correct scratches which penetrate through either the base or emulsion side of the film, and it doesn't correct holes in the film.

Digital ICE has been tested and in some cases titles have been done at most of the major film studios. The company continues to broaden their marketplace. However, in the commercial photography world ICE is pretty much a standard nowadays. It has been on nearly all professional film scanners since the late 1990s, beginning with the Nikon Coolscan scanner in the mid-1990s.

4.5 The handling of various picture issues

According to Friend, the shift from the use of 32-inch Cathrode Ray Tube (CRT) displays to 60-inch LCDs and 4K projection has radically changed how the digital files are viewed. The arrival of large flat panel displays has made artifacts visible that were caused by the use of various digital software tools on the basic data. In recent years, the development and deployment of better scanning technology, i.e. scanning in 4K instead of 2K or HD, has forced restoration facilities to confront hitherto unseen problems in the underlying film material that were not visible in the lower resolution scans of an earlier period. This has raised new classes of problems to be addressed by the restoration software.

Friend explained that all of the active vendors of hardware, software and services attempt to continually improve and upgrade their products and that these products are generic and their development is incremental. Theakston stated that the latest generation software can, for example, completely reconstruct areas of lost information that fit no specific geometric pattern, such as mottling from water or mold damage. This would have been unthinkable in the year 2000. According to White, the correction of various defects depends on the extent of the damage, and how challenging it is to fix. The important thing is to maintain consistency and not draw attention to the fix, as any improvement of this kind should be invisible.

Koerber noted that because digital tools are powerful, there can be tendency to make things look nicer than what they originally were, so it requires a lot of vigor and discipline to avoid that. According to Theakston, there is a threshold of overdoing things with automated processes so they should be used sparingly, and that's what some facilities need to understand before using automation as a tool. Gluck stated that automation can be good as it saves time, which can save money. However, one should be careful not to have an overzealous Digital Restoration System (DRS) remove highlights by thinking that it is dust. Friend confirmed that automated picture restoration tools still have trouble differentiating some picture elements from damage. These include elements like raindrops, smoke, sparks, and trees and bushes blowing in the breeze. Automatic Color Equalization (ACE) was referenced in section 2.7. When asked of automated color grading processes, Harris' reply was that he only uses manual processes. In the following subsections, some of the processes to fix certain picture issues are explained, and there is also discussion on which should be left alone.

4.5.1 Tight registration of separation masters

As it was written in section 2.7.1, separation masters do not usually align properly first due to warping and shrinkage. It is a common problem on older separation masters that

were produced optically. The problem can also appear, though usually to a lesser degree, on newer separation masters that were digitally recorded. Color fringing can also occur, and these warped or shrunken elements cannot be effectively recombined physically. Facilities such as Technicolor have created proprietary software that allows these elements to be scanned and digitally processed to re-shape them to a correct fit, resulting in a properly registered combined image where none was possible previously.

There are several ways to approach this problem. The most advanced methods will consider magnification (size) differences between the color planes, image rotation and X/Y alignment. This can be accomplished by using a non-image reference like the corners and sides of the gate mask in the images. Sometimes it is done by looking for sharp, high contrast edges in at least three spatially disparate points in each color plane, then rotating, scaling and positioning them on each other in the composite RGB (red, green, blue) image.

4.5.2 Image instability

The origin of image vibrations was described in section 2.7.1. According to Harris, though, the more accurate term is actually image instability. Most of the restoration software packages have a tool to address this issue. The tools generally work either by using a non-image structure in the scans, such as the edges and corners of the gate mask, or sometimes the perforations if they are visible in the scan. Another way is to do motion vector estimation in the actual image content, and then smoothing out the noise in that profile by repositioning the frames. However, it is important to realize that in order to do stabilization, some of the image must be lost. The more there is instability, the more of the image must be sacrificed. This is why an archival scanning gate is made, which allows the capture of an oversized area. The area ranges from the bottom of the previous frame to the top of the next one and well into the perforations on both sides.

4.5.3 Color breathing

According to Harris, color breathing refers to instability toward continuous colors on contiguous frames. It can normally be found in damaged three-strip OCNs, separation masters or dupes, as well as chemically damaged Eastman Kodak (EK) negatives and dupes. Antley explained that there are several tools to address lower frequency color breathing. Normally the tools work by calculating luminance from frame to frame and over longer periods using Fast Fourier Transform (FFT) calculations to find the frequency. Then an inverse function is applied to bring them all to an average luminance. This is generally done separately in each color channel. The same tools can be used to address frame to frame flicker as well.

4.5.4 Digital noise reduction tools

Film grain and its characteristics were described in section 2.6.5. White explained that noise is a term specific to video and comes as a result of the video not being able to handle a specific film's grain, flicker and so on without a slight adjustment in settings. Antley said that there are two main methods employed for digital noise reduction (DNR) in digital images. The first one is spatial, which deals only with one image at a time. The second one is temporal, which deals with a series of images like a motion picture. In some instances, the two techniques are combined.

Spatial processing usually will not remove all noise, and some loss of image detail is almost always inevitable. There are several types of algorithms for doing this, but

essentially this process looks for high-frequency peaks in the original signal and blurs the image a little bit to smooth out the noise.

There are many ways to do temporal noise reduction. Most of these methods rely on first analyzing a series of frames in order to estimate the motion vectors of objects in the scene. This allows the software to remove all the real image content so that all what is left is the noise. By analyzing the remaining noise images, the characteristics of the noise such as spatial frequency can be estimated and the filters tuned to remove the noise.

A combination of temporal and spatial methods is used in order to suppress the noise to the desired level while preserving as much image detail as possible. Sharpening filters are often used after the noise filtering to bring some of the detail back into the image. There is a selection of different types of filters available, and each type generally has several parameters that control what it does. Sharpening filters often require some amount of tuning specific to the content in the images. Harris was unaware of any other facility other than Reliance MediaWorks, formerly Lowry Digital, whose proprietary tools can reduce or even remove film grain and noise entirely without affecting the resolution, detail or high frequency information.

Sharpening of some sort is used in a variety of instances. In addition to recovering sharpness losses from noise reduction, it is used to compensate for losses in the film recording process for features that are re-released on film, and for losses in the film scanning or telecine process. Sharpening can be applied for aesthetic reasons as well, just to give the picture more “snap” or “pop”. Gluck’s take on the use of sharpening tools was that at Disney they’ve been used sparingly on some shots that were actually shot out of focus.

4.5.4.1 Appropriate use of DNR

Generally speaking, the goal in motion picture applications is to suppress film grain and noise in order to present a more pleasing image, and to make it improve the ratio between image quality and bit rate for delivery in compressed formats like DVD or Blu-ray. While Blu-ray’s resolution offers something much closer to film than standard definition ever did, it is still just an approximation of the film image in pixels.

According to Koerber, in order to restore heavily damaged material it may be necessary to remove the grain entirely, and then re-introduce it. This problem was faced in the most recent restoration of Fritz Lang’s *Metropolis*. The extra footage that was discovered in Argentina came from an extremely poor 16mm source, which at first seemed to be beyond restoration. The film grain was another major challenge, and had to be eliminated entirely so that the material could be cleaned to a certain degree. Antley told that in some cases, such as simulating the look of 35mm film on material that was actually photographed in 16mm, the original noise, which is the film grain, would be removed as completely as possible and then a synthetic noise applied at higher spatial frequencies to resemble 35mm grain size. Koerber stated that this kind of process was applied on the restoration of *Metropolis*, where the grain of the camera negative, which was the other source the restorers had, was re-introduced into the 16mm source. The assumption was that if there had been better material for the damaged sequences, it would have had the grain that was re-introduced. Koerber acknowledged that while this isn’t authentic, the solution gave the film an overall look that is surprisingly convincing, despite the very different elements that had to be mixed.

According to Burton, the type of film grain that is considered problematic or not depends on many variables, and standards of acceptance govern most situations. Grain management in a legacy title is always a point of discussion. The decision regarding it often lies with the rights holder, and whether they want newly restored material to reflect the conditions of its origin, or whether to make the film look more modern and polished.

According to Gluck, film grain should still be visible. However, instances where the film element might be a poorly made dupe and makes the grain too distracting, a reasonable and intelligent use of grain reduction tools can help. At Disney, DNR is used very conservatively in the remastering of live-action films. For example, no grain management was done on the scans of *20,000 Leagues Under the Sea* (USA, 1954). The animated classics, however, receive a large amount of grain reduction. This is due to the triple exposure of the Sequential Exposure (SE) frames dramatically increasing the grain structure in the final composite image. The term SE means that the three separate color records for each frame are recorded sequentially, one following another, on a single strip film. While Gluck said that he has no doubt that there will be comments about the grain management done on the animated classics, the decision to do the reduction was done after conducting multiple tests and in consultations with the Studio.

White said that film grain is an integral part of the film image and if people say they don't like grain, they do not like film. Blu-ray is there to give the closest approximation possible to the original film. Therefore, when the team at the British Film Institute works on a new master in preparation for Blu-ray, the goal is to preserve the original grain structure as closely as possible. Because this approach might not please everyone, there are occasional customer complaints about the graininess of certain films on Blu-ray. This happens particularly on older titles, or titles originally shot on smaller film gauges than 35mm, or titles produced on a lower budget than the standard Hollywood film. It should also be noted that that films produced several years ago will not have the look of a film produced today, nor should anyone expect them to. A film produced in the 1940s will look quite different than film made in the 1950s, 60s, 70s and so on.

