FRAMING FILM

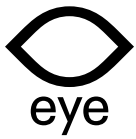
FRAMING FILM is a book series dedicated to theoretical and analytical studies in restoration, collection, archival, and exhibition practices in line with the existing archive of EYE Filmmuseum. With this series, Amsterdam University Press and EYE aim to support the academic research community, as well as practitioners in archive and restoration.

GIOVANNA FOSSATI, VICTORIA JACKSON,
BREGT LAMERIS, ELIF RONGEN-KAYNAKÇI,
SARAH STREET, JOSHUA YUMIBE

THE COLOUR FANTASTIC

Chromatic Worlds of Silent Cinema

AMSTERDAM UNIVERSITY PRESS



Published by EYE Filmmuseum / Amsterdam University Press

Cover illustration:
Cover design and lay-out: Magenta Ontwerpers, Bussum

Amsterdam University Press English-language titles are distributed in the US and Canada by the University of Chicago Press.

ISBN 978 94 6298 301 4
e-ISBN 978 90 4853 298 8
DOI 10.5117/9789462983014
NUR 670

TABLE OF CONTENTS

CHAPTER 12

A Material-Based Approach to the Digitization of Early Film Colours

Barbara Flueckiger, Claudy Op den Kamp, David Pfluger

G. Fossati, V. Jackson, B. Lameris, E. Rongen-Kaynakçi, S. Street, J. Yumibe, *The Colour Fantastic. Chromatic Worlds of Silent Cinema.* Amsterdam University Press, 2018

DOI 10.5117/9789462983014/CH12

ABSTRACT

While the digitization of archival films has been practiced for more than a decade, there is still a lack of academic rigour in this field, both on a scientific as well as on an interdisciplinary level. Therefore, we are in need of a better understanding of basic principles, both technological and aesthetic, that guide the many decisions taken throughout the process. This paper presents three interconnected research projects that investigate these topics with a comprehensive approach. Based on thorough analyses of the technology, physics, and aesthetics of film colours, this material-based approach connects these diverse disciplines with the aim to translate the appearance of analogue film colours into the digital domain.

KEYWORDS
film, colours, aesthetics, technology, digital, restoration

While the digitization of archival films has been practiced for more than a decade, there is still a lack of academic rigour in this field, both on a scientific as well as on an interdisciplinary level. In the specific case of translating early colours into the digital domain, curators and service providers have found practical solutions to the many related obstacles and diverse requirements. However, we are in need of a better understanding of basic principles, both technological and aesthetic, that guide the many decisions to be taken along the process. This paper presents three interconnected research projects that investigate these topics.

In her recent text *The Archival Life of Early Color Films*, Giovanna Fossati writes with regard to the digitization of tinted material:

> As not many laboratories are working on the 'digital Desmet' method, there is still very limited experience and the results are not yet as successful as in the case of the photochemical method. In particular, the reproduction of the original tints is not always accurate, while the reproduction of the black and whites, instead of remaining neutral, acquires an undesired tint.[1]

One of the main causes of this problem is the complexity of the task. Research in this field has to consider a wide array of disciplinary approaches, from chemistry, physics, and IT, to aesthetic and historical aspects, and not the least, psychophysical questions of colour perception and colour appearance.

In the analogue film-restoration era, there have been numerous solid approaches to combine practices with academic research, restoration ethics, and curatorial considerations. From the 1980s, there has been the so-called Italian *Scuola Bolognese*[2]; in the Netherlands, there is the master programme 'Heritage Studies: Preservation and Presentation of the Moving Image', closely connected to EYE Filmmuseum; and in the US, various master programmes at NYU and UCLA have been established as well as the L. Jeffrey Selznick School of Film Preservation, in collaboration with the University of Rochester. In archival practices, we can identify several film laboratories and audiovisual archives that helped to invent ingenious approaches to the problem of transferring early film colours to modern film stocks, including applying historical techniques of tinting and toning.[3] The properties of modern chromogenic stocks and their material supports, which differed considerably from the historical nitrate film, have continued to pose severe limitations.[4] Digital tools, in contrast, are a relatively recent development, and still poorly understood, not in the least because many commercial tools available to the industry are black-box operations.

This paper gives an overview of three research projects: 'Timeline of His-

torical Film Colors', 'DIASTOR', and 'ERC Advanced Grant FilmColors', all of which are located at the Department of Film Studies at the University of Zurich and managed by Barbara Flueckiger as principal investigator. The common denominator of these projects has been the search for an interdisciplinary approach that bridges the gap between a humanities-based investigation of historical technologies and aesthetics of analogue and digital film on the one hand, and applied technological research in IT, combined with material science and optics on the other hand. Over the course of these projects, the research team(s) established a material-based approach to the digitization and reconstruction of (early) historical film colours. This approach combines a deep investigation of the material properties of the films with contextual research on the films' aesthetics. In addition, it explores the principles of the digitization chain, from scanning to post-processing, colour grading, and projection. As a general objective, the approach aims to build a bridge between the different aspects by integrating them in the digitization and restoration workflow to the material characteristics of the film element(s).

'TIMELINE OF HISTORICAL FILM COLORS', A COMPREHENSIVE WEB RESOURCE

In the framework of the research project 'Film History Re-mastered' (2011-2013), Barbara Flueckiger and Franziska Heller investigated the changing perception of film history as a result of the digitization of archival films. One of the main topics of this project was the change of film aesthetics in regard to the rendition of colours, which led to the development of the 'Timeline of Historical Colors'.

Early film colour research is based on technical handbooks, including those on colour photography from even before the advent of film.[5] This line of investigation was pursued throughout the twentieth century, with the publications *Colour Cinematography*[6] and *A History of Motion Picture Color Technology*[7] widely regarded as the most important works. While these overviews are essential in providing solid knowledge about the chemical, mechanical, and optical principles in operation, they do not discuss the aesthetic or narrative application of these processes in film or media production, nor their contemporary reception.

By contrast, a growing number of books in recent years have focussed on semantic, narrative, and aesthetic features of colour in film.[8] With some notable exceptions of texts that investigate historical developments,[9] such as silent film, early Technicolor, or colours in British or Italian film production, these texts only rarely build a connection to technology. When they do, they hardly explore the technical foundations of the colours scientifically; they instead

rely entirely on written sources, and are located within a 'text-based', bottom-up, analytical approach.

Predominantly after the famous 1978 Brighton, UK International Federation of Film Archives (FIAF) Congress, academic interest grew to explore uncharted film archival collections. The quest focussed most notably on early film colours, eventually leading to the 1995 workshop on colour in silent cinema held in Amsterdam and to an increase in colour restorations.[10] Analogue techniques of film colour restoration were the topic of the seminal publication by Paul Read and Mark-Paul Meyer.[11] In summary, there is a wealth of publications, but it is the interconnectedness of the different approaches to the investigation of (early) film colours that has never been explored.