4.5.4.2 Overuse of DNR

Burton explained that as the image is processed too much with DNR, it can contribute to the perceived sharpness of the image. When the grain reduction is taken too far, a softening of the image can result, which can be more problematic than the grain. Antley said a cognitive effect causes people to perceive images with a little noise in them as sharper, even though the actual image detail is the same.

According to White, DNR has been the cause of a great deal of debate in recent years and that there are numerous examples of excessive use of it on both older and more recent titles. Burton claimed the debate is religious as much as it is technical. Theakston said it is an aspect where studio policies and the larger consumer base dictate what will happen. The consumers who complain about the use of DNR online are enthusiasts who have learned to be quality conscious. However, both White and Harris agreed that the current general consensus is that grain removal is a bad thing.

Part of the reason in recent years, according to Theakston, has been the over-scanning of film elements where the scanning has been done in 4K or even 8K resolution when 2K would have been perfectly acceptable. Higher resolutions have the tendency to accentuate grain structure. As the grain becomes more noticeable, it is compensated for with DNR. According to Antley, part of the reason DNR has been used too heavily on

several titles is because the remastering work done for them is done quickly just to get it into the market. This means that not enough time and money is spent on doing a better job because the general consumer doesn't really know and therefore the effort won't generate more revenue. Also, due to this kind of approach, usually the original filmmakers (cinematographer, director) who have the closest connection to the film and would care most about the quality of the presentation, are not involved in the remastering process.

4.5.5 Optical effects

White explained that fade-outs and dissolves, as well as titles, wipes, logos, crawls and so on are what have traditionally been called opticals, as effects of this type were usually created in a film laboratory using an optical printer. A degree of generational loss was a standard consequence due to these methods involving combining footage and then duplicating frames in some form. For example, a shot leading up to a fade or out of one in an older film will often look somewhat grainier or courser than the surrounding shots that have been edited together through straight cuts. As almost all film post-production now involves digital workflow, these optical effects are now accomplished digitally. Most agree that this is an improvement, as it offers so many new tools and choices, as well as the fact that digital workflow does not introduce any generational loss.

Antley said that if there are fade-ins or fade-outs in the source material for the restoration, the handling of them can be quite challenging. This is in part because any tools that use motion estimation or other temporal techniques will have trouble dealing with these areas. According to White and Antley, the original effect should be kept as it originally appeared in the film, rather than replacing or "improving" the effect digitally. Koerber stated that if the opticals are corrected, it might result in being impossible to read them as opticals any more, and viewers may make false assumptions about film production techniques that were available to the filmmaker at the time.

4.5.6 Wire removal

The high resolution scanning of film elements tends to bring to the fore certain problems that would not have been seen in prints, such as wires. According to Theakston, there have been intense debates over wire removal. Based on his experience, when a filmmaker is alive and is consulted on the project, one of the first things that he or she is actively asked for is wire removal. Theakston claimed that in the restoration of *The Wizard of Oz*, Warner Bros. decided to remove the wires on the Cowardly Lion's tail because it distracted from the story. It is up to the individual viewer to decide whether that was the correct ethical decision or not.

Koerber stated that if the wires were visible in a print when the film was originally released, they should not be removed because part of the charm of seeing productions from a different era is to examine how they were made. However, if things become visible now because new printing or scanning technologies bring them out more than they would have at the time, then the problem or nuance would be masked as much as current technology allows, but not more than technology used at the time of production would have masked. In film restoration, it should be made sure that historical artifacts are kept readable in their original context in order not to give a falsified impression of what was possible or intended. Even if a mistake occurs during the production of a film that stays in the released version, it is to be respected and should be left alone, as it was,

for better or worse, part of the authentic experience. Harris agreed with these statements.

Harris said the important factor in the decision making is defining the term print. As it was referenced in section 2.6.6, the wires holding the miniature planes in Dr. Strangelove were not removed from the restoration. Harris emphasizes that it is important to know precisely what fine grain positive, what 35mm duplicate negative and what print stock were being used. The easy answer is to use an original print as the guide. However, it is possible that a print derived from the original camera negative might have exposed wires, while a print from a dupe derived from a fine grain positive might have hid the wires.

The *Godfather* movies have been used as the main restoration example throughout this thesis. Harris explained that the 4K scans of *The Godfather: Part II* revealed wires. They were also visible in a newly struck test print, but not in contemporary dye transfer prints. The optical dye transfer matrices hid them in original prints, so the decision was made to have the wires removed in the restoration.

Gluck told that there were many debates whether the very visible wires in the giant squid sequence in *20,000 Leagues Under the Sea* should be removed or not. It is important to note that when the scene was first filmed it was staged to happen at sunset, but Walt Disney was upset over how obvious the mechanics were that he ordered the sequence to be restaged and reshot to make it look like it was happening at night. This was done to further help hide the wires. The filmmakers made substantial efforts to hide the wires so it is safe to assume they did not want the wires to be seen. In the case of *20,000 Leagues Under the Sea* and *The Wizard of Oz*, for example, the nostalgia of some viewers who like seeing the wires has to tempered with the knowledge that the craftsmanship and attention to detail is a testament to the filmmakers not wanting wires and the like to be readily seen by viewers. Theakston noted that it is protocol to preserve the original film's gaffes such as these. This means that the altered version is not what would be considered the preservation. Koerber also said that everything should be left as is in the preservation element and that it must be catalogued to point out these characteristics.

Antley explained the actual process of digitally removing the wires is generally done by an operator manually locating the wires in the images. This is sometimes helped by edge detection or motion estimation algorithms. Another way to do the actual repair is by cutting out the wires and replacing them with image content from the previous or next frame. This method sometimes requires the operator to manually adjust X/Y offsets of the image that is pulled through.

4.5.7 Modifying the original look of the film

Theakston told that when he started in the field of film restoration, the point of a restoration was to make a film look as good as it did the day it was released, and that modern day restoration is mostly about making it look better than it did when it was originally released. Harris agreed with the statement in some regards, as some studio decisions have been made which digitally take a film far past any point at which it might have been seen during its original release. For example, resolution enhancement and grain removal create more problems than they solve. When a film is being restored, it should be brought to look as close as it can to an original answer print. Everything else simply creates a new edition of the film. The example Harris used were the Disney animated classics, but added that there is nothing wrong with this kind of approach as

it's for a new audience consisting mainly of children, and the original film elements, by virtue of the new work performed, have been digitally preserved.

According to Theakston, the consumer generally has little idea what the original look of a film might be. The example he mentioned was the latest digital restoration of Disney's *Snow White and the Seven Dwarfs* (USA, 1937) where the color has been timed so that grays are neutral, and there has been a distinct increase in chroma. This is not the way the film looked in 1937 as color films looked different, for both artistic and technical reasons, during that era. Original prints of Snow White were subdued, soft, and had a distinct yellow cast. From a purist's point of view, if that is the visual look that made the film a success then it should be kept that way, but the ethical dilemma lies in whether that is appropriate for today's audiences who are used to saturated colors in cartoons. Even Walt Disney himself approved of several different color-timings of his films over the years.

Friend argued that simply duplicating the original as it exists or returning it to its original achievement may be very off-putting for contemporary general audiences. While an archive preservationist might want to or be economically constrained to bring the film for viewing within the archival context, a studio archivist will be preparing the film for a much larger and more general audience. Due to current expectations or standards of quality, which includes things like stability, cleanliness and clarity, the limitations of a really old film become more destructive to the immersive viewing environment of the original experience. These limitations can consist of several of things, such as poor opticals, weave, color or density drift, occasional lack of focus, camera ghosting, distortion of the image at splices, contrast or gamma problems, in-frame production equipment, excessive grain and halation. Because of this, the archivist may address any or all of those issues. Returning the film to its original achievement is the most desirable from the practicing scholar's perspective, but all later stages of the process that includes fixing the issues listed above are simply viewing variants that correspond to the tastes or expectations of a broader audience. These later versions will change as digital technology evolves with the mediasphere, and they become obsolete quite quickly.

Gluck would always defer to the filmmaker's decision as he or she is the author of the work and they should have the opportunity to revise it as they see fit. As far as Disney's animated features are concerned, the team is always very aware of what is considered artistic intent and animation, and what is considered an obvious flaw. Instances where mis-painted cels and glaring omissions show up will be corrected. The stance is that if the filmmakers had seen the error, and in most cases did see it, they would have absolutely fixed it if they had the luxury of time and budget. To fix a mis-painted cel meant going back and repainting the cel and then re-photographing the entire image sequence. Today's digital tools can fix a paint flaw in a matter of seconds. On the other hand, in a film like *The Jungle Book* (USA, 1967), which has very strong pencil sketch and animator drawing lines that are still quite prevalent, the restoration team chose not to remove any of that work. What is sometimes left in the picture is more important than what is removed. If there is a hair in the film gate as the film is shot or the negative gets scratched during shooting, Harris would remove those in the restoration. Unlike what Fossati stated in section 2.6.6, a scratch that occurs during shooting is damage, and is not inherent to the film.

4.6 Starting a sound restoration project

At Chace Audio by Deluxe, a restoration project begins with research and evaluation of the materials from the very first day the client is thinking about doing the restoration. In the overall restoration workflow, some of the basic work can be done before the picture restoration is done, but the final step must wait for a finished picture.

In the more complex technical projects workflow diagrams are generally made, particularly if the people aren't working in close approximation to each other. This assures that everyone involved in the project understands what their role is in the process and avoids the danger of three people, for example, doing the same job three different ways. Generally speaking, in sound restoration only one engineer will be responsible for the actual overall sound quality and restoration work. There might be a digitization engineer, a film prep technician and a final mastering engineer, but generally only one person will be responsible for addressing all the noise issues and what the sound quality will be.