This insight led to the development of the 'Timeline of Historical Film Colors' by Barbara Flueckiger in 2011. During two research visits at Harvard University, she started to collect written sources from the different fields of study relevant to the topic. From the inception of the project, she aimed to integrate pictorial representations of the various film colour aesthetics by taking photographs of historical films in audiovisual archives. To this end, she has developed a modular, calibrated camera setup that allows her to capture the images on an inspection bench at a high resolution – currently 50 MP with a Canon EOS 5Ds R – and high dynamic range (HDR).[12] Firstly, these images give the user of the web resource an immediate sensorial impression of the colour appearance of the films as material objects. Secondly, they provide important information about each of the depicted film colour's characteristics, most importantly about those parts of the film that are not seen in projection, such as frame lines, the perforation area including edge codes, foot numbers, and typical colourings, damages, or contaminations.

Various illumination techniques have been applied to render the film's material properties, including its three-dimensional information, reflection, and texture. Raking light, for instance, produces images that show the surface properties including dust, scratches, dirt, silver mirroring, and blemishes. A range of specific information about dyeing techniques and the hues of individual dyes or pigments become visible at splices and in nonimage parts where leaking dyes can be identified individually. Photomicrographs with up to 20x magnification and super-macro photographs give detailed information about the small-scale variations of the film colours. Furthermore, the standardized procedure enables the comparison of different prints of the same film in various archives.

First published online in 2012 as a chronological overview, the 'Timeline of Historical Film Colours' was redeveloped in 2013 to serve as a Digital Humanities platform that allows external contributors to upload texts and images directly. As of 2018, it contains over 9500 photographs, more than one

thousand original papers and secondary sources – accessible through a pop-up reader – such as patents, selected analyses, firsthand accounts of contemporary reception, restoration case studies, filmographies, links, and downloads, and a section on edge codes and identification of colour-film stock, plus colorimetric measurements.

'DIASTOR - BRIDGING THE GAP BETWEEN ANALOGUE FILM HISTORY AND DIGITAL TECHNOLOGY'

As a result of insights gathered in previous projects, 'DIASTOR', an applied research project, was conceived to focus on several identified research gaps. Even before 'Film History Re-mastered', the earlier applied research project 'AFRESA' focussed on technical questions of film restoration and aimed to develop a mobile scanner unit for middle-level requirements to produce digital access elements in archives. With their background in digital image processing, physical chemistry, and scientific photography, collaborative partner Image and Media Lab (now Digital Humanities Lab) at the University of Basel, built on a long history of basic and applied research on the digitization of photographic colours with a special emphasis on the reconstruction of faded chromogenic stocks.[13] 'AFRESA' therefore aimed to implement these insights into the digitization of moving images. The project instantly made clear that, firstly and not so surprisingly, film scanning is the most crucial step in the digitization of archival film, and, secondly, that there is a thorough lack of interdisciplinary research into unresolved problems of practice and technology. In general, most of the film scanners were never developed to match the requirements of archival film. Furthermore, they were and are severely limited in their scope to adjust to a variety of different colour-film stocks.

Subsequently, 'DIASTOR' set out to investigate these limitations by connecting various players in film preservation, digitization, and IT research from the Federal Institute of Technology in Zurich and advanced research in visual computing from the Disney Research Lab. Service providers[14] were at the core of the project, both by providing their technical infrastructure and by implementing the results. They included the only film laboratory still operating in Switzerland, Egli Film, which soon thereafter was taken over to form cinegrell postproduction; engineering companies, such as Sondor Willi Hungerbühler, and – perhaps most importantly – audiovisual archives; the Cinémathèque suisse and SRF Swiss Radio and Television, which were asked to identify and express their special needs.

Several case studies – applied-digitization and restoration projects – were provided not only by DIASTOR's partner archives, but also by external archives,

such as Stiftung Deutsche Kinemathek, EYE Filmmuseum, the Friedrich Wilhelm Murnau Foundation in Wiesbaden, and Harvard Film Archive. Three of these case studies focussed on early film colours – mainly tinting, and, to a lesser degree, toning.

Each of these case studies was designed to target a principal practical question:

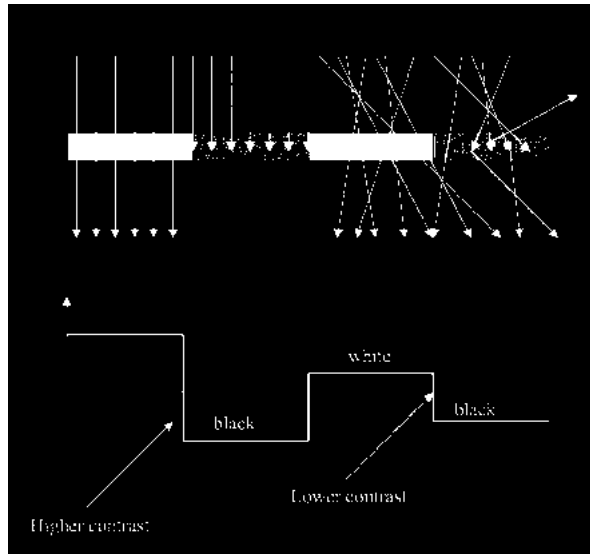
- *Der Märchenwald – Ein Schattenspiel* (provided by the Stiftung Deutsche Kinemathek) was used for the reconstruction of tinting with a newly invented workflow, which will be presented and discussed in a later section of this paper, entitled 'Colour and Style Transfer';
- The colour analysis for the digital restoration of *Das Cabinet des Dr. Caligari* was used for the documentation, appearance, and chemico-physical measurement of tinting and toning in five different prints;[15]
- The digital Desmet study executed on the tinted title *Aan de kust van Istrië* [*On Istria's coast]* aimed to investigate the influence of a laboratory environment on scanning and to devise an environment-independent 'recipe' for scanning and post-processing films with early applied colours.

Each of the applied-colour schemes had special characteristics that further informed the research questions. While, as a silhouette film, *Märchenwald* was very particular regarding the high-contrast characteristics with deep blacks that often pose a problem to colour grading, *Aan de kust van Istri*ë had many mid-tones that show the interaction of the tinting dyes with the blacks and greys of the silver image. The colour analysis for *Caligari* was a particularly interesting case study because the existence of five differently tinted and toned elements required extensive research into the colour aesthetics and the genealogy of the prints.