An important note to make about sound restoration is that no film ever sounded bad on the day it was released. It sounds bad because of the wear and tear and the mishandling that has been done to it since the first day of release. This doesn't mean a film from the 1930s is expected to sound like a modern day blockbuster movie. On the other hand, the recording technologies of the 1930s and 40s were actually far superior to the playback technologies. It is one of the reasons why classic movies that are restored well today sound so good. What is heard today can literally sound better than when the film was originally made.

4.6.1 Research and evaluation

One of the most important aspects of sound restoration is research. Every film has similarities and every film has differences, but the basic process does not really change and that is: search for the most original audio elements and understand the context of their origins. An audio house like Chace doesn't generally do the research themselves other than interview the clients who have access to their databases. The clients can try to tell where the elements came from, but far more information is acquired when the film cans are received. To see how they're labeled and if lucky, there might be a piece of paper in the film can that contains an important piece of information. In particular, the date of the element is essential because the closer it is to the original release date, the more likely it will be the master set. However, vault inventories are known to have errors because they are input by clerks who are often not particularly knowledgeable about sound elements. So sets are often mixed up by accident. If there is no information, the only way to recognize the element is to play it. The good part about sound is that the criterion is very subjective, so if the audio element sounds good, knowing the history of the element becomes less important unless there is a question of versions. Most films only have one version, but some of the more successful films might have many versions. Three examples were presented in section 2.3.1. *Close Encounters of the Third Kind* is another example of a film with more than one version, and this caused challenges in the audio restoration process.

Studios usually keep good records of their material and very often for legal purposes they have copies of their scripts. This allows for the comparison between the script and the soundtrack to see the content matches. However, there can be cases where changes were made on the day the final sound mix was done; a sound effect might have been added or left out, and that wasn't documented. In the case of the three different versions

of *Close Encounters of the Third Kind*, there are several scenes where Steven Spielberg actually altered the dialogue by finding new dialogue to remix into the picture because he didn't like what he did the first time. This means that there might be a scene that essentially plays the same, but there is one little piece where the dialogue has been changed. So it is very important to be very meticulous in comparing versions and making sure nothing is left out of the film.

Once the research has been done, the collected material is prepared for an evaluation process. This can literally mean that film cans are laid out on a big table. Depending on the condition and format of the element, this is often the most challenging part of the process, because the elements have sometimes been sitting in their cans 50, 60 or even 70 years. If it has not been a popular film, the material may not have been inspected in a long time, though old nitrate materials are fairly often inspected to make sure they haven't deteriorated too much. The audition process is subjective as the elements are evaluated by listening to them and deciding which set sounds better than the other. The amount of elements used for a restoration depends largely on what the project is, but the goal is to use as few elements as possible. This is due to the cost factor and the possibility of introducing things by working with a copy that is not the final version of the film.

In the early 1950s, magnetic sound was introduced. This initially consisted of three tracks of audio: dialogue, music and sound effects. This way changes could be easily made, particularly regarding music and sound effects. For example, if there was a music cue that was taken out in the final version but the copy which is used for the restoration has it, then a music cue has been added to the film even though it should not be there. In order to avoid such a thing happening, often the decision is to use an optical soundtrack negative as a reference. It is the most final version that could exist because when a film print is made, the picture negative and the soundtrack negative is printed to positive stock. If there are any suspicions that there might be different versions with the magnetic material, the soundtrack negative or a film print can be used as a reference copy to hear what should be on the soundtrack.

4.6.2 Playback and digitization

Primarily all the material that is worked with in preservation and restoration is analog. The analog material has to be turned into digital data. The first step is to have the best analog machines that can handle the analog format for playback. The next step is to have high quality analog-to-digital converters to digitize the audio as it is played back from its original analog carrier. The Library of Congress in the United States has stated that 24-bit, 96 kilohertz (kHz) audio sampling rate is considered preservation quality digitization. One kilohertz equals 1,000 hertz. Hertz is the basic unit of measure for frequency, and basically refers to how many cycles there are per second. In audio, one cycle is one complete vibration of sound waveform. Chace Audio does all of its preservation copying at that sampling rate, and the standard format is the Broadcast Wave Format (BWF), which is an extension of the Waveform Audio File Format (WAVE, or more commonly known as WAV).

A key issue in the digitization process is to make sure that the sound is played back with the correct speed with the proper synchronization resolving. In the case of film, it is quite simple because film runs at 24 frames per second. However, once in a while there might be a copy that was made at 50Hz and 25 frames per second at PAL (Phase Alternate Line) speed for European TV broadcasting, for example. It is important that no speed alterations occur.

One challenge with playing back the sound is the wide number of audio formats. In picture restoration, the number is considerably lower. Chace Audio handles over 140 different audio and video formats. Sixty-seven of these consist of different magnetic and optical film formats, audiotapes and phonographs. Another challenge is the condition of the elements.

4.6.2.1 Heavily flawed elements

Fullcoat is a mag stock with a layer of oxide that completely covers one side of the film. 35mm fullcoat can be used for recording several tracks, and is generally used for the final mix master. Picture A in Figure 7 (see attachment C on pages 69 and 70 for a larger size version) shows a piece of 35mm fullcoat mag that has suffered from catastrophic binder failure. There is a big clear area in the element where the mag emulsion has fallen off the film because the binder or glue has lost its ability to hold it on to the base, thus making it impossible to get a playback from it. Picture B showcases a piece of a sound negative which had been kept in very hot and humid conditions. The negative has deteriorated, and looks like toxic waste. The emulsion had become so soft and sticky that even to attempt to wipe it down would wipe the entire soundtrack right off the film. There is no way to recover that film, nor can it be played.

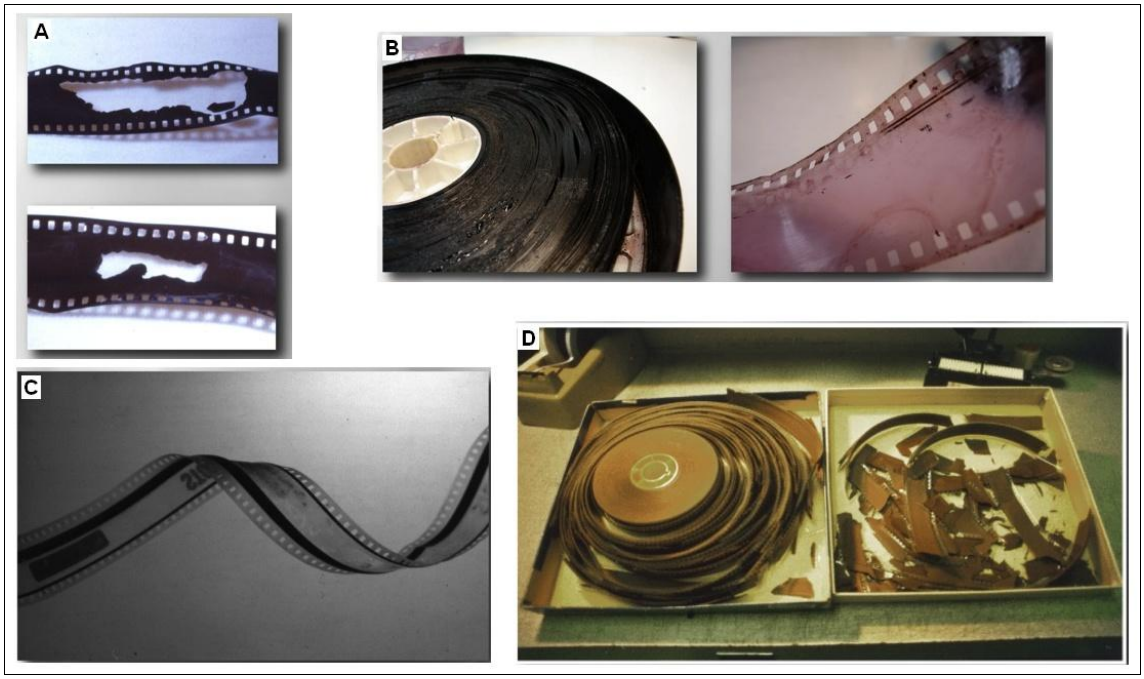

Figure 7. Examples of heavily flawed sound elements that cannot be digitized[8].

Picture C in Figure 7 shows a piece of 35mm warped fullcoat film. Vinegar syndrome has affected the element in a way that the binder, which is the glue that holds the magnetic oxide on to the clear film, has failed. There is clear film behind it, but the magnetic oxide where the sound was recorded, is gone. Finally, picture D on the lower right side in Figure 7 shows a film element where the acetate has become extremely fragile to the point where touching the element would result in having it destruct into hundreds of tiny pieces. The element will never be played again.

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[8] Courtesy of Chace Audio by Deluxe. All rights reserved

4.6.2.2 Flawed elements that can be digitized

Figure 8 (see attachment D on pages 71 and 72 for a larger size version) shows three examples of flawed film elements that have been successfully digitized. The first example, picture E, shows an optical soundtrack negative where 50 meters of the film was torn off so basically there is 50 meters of the 35mm film in 16mm now. The film can't be printed anymore but fortunately the soundtrack was only torn from the side with the sprockets so the soundtrack could be carefully played back.

At Chace, a lot of the vinegar syndrome is solved with the Sondor OMA SE-Chace, an audio recorder made in Switzerland. Picture E shows how a warped piece of film can be played back with the special little headstack arrangement, which holds the film to the mag head. This is a physical solution to the problem.

Lastly, picture G in Figure 8 shows what a mag head looks like when the magnetic film develops plasticizer, which is yet another symptom of vinegar syndrome. The plasticizer gets all over the mag sound head. If there is a gap of more than one thousandth of an inch between the film and the mag sound head, it causes a spacing loss of about 50 decibels (dB), or 16 kHz, from the normal level. This results in a severe loss to the high frequency response of the soundtrack. The solution to that problem was to create a formula to allow the film to re-plasticize it. However, this kind of buildup comes with friction so it was necessary to reduce the friction at the mag head and to keep the mag as close as possible to the film to avoid the spacing loss.

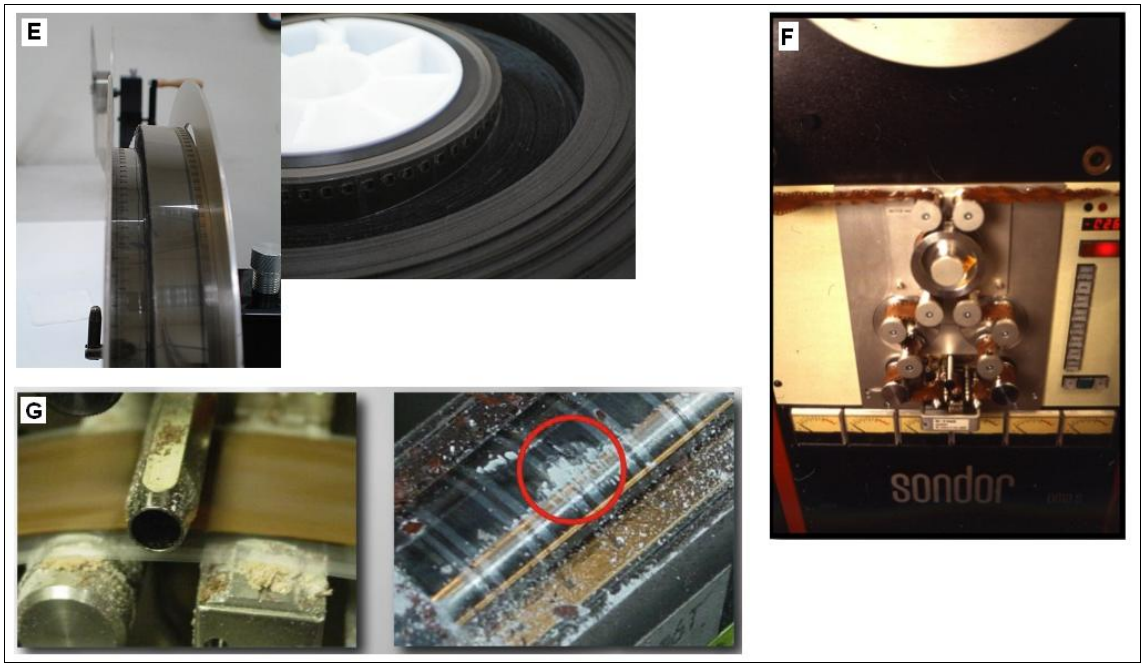

Figure 8. Three flawed elements that can be digitized[9].

Preservation is simple as it's a technical copying process, but the reasons and examples listed above prove that it is sometimes necessary to create custom machinery and solutions to be able to playback and digitize the various elements. A bad copy is always going to sound like a bad copy. Digital tools will help, but there aren't audio

[9] Courtesy of Chace Audio by Deluxe. All rights reserved

revitalization tools yet that can make something that was recorded poorly sound good. That is why the goal is always to make the best possible preservation copy, which becomes the foundation of the whole restoration project.

4.6.3 The handling of various sound issues

According to Polito, once the elements have been digitally captured, an engineer will work on a computer workstation in a controlled listening environment to identify the various problems and remove them with no or very little affect on sound quality. There are extreme cases of every sound problem that can't be completely corrected. Hums, thumps, clicks and pops are defects that can generally easily just be filtered out with software. Hiss can typically only be reduced, not removed. Perforation noise is created in the transfer process if the optical reader sees the perforations. One solution is to use Chace Optical Sound Processor (COSP) technologies to avoid it. Another solution is to try to process it out by using a filter after it has been digitized.

Figure 9 is a screenshot comparison of a spectrogram view of a pop removal. A sound spectrogram is a visual representation of sound that shows how the spectral density of a signal varies with time. The horizontal dimension corresponds to time, and the vertical dimension corresponds to frequency, with higher sounds shown higher on the display. The color of the spectrogram indicates the relative intensity of the sound at any particular time and frequency. The left side in Figure 8 is a raw print of a soundtrack where the circled area highlights a pop. As this pop sound should not be on the film's soundtrack, it has to be removed. The circled area on the right side in Figure 8 illustrates what the spectrogram looks like after the pop has been processed out with a pop-reducing algorithm.

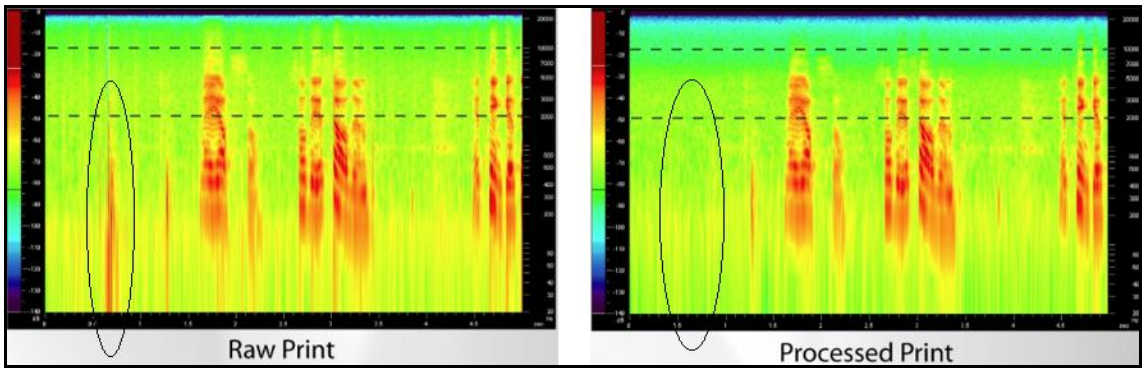

Figure 9. Spectrogram illustration of a pop removal[10].

Similar to picture restoration tools, digital sound restoration tools are very powerful, and a soundtrack can be easily ruined if the tools aren't used properly. The hardest thing in digital restoration is to make sure a digital artifact is not introduced, thus creating a sound that is not organic to the film. There aren't tools to correct digital artifacts. The preferable thing is to leave a problem that can't be fixed but is original to the soundtrack, rather than try to make a repair that doesn't sound realistic. There are issues that even today's tools can't solve, so the important thing is to have the preservation copy that has no alterations done to it.

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[10] Courtesy of Chace Audio by Deluxe. All rights reserved

4.6.3.1 Sound polarity discrepancies between tracks

Sound polarity is the ability to take a soundtrack and put it in phase or out of phase. It was used early on by sound engineers. Particularly with stereo recordings it was discovered that if the polarity is changed in one track from another it creates a more spatial sound in the theater. If one sound is in phase and another sound is out of phase it arrives at the listener's ears half a cycle later, thus creating a bigger, more spacious sound. It worked well for discreet stereo presentations in the early 1950s. Nowadays there are many other tools, such as reverberation and electronic delays, to create a spacious sound and change the delivery of the sound to the ears where the polarity isn't changed.

According to Regal, it is easy to flip the polarity on any tracks with today's technology. With each step of a project there are metering devices that are checked constantly to look out for changes in polarity and phase shifts between tracks. Any occurring issue can be spotted with listening too.

Polarity is a major issue in the restoration of movies made in the 1950s and 60s where they didn't have all the tools that are available today. The issue arises when the stereo tracks are mixed to mono compatible material, because a track can't be made where one sound is in phase and one is out of phase. The result is a flat line with no sound. The polarity problems are also a major issue for compatible stereo formats like Dolby Stereo, where audio that was originally mastered as four discrete channels is matrixed to two channels for delivery. The only solution to this is to compromise by narrowing the stereo image and making it more mono. These kinds of sound polarity issues are one of the hardest things that have to be fixed, and sometimes they can't be fixed.

In the late 1980s and early 90s, a lot work had to be done to make the make the tracks compatible for VHS, but for DVD and Blu-ray, the issue doesn't have to be fixed. The 5.1 capability on these formats can deliver the sound just as it was heard back in the 1950s and 60s. The end result is an authentic presentation of the sound.

4.6.3.2 Splice bloops

In the early days of soundtracks, scenes were edited together with hard splices. When it goes through an optical reproducer it makes a very loud pop sound. In order to reduce the sound the editor would literally punch the track with a diamond, for example, to hide the actual physical edit behind the dark shape the red arrow is pointing at in Figure 10. The shapes below the film strip show other common shapes. This process reduced the loud pop sound considerably into a very soft, little pop sound.

Due to the lack of low frequency response in theaters back in the 1930s and 40s, the sound would not be heard very well because the speakers could not reproduce it. However, today's speakers would reproduce it perfectly; when it goes through a subwoofer it produces a very loud low frequency response. The process of removing the sound digitally is to either edit it out or to process it out with a pop-reducing algorithm.

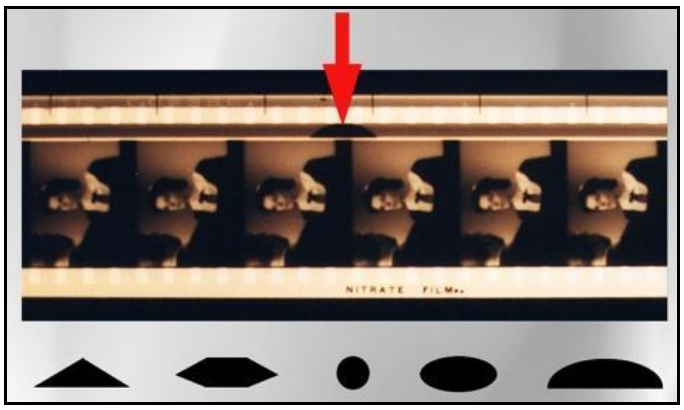

Figure 10. Splice bloops were reduced with a dark shape in the early days of soundtracks[11].