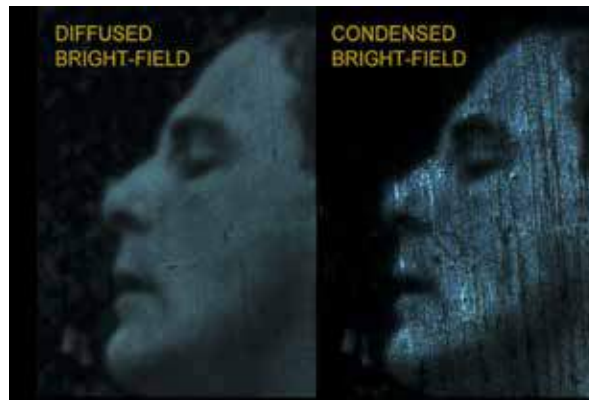
Each of these case studies necessitated an individual approach embedded in overall principles according to the three-pillar model discussed in a recent publication of the DIASTOR team:[16]

1. Photographic documentation, plus analysis of dyes or colour compounds;
2. Research into stability and decay models of dyes and colour compounds;
3. Film historical and aesthetic analyses; study of written historical sources.

The first pillar makes extensive use of the photographic documentation elaborated for the 'Timeline of Historical Film Colors'. It soon became clear that a close analysis of colour appearance is paramount to understanding the problems in scanning and reconstructing early applied colours. Colour appearance means the interaction of matter with light under certain viewing conditions.[17]



12.1: Influence of condensed (left) vs. diffuse light on contrast rendering: the Callier effect.



12.2: Diffuse (left) versus collimated (right) illumination.

It includes studies of colour perception in the human visual system, physical properties of spectral characteristics of dyes and colour compounds, and studies of different types of illumination.[18] The appearance of tinting and toning in projection is highly affected by the apparatus, the brightness of the source of illumination, its colour temperature and spectral power distribution, the distance to the screen, and the reflection of the screen. As mentioned in the *Caligari* paper, there is a significant difference between collimated – that is, directed illumination as applied in projection – and diffuse light sources, especially in the domain of tinted and toned films, which contain silver grains that scatter the incidental light. As a result of the *Callier effect*[19] produced by collimated illumination, tinting and toning appear to have higher contrast,

look crispier, and small-scale detail including scratches and dirt become more visible.[20]

The influence of the Callier effect on the rendition of tinting hues is highly unpredictable and needs further investigation. While cinema projectors operate with collimated light sources, most inspection situations in film labs, archives, and colour grading suites rely on diffuse illumination. It has to be noted that scanners operate with diffuse light as well.

To analyse the dyes or colour compounds, we resorted to a variety of methods as discussed in the *Caligari* paper. For tinting or toning only, colorimetric measurements with the spectrophotometer are sufficient to devise the spectral characteristics of dyes or colour compounds and to identify them based on reference books. Tinting–toning combinations may require additional methods. One colourimetric method that was used in DIASTOR extensively and successfully was the 'Principal Component Analysis', according to Ohta.[21]

12.3: A tinted nitrate print of *Das Cabinet des Dr. Caligari* (GER 1919, Robert Wiene). Copyright: Friedrich-Wilhelm-Murnau-Stiftung, Wiesbaden. Photograph by Barbara Flueckiger. Source: Archivo Nacional de la Imagen – Sodre, Montevideo/ Cineteca di Bologna. Photography: Barbara Fluckiger, Timeline of Historical Film Colors.

This method allowed for the identification of the spectral characteristics of single dyes in film stocks that apply several dyes, such as tinting–toning combinations or more recent chromogenic stocks.

Applied colours are often unstable and it is difficult to identify the decay of the dyes because their original hues are unknown. For instance, in the two *Caligari* prints from South American archives, the nocturnal scenes were tinted green while they were blue in other prints, more in tune with established colour codes of the time. Often, however, the decay affects only part of the images, mainly the frame area that used to be exposed to the heat of the projector. Individual sections of film tinted in the same hue may show variations due to the printing and dying process. Before the advent of the mechanical control of the printing lights, the positives had to be developed in patches according to their density and were subsequently dyed, thereby producing slight variations, probably due to the concentrations of dye baths.[22]

For pillar three – film-historical and aesthetic analyses and study of written historical sources – we could resort to the 'Timeline of Historical Film Colors'. Either the necessary information was readily available or we could add external sources by visiting archives or by papers already gathered but not yet included in the 'Timeline'. Therefore, it acted both as a resource, but also as a platform to share insights elaborated within the project. These are two of the main functions of this Digital Humanities platform and will become more extended in the research project 'ERC Advanced Grant FilmColors', which will be the topic of the last section of this paper.

MATERIAL-SCANNER INTERACTION

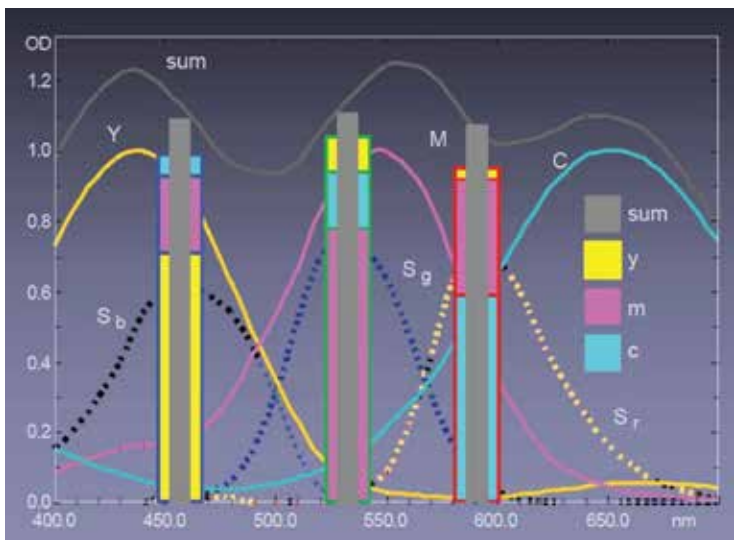
To understand basic principles of material–scanner interaction, the DIASTOR team developed and executed a scanner study that included eight professional high-end scanners.[23] In this study the team scanned a variety of seven different color film stocks to explore the optical and mechanical constraints of the scanners.[24] A comprehensive account of the scanner study and its results will remain outside of the scope of this paper, but a detailed report has been written and is currently available. The present paper rather aims to summarize some basic principles by referring to previous work and to analyse the specific case of scanning early applied colours in more detail.

As Flueckiger notes elsewhere, scanning is a reduction process, governed by selection principles, or, to put it differently: in essence, digitization is an extraction of discrete data from a continuum of physical properties of the outside world.[25] In his 1968 seminal study of digitization in *Languages of Art*, Nelson Goodman discusses the concept in regards to earlier meas-

urement methods that try to extract data in a similar fashion, such as a thermometer. While temperatures are continuous phenomena, their digital measurement is based on a numerical order system and converts the physical and sensorial dimension into this system by assigning arbitrary and discrete numbers to it according to a specified protocol. The same principle is at the foundation of scanning. Continuous colour (or grey) tones are mapped into a discrete RGB space by a combination of two processes: sampling and quantization. Sampling means the extraction of values from a spatiotemporal entity by filtering this entity into small units: pixels in the spatial domain and discrete frames in the temporal domain. Quantization describes the assignment of binary values to the discrete data extracted in the sampling process. This assignment of binary values is defined by a reference system such as a colour space and their organization within a given scale, for instance, 16bit linear per channel RGB. By definition, all data outside this system is lost.

It is important to note that the first step – sampling – is essentially defined by optical and, to a lesser degree, mechanical operations of the extraction system, in this case, the scanner. Therefore, it is important to look into the interaction between the scanner and the film material on a physical basis. Early on, Rudolf Gschwind and Franziska Frey started to highlight some fundamental problems of this interaction, displayed in figure 12.4.[26]

12.4: Material–scanner interaction for chromogenic negatives. Illustration by Franziska Frey and Rudolf Gschwind.



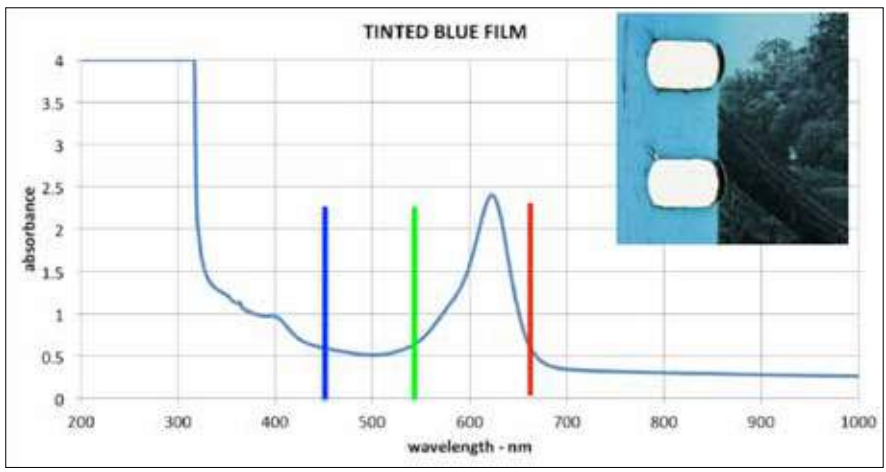
Each of the vertical bars and dotted lines indicate the narrow band characteristics of the scanners' sensors. Ideally, the scanners' sensitivity would match the absorbance maximum of each individual dye when scanning negatives or faded chromogenic stock. Individual scanners may have slightly different properties, but, in essence, they have fixed spectral sensitivities that may or may not comply with the spectral characteristics of the film stock to be scanned. Especially in the domain of early applied colours, we may be confronted with unusual properties of dyes and colour compounds.

In the course of the preliminary scanner studies performed during the International Broadcasting Convention in Amsterdam in 2013, it became obvious that some of the scanners were not able to capture the blue tinting at all. They were, as we were told by one of the manufacturers, 'colour blind'.

While it was difficult or even entirely impossible to obtain information about the scanner sensor's and the illuminant's properties, we could tackle part of the problem by investigating the film stock. This task was executed by Giorgio Trumpy, an associate senior researcher in DIASTOR, employed at the University of Basel at the time. Trumpy measured the blue tinting on a bench spectrophotometer SHIMADZU UV-1800, which delivered the result shown in fig. 12.5.

The three vertical bars – red, green, and blue – indicate typical characteristics of narrow-band illumination. As a result of the mismatch between the

12.5: Measurement of the blue tinting with the bench spectrophotometer Shimadzu UV 1800 by Giorgio Trumpy, the blue, green, red lines indicate narrow band LEDs of a typical scanner.



physical properties of the scanner and the spectral absorbance of the blue dye with a peak between the green and the red line, the scanner shows difficulties to capture this specific blue hue.

While it may seem that this mismatch is an exception due to the particularities of this specific dye, similar effects occurred in all the other instances in which we scanned tinted materials. In the case study *Aan de kust van Istrië*, we scanned the same material on an Oxberry scanner and on an ARRISCAN at Haghefilm Digitaal in Amsterdam, plus on an ARRISCAN at DIASTOR partner cinegrell postproduction in Zurich, in collaboration with scanner operator Markus Mastaller from ARRI in Munich.

The results were similar for the different hues in *Märchenwald*, compared to the reference images captured with the method described in the section that addresses the 'Timeline'.

It has to be noted, however, that the scans on the ARRISCAN were not primarily captured with the aim to render the colours as faithfully as possible, but with the aim to avoid any clipping, i.e. a situation in which the density of one of the channels is not within the tonal range of the selected colour space and bit-depth. Even when trying to match the colours better, the results were far from rendering the hues in their saturated and glowing quality as they appeared on the nitrate print.

12.6-12.9: *Der Märchenwald. Ein Schattenspiel*: Comparison raw scans (left) with reference photographs (right). Credit: Stiftung Deutsche Kinemathek. Photographs by Barbara Flueckiger.

As elaborated in more detail in the article '"Digital Desmet": Translating Early Applied Colors',[27] we decided to abandon the concept of scanning as a process to capture the appearance of the film completely and instead devised a method that we termed 'Digital Desmet Plus', a strategy that aimed to capture each RGB channel individually by capturing the maximum amount of information while, at the same time, preventing any clipping in the black-and-white range. In accordance with the thoughts about the principles of the scanner–material interaction mentioned above, this strategy provided the most flexibility for colour grading.