In these instances the clients are always asked would they like to have the splice bloops removed. Most clients are aware of the issue and generally choose to have it taken out. However, there are example cases where this has been debated. There was a restoration of an early optical sound film from 1930. The soundtrack was filled with splice bloops, which were then taken out for the restoration. A member of AMIA complained about this decision, and the studio responded by saying that today's audiences don't want to know about every edit in the film because they don't want to hear edits in new productions either. The preservation copy, however, includes all the splice bloops, and a copy can be made if the AMIA member wants to hear them. In another restoration the client insisted that all the splice bloops should be left in because they felt it was organic to the film. This can sometimes cause debates because audiences did not really hear the splice bloops when the movie was originally released.

4.6.3.3 Poor frequency response

The example about the spacing loss in section 4.6.2.2 can be one of the reasons for poor frequency loss. It can also happen if the playback equipment starts to fail during the transfer process. There was a transfer where the mag head was at the end of its useful life and it started to really degrade the signal quality during the transfer. Because the degradation was gradual and not instantaneous, the engineer didn't notice it because a person's ears can make up for the gradual changes in sound quality. It wasn't until the next engineer noticed the poor frequency loss at a computer workstation and the transfer was redone with equipment that was functioning properly.

Physical deterioration issues and bad equipment issues aside, there can be times where the actual recording was done incorrectly, thus resulting in poor frequency response. For example, a rumble might have been recorded in the track, but due to speakers being unable to play it at that time, it wasn't a problem. Today the rumble would be heard on the track. The client is always told of the issue and it's their choice whether they'd like to have it taken out or not. Today's audiences have high expectations of what the sound of a movie should be so particularly if the title is scheduled for a commercial release, the rumble is generally taken out. The preservation copy, however, will have the flaw. According to Koerber, it is vital to recreate in the digital domain the original chain of technology from recording to the speakers in a theater, and thus not read frequencies that are there but were never meant to be audible. Otherwise the same authenticity

[11] Courtesy of Chace Audio by Deluxe. All rights reserved

paradigm applies as to picture restoration, such as in the case whether wires should be removed or not.

4.6.3.4 Frame line noise

Heiber told that frame line noise results from incorrect printing and is considered a severe problem. It creates a sound that resembles the sound of a motorboat. It is an almost impossible problem to completely fix, because it not only creates its own buzz, which will be a 24 Hz, but it will also modulate the audio around it resembling that of a FM signal. According to Polito, whether it can be completely corrected or not depends on the severity of the problem and the source involved. Sometimes it can be corrected at the digitization stage, and sometimes various digital tools have to be used to try to remove it. If the frame line noise is extreme, dealing with it can be quite difficult and not always 100 per cent successful.

4.6.3.5 Distortion

According to Polito, distortion is one of the last major problems of audio restoration because there really aren't any tools that are designed to deal with it specifically. Regal also mentioned distortion as the biggest issue in sound restoration. Peak distortion can be dealt with some success. This involves rebuilding the peaks in the software process. Intermodulated distortion is literally on the modulation of the audio waveform. This type of distortion looks like little jagged edges that are not just on the tops or bottoms of the peaks, but all over the waveform. Regal added that intermodulated distortion is impossible to remove.

Chace Audio uses the Audiocube, which is a software created by a German company called Cube-Tec. The software has some sophisticated distortion algorithm tools, but Heiber also stated that noise modulation is a big problem in soundtracks and the correction of it has always been very difficult.

4.6.3.6 Mismatch of sound between two elements

Mismatch of sound between two elements being used for the restoration is a common audio engineering problem that occurs when multiple elements have to be used in the restoration of a soundtrack. Generally speaking, if the change in elements can be made when a cut or perspective change occurs in a scene, the difference in sound quality will be less apparent. If the change happens right in the middle of a dialogue scene, taking the poorer quality element and using it for the whole dialogue scene is generally done in order to avoid making the change in sound quality less obvious.

Another thing to take into consideration in these instances is level inconsistencies where some material might have been recorded too low. When the level is brought up to match the current level, the noise level generally rises too. In situations where there are only two words, for example, to substitute, the change in elements might not be necessary, especially if the viewer is caught up in the story and won't even notice the flaw.

4.6.3.7 Stereo panning problems and dialogue sync issues

If there is a stereo panning problem in the soundtrack, a stereo processor can fix it precisely even within inside frames. However, the question is whether it can actually be considered a problem or not. For example, if there is a situation where a sound is supposed to come from the left but is coming from the right, it is often an artistic

decision that was made by somebody who is not alive anymore. At Chace, this would not generally be corrected unless the client requests it. According to Harris, research would be necessary first before any changes are made.

A similar issue can happen with dialogue synchronization. If the tools at the time the film was made didn't allow the dialogue to be entirely in sync, slight movements can be made with today's tools by editorial processes. If the dialogue is married to the music and sound effects, the client is told that making those small movements with digital tools may fix it, but again it's the client who makes the final decision, and whether the result is better is entirely subjective.

4.6.3.8 Missing sounds

At Chace, traditionally a new sound effect will never be added unless they're directed by their clients. In a restoration, it is not favorable to add anything new unless the client has a desire or, in some cases, knowledge of the desires of the filmmaker that were never fulfilled. There are instances where things are happening on screen that looks like it was a mistake. The client is then asked would they like have a sound effect added or not. If there is a need to add a sound effect where it looks like one is missing, the goal is to find the same sound in other parts of the movie. This way what is added is something that always was in the film, so it'll be closer to what the filmmaker heard. Extensive libraries of old sound effects have been created to match the character and period of the time, because old sound effects do not sound the same as new sound effects due to the way they were recorded. In the 1950s and 60s, sound libraries were very basic, particularly for television production work. The same sound effect would be used over and over again. However, if the same sound is not found in the movie, it might appear in a different movie from the same studio because generally speaking, studios in those days had sound departments and sound libraries that the whole studio would use. In the worst case scenario, the sound effect is recreated by trying to give it the appropriate characteristic. These instances would be highly documented. For example, one client supervises the placement and creation of every single sound effect. He is a given a list of all of the added sound effects and then proceeds to audition every single one of them to make sure he's happy with it.

There was a restoration of a title where the materials that were available were damaged and didn't contain some of the dialogue. The decision was to find actors who sounded like the people heard in the 30-year-old film. The voice doubles' lines were recorded and then remixed back into the film because there were gaps where the dialogue was missing. The script was referenced to find out what the missing words were, but additional challenges occurred as some of the words were ad-libbed, thus they were not documented. The alternative would have been to leave the dialogue silent, fill it with music and sound effects that was happening in the background, and put subtitles to replace the missing dialogue. However, if a viewer is not reading subtitles and all of a sudden a subtitle comes up for one sentence and then disappears, the viewer might not catch it. That is why the decision was to fill in the words.

4.6.4 Automated processes in sound restoration

Automated processes in sound restoration can be used for taking out unwanted noise such as pops, ticks and some of the crackle heard in the film. At Audio Mechanics, automated processes are used for click and crackle removal. The processes are anywhere from 20 to 90 per cent effective. Polito estimated that they are on average about 70 per cent effective. At NBC Universal, the use of automated processes is

generally avoided. While there are cases where it can be beneficial, the processes tend to cause artifacts that need to be fixed. At Chace Audio, automated processes are generally used very sparingly in order to avoid the problem of removing sounds that should not be removed. In projects where the budgets are very low and it is more important to get a product out that is acceptable than having it be aesthetically perfect, compromises have to be made so in those projects automation might be used more, but it is client-driven.

According to Heiber, the process of using automated de-popping software, for example, begins with auditioning the soundtrack. Nowadays the tools are very efficient in that a two-hour movie can be auditioned in less than real time. Once the auditioning is done, the entire soundtrack is de-popped. It is mandatory to then closely inspect the soundtrack to hear what the software has done. This raises the issue of removing sounds from the soundtrack that should not be removed. For example, if a person is walking across gravel, it sounds just like static on the soundtrack. Regal said automated processes would compromise a film scene that takes place near a crackling fire, as the crackling sound effect would be mistaken for noise. In some foreign language films, lip smacks or similar mouth noises that are part of the language would also be compromised. In addition to these, artifacts can also appear when automated processes are used on films made in the 1930s. Due to the limited frequency response of the recording technology of the time, the female voices have the tendency to sound quite shrill. This results in sharp peaks in the audio waveform, and the processor mistakes them for ticks.

Removing layers of noise can sometimes uncover other noises that really were never heard before. This occurred in a restoration of a film from the 1950s, which was shot on a soundstage. There was a fair amount of hiss and machine noise that resulted in layers of soft noise built into the soundtrack. As those layers of noise were removed, it uncovered the sounds of cars going by because the scene was shot outside the soundstage. However, the scene was supposed to take place out in the middle of fields where there are no cars. The solution was to start adding the noise back into the soundtrack so that the cars could not be heard because that was more authentic to the picture as opposed to making the track free of noise but now uncovering this noise that never existed.