Most importantly, the DIASTOR scanner study has shown that there is currently no single scanner on the market that is able to cover the full spectrum of requirements defined by a range of historical film colours. Ideally, scanners should offer much more flexibility; none of them, for instance, operates with collimated light, which could be essential for recreating the look of tinted or toned film in projection. Additionally, a modular scanner system, which allows the adjustment of sensor, optical system, and illumination, would be of great use to capture these early films. Most scanners are not able to record the full film width and thus they cut off important metadata present in the non-frame portions of the film. Once the film print is decayed or lost, these metadata will be lost forever, and, with the loss of metadata, the film print's history will become more obscure to future researchers and archivists.[28]

As discussed elsewhere,[29] we should envisage a scanning process that captures the films' material properties beyond the reduction to one single reading of the image plane with reference to the *imago–struttura* ('image–structure') dichotomy proposed by Cesare Brandi.[30] Traditional scans flatten the three-dimensional structure of a film, its emulsion, and support into a two-dimensional representation. New technologies – including so-called computational photography – are evolving in other fields of film production. They combine a multitude of lighting situations with varying camera angles, focus planes, and/or 3D scans to form a comprehensive representation of scenes or objects. Future film scanning technologies should make use of these tools to register the full colour range with a multispectral approach and to capture the three-dimensional layers of the film as a material object.[31]

COLOUR AND STYLE TRANSFER

When we understand scanning primarily as the gathering of information, we have to develop a complementary strategy that aims to reconstruct the appearance of a film. We called this approach the *information-versus-appearance model*. As noted in the section that addresses the 'Timeline', the documenta-

tion of the colour appearance of a film's material manifestation necessitates a calibrated camera setup that allows for the adjustment of every single component to render the visual impression of the film as closely as possible. Even such a sophisticated work flow is still confined to several constraints.

First of all, the reference object, the individual print, is rarely devoid of any flaws and it is not necessarily representative of the artwork's integrity. It may be faded or damaged; it may be incomplete or altered; it may contain material from different sources; and we often do not know its origin or history.

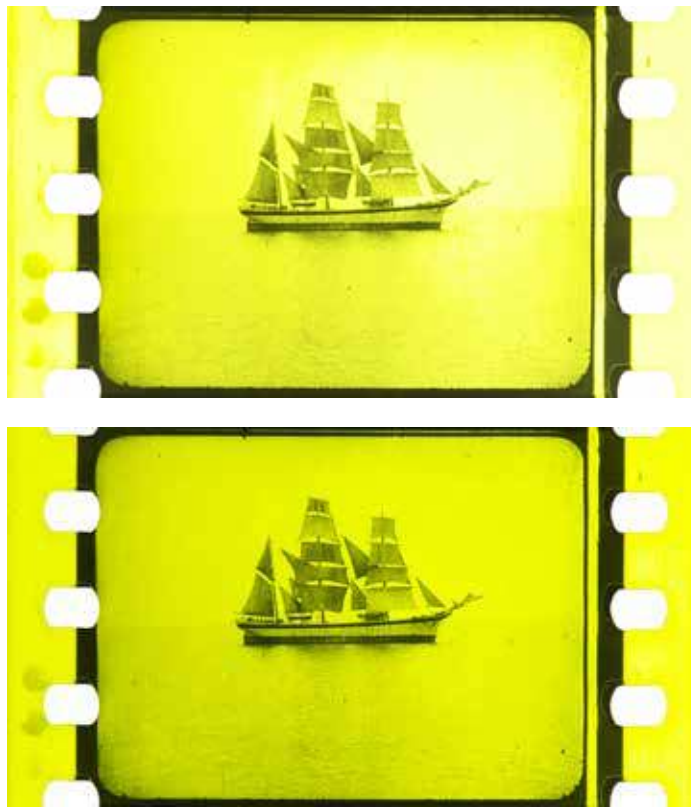
The second, perhaps more important question, refers to the source material(s) that serve(s) as object(s) of reference(s). While the question of the source material has been the topic of a long-standing debate in film restoration,[32] digital tools add another level of complexity to these questions. The two-step process used in analogue Desmet[33] is a predecessor of a vast array of procedures to combine elements from different sources. Due to restrictions of space in this paper, we omit the complex problem of the 'original'[34] as well as the question of a film's philological reconstruction. However, we can refer to the difference between *variants*, different instances of the film intended at the time of film production, and *versions*, historically altered textual instances of a film. This investigation is necessary to devise the colour scheme of the digitized element, and it includes a comprehensive documentation of the origin and the genealogy of all the elements available. While the philological reconstruction of the text may define the recourse to a variety of variants and versions of a specific film, including written sources, such as censorship cards or intertitles with a focus on textual completeness, the aesthetic appearance and the colour scheme might need to go beyond the field of a single film. We have to consider the technologies and style of the cultural context, the material appearance of a specific film stock produced in a certain period and/or the diachronic style of a film director, a production company, or a cinematographer who was instrumental to create a cinematographic work of art. This is especially the case when we have to assume that the surviving material manifestations of a film do not represent the historical authenticity of a film's aesthetics.

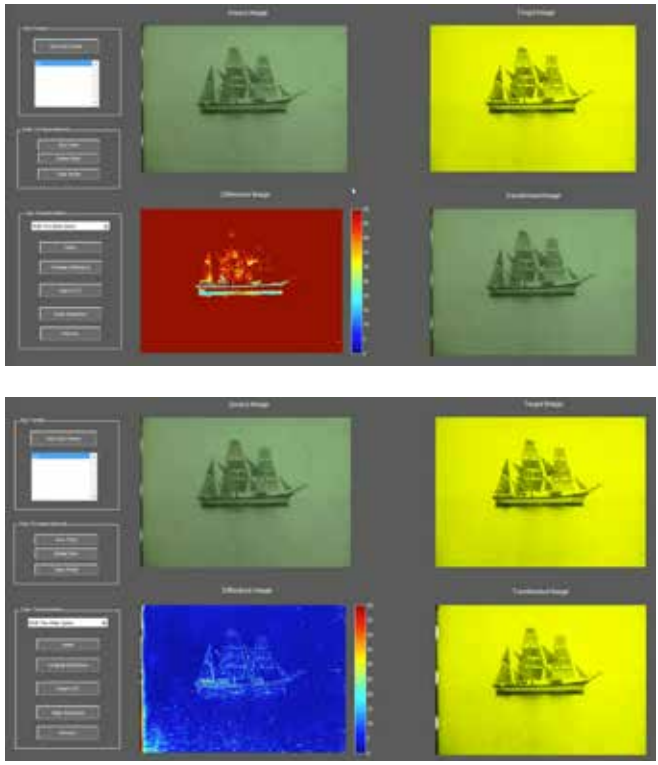
As a result, it is important to note that there is not a single reference, but a multitude of references, or a field of references, that should be considered when we aim to emulate a film's appearance. The technological, cultural, and aesthetic contextualization remains at the core of the basic idea behind the 'Timeline of Historical Film Colors'. The documented film prints and manuals by Eastman, Pathé, and Agfa,[35] plus the primary- and secondary-source papers, should provide a variety of elements to support the decision process. With regard to early applied colours, we are often confronted with material objects in black and white that serve as the material basis for the scanning process such as the camera negative, and we need to draw information about

the applied hues from the extended research into the historic style and the documentation of other surviving elements, a process that includes all the three pillars mentioned in the previous section.

Once the decision process has been established and all the source materials have been investigated and measured colourimetrically, this collection of elements has to be documented photographically to translate the necessary references into the digital domain. As mentioned above, colour appearance is tied to the interaction of matter with light and to the viewing conditions. Therefore, the documentation of the film material requires careful consideration of the illuminants and of other parameters of the work flow. If, for instance, the photos are only slightly overexposed, the characteristics of tinted film might be lost and the saturation of the brighter, tinted areas appears attenuated and uneven.

12.10 & 12.11: Slight overexposure (< 1EV) of the lime-tinted frames from *Aan the kust* (top), correct exposure (bottom). Credit: EYE Filmmuseum. Photographs by Barbara Flueckiger.





12.12 & 12.13: RestoGUI stage 1 (top) and stage 2 (bottom). Screenshots by Simone Croci.

Exposure needs to be controlled at all times by a histogram. In certain cases of densely tinted and toned films, a series of exposures has to be combined into an HDR image. To consider the effect of collimated light and of carbon-arc projection lights, additional measures need to be taken, part of which need further development. The spectral-power distribution of carbon arcs is documented in several papers.[36]

An often-overlooked aspect of colour appearance is texture. Small-scale variations of colour distribution on the film's surface are instrumental for aesthetic and affective appreciation of the artwork. These dimensions are especially important in the domain of early applied colours. There is a particular interaction between the silver image – or, in the case of metallic or mordant toning of the corresponding distribution of pigments or dyes, respectively – and the applied dyes in tinting, hand or stencil colouring. Even a slight reduction of the grain structure and the covariations of colour distribution can alter the colour impression considerably. Digital de-graining and re-graining tools hardly ever consider the specific influence of texture on colour appearance. *Debayering*[37] of digital files captured on scanners with Bayer-sensors also

destroys the grain structure, unless the resolution is very high and greatly surpasses the resolution of film.[38]

Based on our insights, DIASTOR partners Disney Research Zurich and the Federal Institute of Technology Zurich developed a tool for the colour and style transfer, called RestoGUI.[39] It allows the colour grader to semi-automatically extract and apply colour values from a reference image, captured according to the considerations described above, onto the information contained in the scanned image. The RestoGUI is a feature-based approach that selects several regions of interest in the source image and applies the colour values (and texture) to a target image. The automatic selections can be adjusted manually. After a first stage of colour and style transfer, a 'difference' image shows the necessary adjustments, which can then be applied manually. In addition, the RestoGUI allows the export of a lookup table [LUT] in a specific format. Since we worked with a Baselight colour-grading interface at cinegrell postproduction, we asked the IT specialists to deliver the LUT in the corresponding format.

The advantage of this material-based approach proposed here is directly connected to two of the most important desiderata of restoration ethics, namely transparency and documentation. Each of the steps is transparent by being inter-subjectively accessible and plausible, and each of the steps is also well-documented and standardized, from the careful documentation of the material objects used for the digitization processed, to each step in the work flow.

OUTLOOK: 'ERC ADVANCED GRANT FILMCOLORS', DEVELOPING A MULTIDISCIPLINARY DIGITAL HUMANITIES APPROACH

In 2015, Barbara Flueckiger was awarded an Advanced Grant by the European Research Council for her next project 'FilmColors. An Interdisciplinary Approach'. This grant allows her to pursue the material-based approach as outlined in this paper further, by combining four areas of research with a team of postdocs, a restorer, a web developer, and several PhD and master students:

1. Computer-assisted analysis of film colour aesthetics on a large group of films;
2. Development of a crowdsourcing tool for the systematic analysis of film colours;
3. Studies of technical papers and physico-chemical analyses of colour films;
4. Implementation of the insights from the previous three points into digitization and restoration projects.

The general objective of this project is the systematic exploration of the relationship between aesthetics and technology to be achieved by integrating all these various aspects. Beyond its interdisciplinary approach, this research project applies research tools in the emerging methodology of Digital Humanities to identify diachronic aesthetic patterns in a large group of films and to uncover their relationship to material properties and technological innovation in Europe, the US, and in Asia. This methodology implements a broad range of digital tools to enable the analysis of cultural artefacts, both by focussing on individual works and by the collaboration of researchers from different fields and from all over the world. A range of analytical and colourimetric methods is devised to deliver a set of parameters to characterize each colour process and film stock. All the results of this study including primary and secondary sources are published on the 'Timeline of Historical Film Colors' to enable further research from film scholars, historians, archivists, and scientists.

NOTES

1 Giovanna Fossati, 'The Archival Life of Early Color Films. Restoration and Presentation', in *Fantasia of Color in Early Cinema,* edited by Tom Gunning, Joshua Yumibe, Giovanna Fossati, and Jonathon Rosen (Amsterdam: Amsterdam University Press, 2015), 41.

2 Michele Canosa, 'Per una teoria del restauro cinematografico', in *Storia del cinema mondiale*, Vol. V, edited by Gian Piero Brunetta (Torino: Einaudi, 2001), 1069-1118; Gian Luca Farinelli and Nicola Mazzanti, *Il cinema ritrovato. Teoria e metodologia del restauro cinematografico* (Bologna: Grafis Edizioni, 1994); Nicola Mazzanti, 'The Colours of the Film d'Arte Italiana', in *Tutti i colori del mondo. Il colore nei mass media tra 1900 e 1930*, edited by Luciano Berriatúa et al., (Reggio Emilia: Edizioni Diabasis, 1998), 141-146; Mazzanti, 'Footnotes. (For a glossary of film restoration)', in *Restauro, conservazione e distruzione dei film,* edited by Luisa Comencini and Matteo Pavesi (Milan: Quaderni Fondazione cineteca italiana, 2001), 23-31; Simone Venturini, *Il restauro cinematografico. Principi, teorie, metodi* (Udine: Campanotto, 2006); Rossella Catanese, *Lacune binarie. Il restauro dei film e le tecnologie digitali* (Roma: Bulzoni Editore, 2013); and Marie Frappat, '"L'école bolonaise" de restauration des films', in *L'avenir de la mémoire. Patrimoine, restauration, réemploi cinématographiques*, edited by André Habib and Michel Marie (Villeneuve-d'Ascq: Presses Universitaires du Septentrion, 2013), 39–45.

3 For an overview, see Sean Kelly, *'A Dyeing Art. Research and Documentation as Means of Authenticity in Applied Colour Restoration'* (MA thesis, University of Amsterdam, 2012), 47–48.