4.6.5 Challenges in creating a 5.1 upmix

According to Theakston, the original soundtrack is always a priority in any serious restoration project. Anything that might be remixed later is an afterthought, usually with a commercial reason. The restoration team has done their job as long as the original soundtrack is preserved and presented as an option. Polito stated that digital media, such as DVD and Blu-ray, has affected sound restoration in a way that it has imposed tighter deadlines on the work they do, but has not had an effect on the approach or the quality of the work. There is also an added interest in delivering 5.1 surround audio, even from films that were originally released in mono. Heiber emphasized that in this instance, remastering would be the more appropriate term to use instead of restoration because a soundtrack that never existed cannot be restored. If the client requires 5.1 upmixing for a title, the team at Audio Mechanics will start by restoring the sound in the original theatrical release format and then upmix to 5.1 surround. In most cases, the title is released on DVD or Blu-ray with both the original playback format and the 5.1 surround version. The aesthetic value to uphold in creating a 5.1 upmix is to only use material from the original production. This means only the original sound effects, space

ambiances, wind noise and so on are used. At Audio Mechanics, there hasn't been a 5.1 upmix where they were not able to uphold that standard.

Polito said the quality of the 5.1 version will depend on the elements available and the talent of the engineer. If a mixed composite mono track is the only element available, only the more expensive methods can yield fairly good results. For films originally released in mono, the availability of separated dialog, music and effects stems will make the upmix process much easier and generally more pleasing in the end. In general, films made before 1953 will only have mixed composite masters. There are exceptions, but typically these exceptions will have isolated music cues and a mixed composite master but no separate dialog track. Gluck stated that on titles like *Dumbo*, *Bambi* and *Cinderella*, all that survived were key mono mixes, occasionally some music only, and a mixed music and effects track. The goal when doing a 5.1 mix out of mono materials is to create an aural spread while trying not to overly exaggerate by creating pans or make subwoofer effects too extreme just for the sake of doing so. Instead, the approach has to be very delicate.

Heiber used the 1939 version of *The Wizard of Oz* as a good example of an exception to the above mentioned rule. In the 1960s, the executives at Metro-Goldwyn-Mayer (MGM) decided to make copies of their nitrate film materials. A print was made from the sound negative, and the film scores were transferred to quarter inch audio tape. These materials were used for the restoration and remastering. If those elements that could be considered first generation preservation elements had not been available, the film wouldn't have sounded as good as it does now.

One technology for converting mono to stereo is Chace Digital Stereo (CDS), a sound design tool invented by Rick Chace. The technology can very precisely on a frame-by-frame basis apply up to 18 different psychoacoustic principles 60 times per second that create stereo effects. For example, in stereo, there is a head-related transfer function (HRTF), where a sound can be heard in the front and then transferred over the listener's head so that the sound is then heard behind the listener's ears. Playing this kind of psychoacoustic game, CDS can create a very realistic soundfield from mono material. There are no extractions, newly cut sound effects or machine-determined frequency manipulation. CDS has been used on over 1,000 titles, including *Taxi Driver* (USA, 1976), *Goldfinger* (UK, 1964) and *The Wizard of Oz*.

Heiber also said that there are several tools and technologies available to create a 5.1 upmix. For example, DTS (Digital Theater Systems) has created a neural surround technology that converts two-channel stereo to 5.1. Digital audio workstation platform Pro Tools also has audio spreading algorithms. The French company Audionamix has created technology, which does frequency analysis of the track first to study all the different sounds. Then it starts to create different bands of sound. For example, in a musical score, it can separate high, medium and low violin strings. Once the different bands of sound have been created, the sounds are recombined and remixed for 5.1. The approach is entirely different compared to CDS. Certain material translates really well, but in some cases the separation techniques don't work quite so well. Based on these examples, it is important to know about the tools and technology that are available and which tool to use and which time.

4.6.6 After the restoration and remastering work

At Audio Mechanics, once the restoration and remastering work has been done, a complete listen through with picture is done to make sure that everyone is satisfied with

the end result. In most cases the client is present for this occasion. After the soundtrack has been approved, digital copies are made on archival grade DVD-Rs and sometimes LTO-4 tape. LTO refers to a magnetic tape data storage technology, and 4 is the version number, which can hold 800 gigabytes of storage. Analog 35mm magnetic copies are also created as well as a new optical soundtrack negative if it is required by the client.

4.6.7 Sound restoration and remastering on the *Godfather* films

As the restoration project of the *Godfather* films was used as the main example in throughout the literary review chapter, it was thought appropriate to use the three films as the main example of what kind of sound restoration and remastering had been done on all films and to also give the reader a concrete example of the variety of sound elements that might be used and created. The information presented here is mostly all from an interview conducted with Jeff Cava from Paramount Pictures, who worked on the 2007/2008 restoration project.

The Godfather and *The Godfather: Part II* were originally released theatrically in the 1970s as monaural. In 1997, Walter Murch, who was the post-production consultant on *The Godfather* and sound montage and re-recording supervisor on *The Godfather: Part II*, created 6-track SR-D (SR stands for Dolby SR noise reduction used in the analog soundtrack, and the D refers to the digital track) formatted print masters that were used to make the DTS magneto-optical (MO) disc master used for the 1997 theatrical re-release. 2-track Dolby SR print masters were also made for use as the analog back-up for the DTS tracks.

The source for both of the remixes were the original 35mm 3-track mono dialogue-music-effects mag masters as well as transfers of the original stereo music masters, the source formats for which ranged from 35mm music elements to 2” analog 16 and 24-track music recordings. These materials were supplied to Murch by Paramount Pictures and Paramount Music. One of the specific issues Murch addressed during the course of the 1997 project was that he had improved dialogue sync on some areas in the first film. For the 2007/2008 restoration project he wanted to make sure that these improvements were maintained, which they were.

With the help of new digital tools further dialogue clean-up was performed. Harris told that in the wedding sequence in *The Godfather* where Marlon Brando speaks with Richard Conte, the words Cosa Nostra were helped along a bit and brought forward from background noise. General clean-up in terms of hiss and distortion was also performed on the first two films. Due to time constraints, the music masters on a handful of music cues for both films had not been able to be located during the 1997 re-release project. For the 2007/2008 restoration project these masters were located so that the music could be re-addressed. The elements created in the project included 6-track SR-D print masters, which were printed in Dolby Digital SR-D, DTS, and SDDS (Sony Dynamic Digital Sound) formats. These tracks were closely reviewed by Murch, and changes were made where he deemed them necessary. For archival purposes, the analog tracks on the first two films represent the original theatrical mono tracks.

The Godfather: Part III was originally released theatrically in Dolby Surround, which is an optical 2-track Lt/Rt (Left total/Right total) print master that plays back as LCRS (left, center, right, surround). A 6-track SR-D print master with a 2-track analog back-up was created for the 1997 re-release. For the 2007/2008 restoration project Francis Ford Coppola requested that a 35mm digital negative of the director’s cut would be made. That version of the film had previously existed on home video and LaserDisc in

conjunction with the 1997 re-release of the first two films. The 6-track was remastered by performing any improvements that were necessary. The necessary insert material was re-added to complete the director's version of the film. The end result was a 6-track SR-D format mix of the director's cut, including DTS and SDDS formats, along with a corresponding Dolby Stereo Lt/Rt analog back-up.

4.7 Recording the finished work back to film

At Technicolor, after a full digital restoration of a title, the finished data is output to film via ARRILASER cameras. Often high quality intermediate film stocks, such as Eastman 2242 or 5242, are used for this purpose. New digital yellow-cyan-magenta (YCM) elements can also be created as ultimate preservation records. These elements, which are created on black-and-white fine grain stock, can outlive color stocks, as there is no fading. The YCMs can be created as three-strip elements, meaning each color record is recorded to a separate piece of film. Another method is to record them by SE, on a single strip of film.

Antley explained that the actual recording process is done with a device called a film recorder. The earliest film recorders in the motion picture industry used a monochrome CRT to display each color plane sequentially through red, green and blue filters. These systems were limited in the amount of exposure and imaging speeds they could generate. Because of the limitations, the work used to be done on camera negative film stocks, and generally only very short visual effects shots were recorded. Laser based film recorders were developed due to the need for increased throughput and the desire to record the image directly to color intermediate film stocks. Laser based film recorders use individual red, green and blue lasers as the light source. Each beam in the recorder passes through an acousto-optic modulator (AOM) in order to modulate the intensity according to the digital values for each pixel. The beams are combined and then scanned on to the film at very high speeds. Modern film recorders, such as ARRI's ARRILASER, can expose the entire dynamic range available in the recording stock a little faster than one frame per second with essentially perfect image quality. Practical operational aspects, such as having an appropriate IT infrastructure including large storage volumes and high speed networks, have to be considered too. The main considerations for the quality of the recorded images include things such as resolution, film stock, densitometry and geometric calibration of the recorder, and the potential need for image processing such as color management, re-sampling (re-sizing) and sharpening.

Antley added that other technologies have been tried and some have found modest commercial success, but most of these sacrifice some aspect of image quality in favor of greater speeds. These mostly employee area array modulators, such as LCOS (liquid crystal on silicon) or DLP (Digital Light Processing) panels originally designed for use in video projectors.

4.8 The debate concerning film and digital archiving

According to Cavena, current film archiving is about managing the unpredictable degradation of film, but not eliminating degradation. On the other hand, a digital content archive can store films forever without any degradation. As far as Cavena was aware, no digital file type for archiving has yet been standardized, and the digital archive object is still unknown. This has been a business decision of the entertainment industry, not the IT industry. Cavena claimed that some people think that a digital archive medium can be found where things such as formats, software, chipset instructions and media

wouldn't change. The "store & ignore" model associated with film archiving is entirely irrelevant in the digital world. Digital technology will never be as static as film has been since 35mm film was adopted in the early 20th century.