4 In chromogenic film, the colour-forming substances are either present in several layers in the emulsion or added later during film development. The basic principle was discovered in 1911 by Rudolf Fischer and Hans Siegrist. Unfortunately, the dyes used in these processes proved to be unstable, thus lead to colour fading of the films, see *Timeline of Historical Film Colors*: http://zauberklang.ch/filmcolors/cat/chromogenic-monopack/

5 Josef Maria Eder, *Ausführliches Handbuch der Photographie* (Halle: Wilhelm Knapp, 1892); Arthur Freiherr von Hübl, *Three-Colour Photography. Three-Colour Printing and the Production of Photographic Pigment Pictures in Natural Colours* (London: W.A. Penrose, 1904; E.J. Wall, *The History of Three-color Photography* (Boston: American Photographic Pub. Co., 1925).

6 Adrian Cornwell-Clyne, *Colour Cinematography* (Boston: American Photographic Pub. Co., 1937, 1940, 1951).

7 Ryan T. Roderick, *A History of Motion Picture Color Technology* (London: Focal Press, 1977).

8 Wendy Everett, Ed., *Questions of Colour in Cinema. From Paintbrush to Pixel* (Peter Lang: Oxford, 2007); Scott Higgins, *Harnessing the Technicolor Rainbow. Color Design in the 1930s* (Austin: University of Texas Press, 2007); Raphaëlle Costa de Beauregard, *Cinéma et couleur* (Paris: M. Houdiard, 2009); Richard Misek, *Chromatic Cinema. A History of Screen Color* (John Wiley & Sons, 2010); Susanne Marschall, *Farbe im Kino* (Marburg, Germany: Schüren, 2005); and Christine N. Brinckmann, *Color and Empathy* (Amsterdam: Amsterdam University Press); Jacques Aumont, Ed., *La couleur en cinéma* (Milan: Mazzotta, 1995); as well as some issues of the journals *Film History* (vol. 12, no. 4, 2000 and vol. 21, no. 1, 2009) or *1895* (no. 71, 2014).

9 John Belton, 'Cinecolor', *Film History*, 12.4 (2000): 344–357; Scott Higgins, 'Technology and Aesthetics. Technicolor Cinematography and Design in the Late 1930s,' *Film History*, 11.1 (1999): 55–76; Scott Higgins, 'Demonstrating Three-Colour Technicolor. Early Three-Colour Aesthetics and Design', in *Film History*, 12.4 (2000): 358–383; Joshua Yumibe, 'Silent Cinema Colour Aesthetics', in *Questions of Colour in Cinema. From Paintbrush to Pixel*, edited by Wendy Everett (Oxford: Peter Lang, 2007), 41–56; Joshua Yumibe, 'From Switzerland to Italy and all Around the World. The Josef Joye and Davide Turconi Collections', in *Early Cinema and the "National"*, edited by Richard Abel, Giorgio Bertellini, and Rob King (Bloomington: Indiana University Press, 2008), 321–331; Joshua Yumibe, *Moving Colors. Early Film, Mass Culture, Modernism* (New Brunswick, NJ: Rutgers University Press, 2012); *Color and the Moving Image. History, Theory, Aesthetics, Archive*, edited by Simon Brown, Sarah Street, and Liz Watkins (New York-London: Routledge, 2012); *British Colour Cinema. Practices and Theories*, edited by Simon Brown, Sarah Street, and Liz Watkins (Hampshire: Palgrave Macmillan, 2013); Federico Pierotti, *La seduzione dello spettro. Storia e cultura del colore nel cinema*

(Genova: Le Mani-Microart, 2012); Federico Pierotti, *Un'archeologia del colore nel cinema italiano. Dal Technicolor ad Antonioni* (Pisa: Edizioni ETS, 2016); and James Layton and David Pierce, *The Dawn of Technicolor*, (Rochester, NY: George Eastman House, 2015).

10 Daan Hertogs and Nico De Klerk, Eds., *Disorderly Order. Colours in Silent Film. The 1995 Amsterdam Workshop* (Amsterdam: Stichting Nederlands Filmmuseum, 1996); Fossati, 1996; Binder, 2014; Frappat, 'L'école bolonaise'; Kerstin Parth, Oliver Hanley, and Thomas Ballhausen, Eds., *Works in Progress. Digital Film Restoration Within Archives* (Vienna: Synema, 2013).

11 Paul Read and Mark-Paul Meyer, Eds., *Restoration of Motion Picture Film* (Oxford: Butterworth-Heinemann, 2000). See also Bob Mabberley, Paul Read, and Sonja Snoek, 'Recording and Reproducing the Original Tints and Tones of Quo Vadis. A Technical Case Study', in *Tutti i colori del mondo. Il colore nei mass media tra 1900 e 1930*, edited by Luciano Berriatúa et al., (Reggio Emilia: Edizioni Diabasis, 1998), 151-155; Joao S. de Oliveira, 'Black-and-White in Colour', in *This Film is Dangerous. A Celebration of Nitrate Film*, edited by Roger Smither (Brussels: FIAF, 2002), 117-122.

12 See Barbara Flueckiger, 'Color Analysis for the Digital Restoration of Das Cabinet des Dr Caligari', *The Moving Image,* 15, no. 1 (2015): 22-43 and blog on http://www.filmcolors.org.

13 See Franziska Frey, 'Untersuchung des Stabilitatsverhaltens von fotografischen Farbmaterialien' (PhD Thesis. ETH Zürich, 1994); Rudolf Gschwind, 'Restoration of Movie Films by Digital Image Processing', in *Preserve Then Show*, edited by Dan Nissen (Copenhagen: Danish Film Institute, 2002), 168–178.

14 In the first year, AV Preservation by reto.ch also partnered with DIASTOR.

15 The film was provided by the Friedrich Wilhelm Murnau Foundation, see Barbara Flueckiger, 'Color Analysis for the Digital Restoration of Das Cabinet des Dr Caligari', *The Moving Image,* 15, no. 1 (2015): 22-43. The film was provided by EYE Filmmuseum; see Barbara Flueckiger, Claudy Op den Kamp, Franziska Heller, and David Pfluger '"Digital Desmet": Translating Early Applied Colors', *The Moving Image*, 16, no. 1 (2016): 106–124. DOI: https://muse.jhu.edu/article/640570.

16 Flueckiger *et al.*, '"Digital Desmet"'.

17 Fairchild, 2013.

18 See discussion in Giorgio Trumpy and Barbara Flueckiger, 'Light Source Criteria for Digitizing Color Films', *Proceedings of the Colour and Visual Computing Symposium* 2015, CVCS, Gjøvik Norway, August 2015, IEEE.