It was referenced in section 2.9 that archiving a 100 terabyte digital archive object in a 2000-movie archive would cost $73,000 per archived movie per century. Today the price has come down considerably. According to Cavena's calculations based on current tape technologies, the price is around $39,000 now.

Archiving in 4K is a major local area network (LAN) bandwidth issue, as well as a storage area network (SAN) issue. If an image is scanned at 10-bit DPX (Digital Picture Exchange) in 4K resolution, the net is somewhere between 50 to 100 megabytes per frame, depending on the settings. A typical 4K scan of a single frame in 16-bit linear Tagged Image File Format (TIFF) requires 32 megabytes for each color channel (red, green and blue), which makes the total size of the scanned frame 96 megabytes. At Image Trends, a fourth channel is added due to the IR, which raises the total size of a scanned frame to 128 megabytes. 2K is only ¼ of the data size compared to 4K, but it is mostly only used for TV or archive of old, faded film that no longer has 4K of information.

Heiber presented the question of what the vinegar syndrome of the digital world will be. As examples he mentioned bit rot, copying problems and digital conversion issues. Formats, software and operating systems are big issues as well. However, on the audio side the situation is more fortunate as BWF is a standard format in computers, and it's also open source. Because of this, Heiber predicted that there will less likely be issues with digital audio, but thinks there are some issues that aren't even understood yet as there isn't, for example, 30 years of experience with the digital material. According to Gluck, digital archiving has been and will always be influx due to ever changing files schemes and iterations of storage media. The first key decision is to decide what is stored rather than the concern how it is stored, and that is the essence of an archive. Harris believed the term digital archiving is an oxymoron, where too many unfortunate things can happen over time.

This chapter has provided the study and results portion of the thesis. The information presented here has been constructed from the responses given by 13 experts who work in the areas discussed in the thesis. The next chapter presents conclusions and also suggestions for future research.

5. Conclusions

This thesis has attempted to provide the reader an examination of modern day digital film restoration and remastering techniques without going into specific algorithms. The emphasis has been on finding out about the challenges faced in both picture and sound restoration, what the solutions to those problems are, and what kind of ethical implications might show up in the process. Hopefully this thesis has provided new information to the IS industry, particularly when examined how information derived from analog formats is processed by people using various processing techniques, and what it takes to prepare material for contemporary general audiences who might have high expectations or standards of quality. Also relevant has been the discussion how some of these processes have been used in a questionable manner.

The study was validated by the following people: Dave Cavena, Theo Gluck, Bob Heiber and Martin Koerber. This means that an evaluation version of this thesis was emailed to some of the interviewees so that they could request changes or corrections and make sure that none of their responses were used incorrectly. Changes were then made based on their notes.

The first step in the digital restoration process is the digitization of the film. The study has shown that there can sometimes be debates and factors to determine the scan resolution for each film element, but generally speaking, 4K is enough for 35mm film, at least in cases where the original negative is available. Bit depth and dynamic range also determine the quality of a scan. Even if the images are scanned in 4K, the resolution workflow might be 4K-2K-2K, for example. Compared to 2K, 4K quadruples data flow and also doubles the time and budget. Digital ICE is a technology that can remove surface defects in the scanning process, but its biggest limitation is that it doesn’t work on black-and-white film. Some scanners include a wet gate, which can remove the most superficial scratches.

Once the film elements have been scanned, the digital picture restoration process begins. Digital tools are used to remove spatial defects such as dust and dirt, scratches and chemical damage. The main method for correcting these types of defects is to borrow information from other areas in the same frame or from neighboring frames. Temporal defects such as flicker, image instability and color breathing can be reduced as well. Automated tools in picture restoration can save time and money, but these processes still have the tendency to mistake picture elements that appear in only one frame as defects. It is important to have an operator to make sure that no digital artifacts are introduced and no picture elements are erroneously removed. As digital tools continue to develop and improve, further research is recommended, particularly in the upcoming years. It’ll be interesting to see where digital restoration will be in ten years from now, for example, if indeed only half of the science has been invented so far.

One of the original goals of this study was to contact facilities that have created software and proprietary tools, which then would have been presented and compared in this study. However, this proved to be unsuccessful as most facilities can’t share that kind of information. For example, an interview request was sent to MTI Film to discuss their digital restoration tools. The response received from them explained that because the software they develop is commercially available and competitive due to their unique

algorithms, they were not allowed to be too specific about how their tools work. Similar type of issue happened with Reliance MediaWorks. The company has created very powerful proprietary image processing tools, so it would have been beneficial to this study to discuss at least some of them.

Film grain management has been an issue of debate in recent years. There are numerous examples of remastered titles where film grain and noise have been reduced or even completely removed in order to provide a smoother, more pleasing image. In these instances, typically the original filmmakers are not involved in the process. However, this study claims that in most cases this should not be done, and that film grain should still be visible. The current general consensus is that grain removal is a bad thing.

The handling of production nuances is a more complicated issue, and generalization becomes very difficult. Wire removal was one of the most frequently asked issues in the interviews conducted for this study. There was no consensus among all the responses, but the following conclusions can be made. If wires were visible to audiences in a print at the time the film was originally released, they should not be removed. However, if a high resolution scan of an early generation film element brings out nuances that were not visible at the time, then the problem or nuance should be masked with current technology as much as the technology at the time of production would have masked. If a mistake occurs during the production of a film that stays in the released version it is part of the authentic experience and thus it should be respected and left alone. Digitally altering it can give a falsified impression of film production techniques that were available to the filmmaker at the time.

However, there are two counter arguments: artistic intent and the expectations of broader modern audiences. It can be argued that if the filmmakers had seen the mistake, and in most cases did see it, they would have absolutely fixed it if they had the luxury of time and budget. For example, the reasoning for removing the wires from *20,000 Leagues Under the Sea* was because the filmmakers during the production tried to hide them. Due to current expectations or standards of quality, where contemporary general audiences expect a high level of stability, cleanliness and clarity, the limitations of a really old film becomes more distract from the immersive viewing environment of the original experience. Particularly a studio archivist who is preparing material that will eventually be released on digital media for a much larger and more general audience, he or she may result to fixing any or all of the issues that always were in the original film. The question remains that does this kind of digital manipulation simply create a new edition of the film, and does it then stop being a restoration.

The inevitable process of color fading occurs to all types and brands of color motion picture. Digital color-timing provides more possibilities and is more efficient in terms of speed and exactitude when compared to photochemical color-timing. The lack of reference for restoring the original colors is usually the biggest challenge in the color grading process, and film restorers often need to make a well-educated guess what colors are to be restored.

In sound restoration, research and evaluation is often the most important part of the process. The issue of different versions can cause challenges in the restoration. The examples shown in this study show that it is sometimes necessary to create custom machinery to be able to playback and digitize the various sound elements, which is often the most challenging part of the process. After digitization, an engineer will work on a computer workstation to identify and deal with all the various sound issues. Hums,

thumps, clicks and pops can generally just be filtered or edited out, and hiss can typically only be reduced, not removed.

Modern speakers can perfectly reproduce low frequencies that were recorded in the soundtrack but could not be heard in the early days of sound films. Splice bloops and rumble are examples of these sounds. While there can be debates, generally these types of sounds would be removed in the restoration, as the audiences at the time of the original release did not hear them very well. Stereo panning problems and dialogue synchronization issues can cause debates as well, and whether the end result is better is subjective. In the case of missing sounds, the first solution is to try to find the same sound in the movie and fill it in. The second choice is to try to find the same sound from another movie made in the same era. In the worst case scenario, the sound is recreated with the attempt to give it the appropriate characteristic. This would be highly documented.

Automated processes in sound restoration should be used sparingly in order to prevent the removal of sounds that should not be removed. Examples such as crackling fire and a person walking on gravel are sounds that the software can easily mistake for noise. Removing layers of noise can also uncover sounds that were never heard before. If this happens, often the solution is to layer some of the noise back in to the soundtrack in order to cover the sound that didn't exist before.

Regarding audio restoration and remastering, this study could have benefited from interviews with two companies: Audionamix and Cube-Tec. The former has created technology that can create multi tracks from a mono track, while the latter has designed and is designing new sound restoration algorithms, such as those for handling various types of distortion. Distortion is one of the hardest things to fix, and particularly intermodulated distortion is impossible to remove. There were also several other experts who initially agreed for an interview, but either due to time constraints or lack of interest or trust, did not eventually answer any of the interview questions sent to them.

For this study, 12 of the 13 experts were interviewed by email. One of the benefits of an email interview is that the interviewee can analyze and construct their responses in a clear, precise manner. However, this required the interviews to be fairly structured, as interviewees are less likely to improvise in an email interview. In contrast, the one live interview conducted for this study provided by far the most amount of information. The semi-structured interview allowed room for plenty of improvisation, as other aspects beyond the prepared interview questions were discussed. For future studies that use qualitative interview as data gathering tool, if possible, performing live interviews is more commendable compared to email interviews. This is particularly recommended if the researcher desires to do unstructured or semi-structured interviews.

An effective research method to study digital film restoration would be in the form of participant observation, where the researcher is involved in an actual restoration of a title. The researcher would follow and document each phase of a restoration project, for both picture and sound restoration. In addition to this, the people doing the restoration would be interviewed. This kind of research would result in a detailed case study where all the challenges, problems, ethical questions and solutions are documented and then reported. As this study has shown, each restoration has similarities and differences. This is why one of the challenges in getting answers to some of the interview questions was that the answer would differ from project to project, thus making generalization very difficult. For example, the challenges faced in restoration of a silent black-and-white film from the 1920s might differ greatly from a Hollywood epic from the early 1960s

shot on 65mm color film. This means that conducting more than one case study would be preferable. At the very least, the title chosen for the study should have as many challenges as possible.