19 Callier effect, first described by André Callier, 'Absorption und Diffusion des Lichtes in der entwickelten photographischen Platte, nach Messungen mit dem Martensschen Polarisationsphotometer', *Zeitschrift für wissenschaftliche Photographie*, 7 (1909): 257. 'The ratio between the attenuances, which were measured illuminating the sample specularly (as in a directed bright-field) and diffusely

(as in a diffused bright-field), is termed the Callier Q factor', see Giorgio Trumpy, 'Dust BW. Detection of Dust and Scratches on Photographic Silverhalide (black/white) Material by Polarized Darkfield Illumination' (PhD Thesis, University of Basel, 2013), 41.

20 Trumpy, 'Dust BW'; Trumpy and Flueckiger, 'Light Source Criteria'.

21 Ohta, 1973.

22 Anke Wilkening, 'Die Restaurierung von Das Cabinet des Dr Caligari', *Beiträge zur Erhaltung von Kunst- und Kulturgut, Verband der Restauratoren,* Issue 2 (2014): 27-47.

23 The seven scanners were: DFT Scanity, Northlight, ArriScan, Lasergraphics Director, RTI D-Archiver, Sondor ALTRA, and Kinetta.

24 Barbara Flueckiger, David Pfluger, Giorgio Trumpy, Simone Croci, Tunç Aydın, and Aljoscha Smolic, 'Investigation of Film Material–Scanner Interaction' (2018).

25 Barbara Flueckiger, *Visual Effects. Filmbilder aus dem Computer* (Marburg, Germany: Schüren, 2008); Flueckiger, 'Material Properties of Historical Film in the Digital Age', *Necsus,* 1, no. 2 (2012), http://www.necsus-ejms.org/material-properties-of-historical-film-in-the-digital-age (Accessed 7 March 2016).

26 Gschwind and Frey 1994; 1995.

27 Flueckiger *et al.*, '"Digital Desmet"'.

28 Flueckiger, 'Material Properties'.

29 Flueckiger, 'Material Properties'.

30 Cesare Brandi, *Teoria del restauro [1963]* (Torino: Einaudi, 1977).

31 Flueckiger, 'Material Properties', see also the FILMIC project by Jim Lindner and Josef Marc.

32 See, for instance, Nicola Farinelli and Gian Luca Mazzanti, 'Il restauro. Metodo e tecnica', in *Storia del cinema mondiale* (2001); and Read and Meyer, *Restoration of Motion.*

33 The Desmet method was named after Noël Desmet, who first devised the method at the Cinémathèque Royale in Brussels. A nitrate positive is duplicated onto black-and-white negative film that is panchromatic – that is, sensitive to all colours – so that as muchinformation as possible is captured. The colours, in turn, are brought back in at a later stage when the negative is printed to a colour positive on modern stock and when the particular colour is flashed onto the film for tinting. The Desmet method was devised for several reasons. First, it was cheaper than using colour internegatives. Second, as a safety element, the black-and-white intermediate is chemically more stable. Third, and arguably most important, it was possible to eliminate some of the fluctuations, stains, and unevenness mentioned above. In the early to mid 1990s, the Desmet method became best practice for reproducing films with tinting and toning.

34 See discussion in Farinelli and Mazzanti, *Storia del cinema*, 5; Giovanna Fossati, *From Grain to Pixel. The Archival Life of Film in Transition* (Amsterdam: Amsterdam

University Press, 2009), 117–123; Rossella Catanese, *Lacune binarie. Il restauro dei film e le tecnologie digitali* (Rome: Bulzoni Editore, 2013).

35 Paolo Cherchi Usai, 'The Color of Nitrate. Some Factual Observations on Tinting and Toning Manuals for Silent Films', in *Silent Film*, edited by Richard Abel (New Brunswick, NJ: Rutgers University Press, 1996), 27-30.

36 For a primary source, see F.T. Bowditch and A.C. Downes, 'Spectral Distributions and Color-Temperatures of the Radiant Energy from Carbon Arcs Used in the Motion Picture Industry', *Journal of the Society of Motion Picture Engineers* (1938): 400-409. For an investigation of their influence on the rendition of early film colours, see Christine Keller, 'Die Simulation historischer Filmfärbung unter besonderer Berücksichtigung des Lichtes moderner Filmprojektion' (MA Thesis, Bern, 2007).

37 *Debayering* is a digital image process used to reconstruct a full-colour image from the incomplete colour samples output from an image sensor overlaid with a colour filter array (CFA) in red, green, and blue. It is also known as CFA interpolation or colour reconstruction.

38 Anya Hurlbert, 'The Perceptual Quality of Color', in *Handbook of Experimental Phenomenology*, edited by Liliane Albertazzi (New York: John Wiley & Sons, 2013); and Jianli Liu, Edwin Lughofer, and Xianyi Zeng, 'Could Linear Model Bridge the Gap Between Low-level Statistical Features and Aesthetic Emotions of Visual Textures?' *Neurocomputing,* 168 (2015): 947–960.

39 Simone Croci, Tunç Aydın, Nikolce Stefanoski, Markus Gross, and Aljoscha Smolic, 'Advanced Tools and Framework for Historical Film Restoration' *Journal of Electronic Imaging*, 26.1, 011021 (2017).

ABOUT THE AUTHORS

Prof. Dr. Barbara Flueckiger has been a professor for film studies at the University of Zurich since 2007. Before her studies in film theory and history, she worked internationally as a film professional. She is the author of two text books about "Sound Design" and "Visual Effects". Since 2001 she has developed and led many research projects on the interaction between film technology and aesthetics. Her recent research projects investigate the digitization and restoration of archival film, in collaboration with archives and the film industry. In 2015 she was awarded the prestigious Advanced Grant by the European Research Council.

Dr. Claudy Op den Kamp is a Lecturer in Film and faculty member at the Centre for Intellectual Property Policy and Management at Bournemouth University, UK, and Adjunct Research Fellow at Swinburne Law School, Australia. She holds degrees from the University of Amsterdam (MA Film and Television Studies), the University of East

Anglia (MA in Film Archiving), and Plymouth University (PhD in Art and Media). She has worked as Haghefilm Conservation's Account Manager; as a Film Restoration Project Leader at the Nederlands Filmmuseum; and, between 2013-2015, as a senior research assistant in the DIASTOR project at the Department of Film Studies at the University of Zurich.

Dr. David Pfluger has a doctorate in physical chemistry and was a senior researcher in the DIASTOR project. He brought to the team his background in physical chemistry, cinema postproduction, digital preservation of film and video, and a particular knowledge of the Swiss archiving landscape. He works as an independent consultant for archives and, since 2005, he is a member of the Film and Video Competence Network of Memoriav, Switzerland. His other research includes early cinema history, with an emphasis on the pioneers Georges and Gaston Méliès.