The debate concerning film and digital archiving continues and for this study there was no consensus which is the more appropriate way to archive films. To this day, no digital file type for archiving has yet been standardized, and the digital archive object is still unknown. Archiving in 4K is a major LAN bandwidth issue, as well as a SAN issue. One of the film archivists interviewed for this study felt that digital archiving is an oxymoron where too many unfortunate things can happen over time. 35mm film has essentially been the standard since the early 20th century, and recording the finished DI to YCM separation masters as ultimate preservation records are said to have a 100-year or longer life.

On the other hand, others argue that a digital content archive can store films forever without any degradation. Compared to film, digital technology will never be as static so having a medium where formats, software, chipset instructions and media do not change is irrelevant. As the calculations provided for the study show, archiving a film digitally will be cheaper in the long run compared to archiving it on to YCM separation masters. The technology is available to digitally capture all the information that is available on the film so there is no need to wait for 128K scanners to become available. Finally, as both capture and exhibition are becoming digital, and post-production, libraries and repurpose are already digital, digital archiving will eventually become an incontestable matter that should be endorsed rather than ignored.

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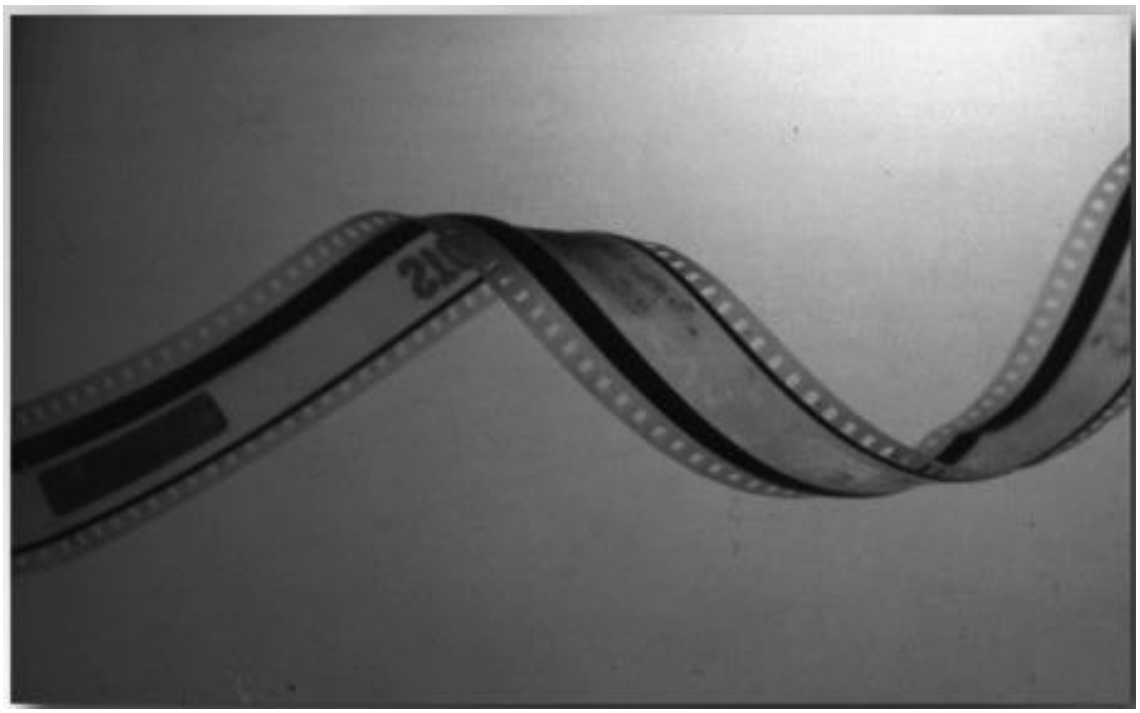
Attachment A. Abbreviations

ACE	Automatic Color Equalization
AFI	American Film Institute
AMIA	Association of Moving Image Archivists
AMPAS	Academy of Motion Picture Arts and Sciences
AOM	acousto-optic modulator
BFI	British Film Institute
BWF	Broadcast Wave Format
CDS	Chace Digital Stereo
CGI	computer-generated imagery
COSP	Chace Optical Sound Processor
CRT	Cathrode Ray Tube
db	decibel
DI	digital intermediate
DIS	Digital Intermediate systems
DLP	Digital Light Processing
DNR	digital noise reduction
DPX	Digital Picture Exchange
DRS	Digital Restoration System
DSP	digital signal processing
DTS	Digital Theater systems
dupe	duplicate negative
DVD	Digital Versatile Disc or Digital Video Disc
EK	Eastman Kodak
FFT	Fast Fourier Transform
HD	high definition
HRTF	head-related transfer function
Hz	hertz
IN	internegative
IP	interpositive
IR	infrared
IS	Information Systems
IT	information technology
kHz	kilohertz
LAN	local area network
LCOS	liquid crystal on silicon
Lt/Rt	Left total/Right total
MDF	Modulation Transfer Function
MGM	Metro-Goldwyn-Mayer
MO	magneto-optical
MPI	Motion Picture Imaging
NFPF	National Film Preservation Foundation
OCN	original camera negative
PAL	Phase Alternate Line
perf	perforation
RGB	red, green, blue
SAN	storage area network

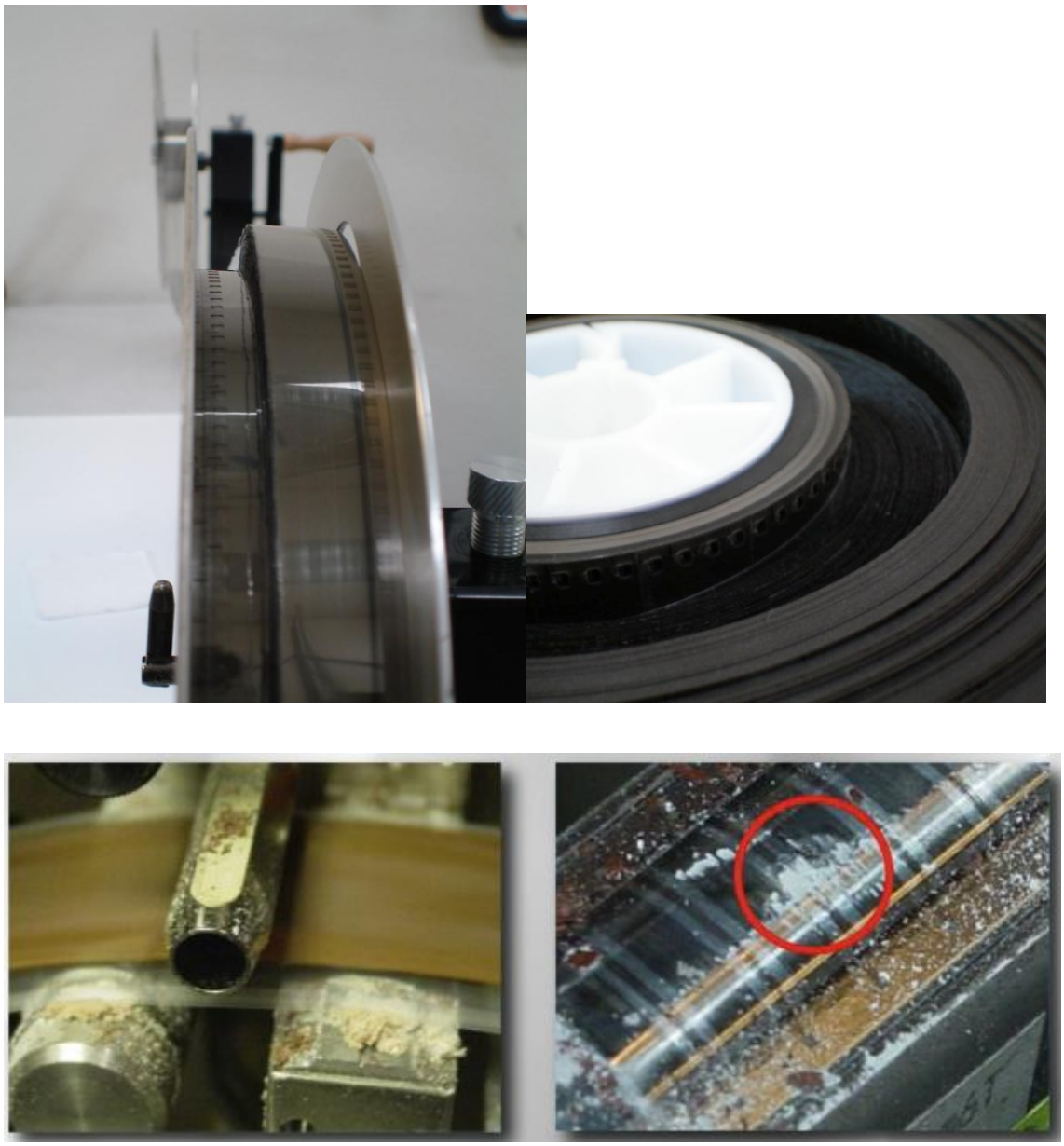
SDDS	Sony Dynamic Digital Sound
SE	Sequential Exposure
TIFF	Tagged Image File Format
UCLA	University of California, Los Angeles
VHS	Video Home System
WAVE	Waveform Audio File Format
YCM	yellow-cyan-magenta

Attachment B. Figure 3

Attachment C. Figure 7



Attachment D. Figure 8



sondor