Storage of Digital Images and Digital Motion Pictures on Photographic Film

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1. Introduction

National Film Center, The National Museum of Modern Art, Tokyo (NFC),[1] is the only nationally established institute for motion pictures in Japan. At the center, we are engaged in the collection, preservation, and restoration of film and related materials as cultural heritage and historical documents.[2] At our headquarters in Kyobashi, Tokyo (Photo 1a), we not only organize screenings and exhibitions with various themes but also maintain a library devoted to literature on motion pictures. The center's Sagamihara Annex, located in Sagamihara City of Kanagawa Prefecture (Photo 1b), is a specialized facility designed to permanently preserve films in the museum's collection.

Archive I of the Sagamihara Annex has the capacity to store 220,000 cans of film while Archives II and III can store 266,000 cans and 1,000 cans, respectively. Archive III, housing nitrate films, is also known as the archive for Important Cultural Property Film Storage. Archive II features an air conditioning system that keeps the films at a constant temperature of 2–10±2˚C and relative humidity (RH) of 35±5%. In addition, it

(a) NFC Headquarters in Kyobash

(b) Sagamihara Annex

Photo 1 National Film Center, The National Museum of Modern Art, Tokyo has technology designed to increase efficiency and reduce energy consumption, such as a cool tube ventilation system utilizing a cool pit and a sock-filtered air intake in the storage room. To control vinegar syndrome, acetic acid removal filters have been installed in the storage room, film acclimation room, film inspection room, and temporary storage room. We thus aim to improve the environment for both film storage and our workers' health. Film that has shown symptoms of vinegar syndrome is stored in a purpose-built room at a temperature of 2±2˚C and 35% RH. Techniques for the removal of acetic acid from the film can (ventilation and use of an acetic acid absorbent) and film rewinding have proved effective in inhibiting the progress of vinegar syndrome. The annex also contains a Reference Room for Motion Picture Literature and a Reference Room for Motion Picture Techniques, where documents are stored at a temperature of 21±2˚C and 50±5% RH.

The NFC is currently engaged in the "National Research Project for the Sustainability of Born-Digital Cinema" (generally known as the BDC Project), funded by a Japanese government grant as part of an Agency for Cultural Affairs program to support art museums and history museums in priority areas (2014~). The BDC Project is composed of the following research themes:

(1) Research on the storage and use of digital films
(2) Research on the digital storage and use of photographic films
(3) Research on technology and legal aspects of digital film storage in other countries
(4) Human resource development for the digital storage and use of film

2. Film Technology and Storage

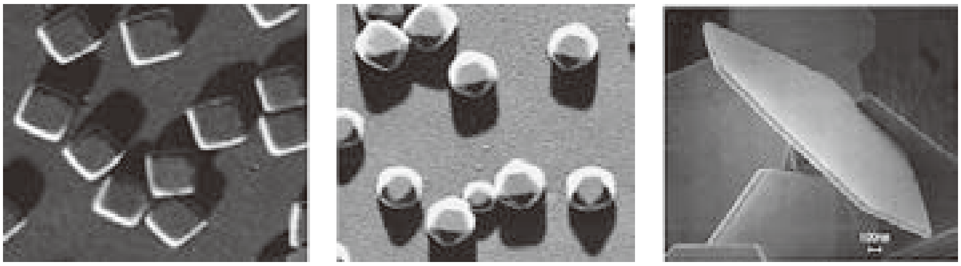
2.1 The Technology That Supports Film

In this section, I will discuss the technology underlying film. The technology used in film for moving images is basically the same as that for still photographs and is founded on the technology of silver halide photographic film. In fact, silver halide photographic film technology has seen continued development for over 160 years. It is extremely rare for the development of a single commercialized technique to continue for such a long period of time.

2.1.1 Silver Halide

Silver halide is formed from silver and halogen atoms (chlorine, bromine, iodine) and generates photolytic silver (the latent image) upon exposure to light. This metallic silver acts as a catalyst to develop the photographic image. As a result of much work on silver halide grains, researchers have developed normal single crystal grains and tabular grains with twin planes. These are used today (Photo 2).

Grains of silver halide are only sensitive to one part of the spectrum of visible light (Figure 1). Sensitivity to the entire spectrum of visible light is achieved by attaching light-absorbing dyes (sensitizing dyes) to the silver halide grains. The electrons in these



(a) Cubic grains (normal crystal grains)
(b) Octahedral grains (normal crystal grains)
(c) Tabular grains (twinned crystal grains)

Photo 2 Examples of silver halide grains (Ohzeki 2016)

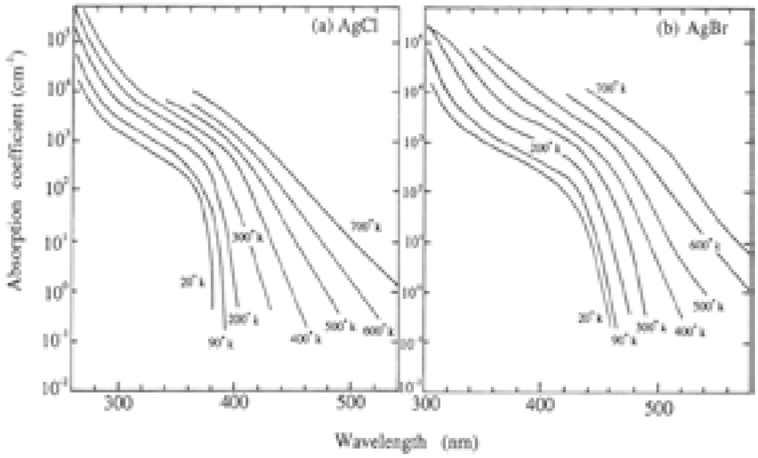


Figure 1 Intrinsic light absorption qualities of silver halide crystals (James 1977: 41)
(a) AgCl crystal, (b) AgBr crystal.

dyes are excited by exposure to light and injected into the silver halide. This technique of spectral sensitization was invented by Hermann Wilhelm Vogel in 1873.

2.1.2 The Gelatin Matrix

In 1871, Richard Leach Maddox invented gelatin dry plates by dispersing silver bromide in gelatin, then coating the resulting gelatin emulsion onto glass or paper. Unlike the former collodion wet plate process (where grains of silver iodide are formed in a collodion membrane and exposed while still wet), gelatin dry plates could be mass produced. The new process also had other advantages, including silver halides' high photosensitivity, resistance to deterioration, and high contrast. The process was improved further, and no better medium than gelatin was ever developed (Commission on Methods for Testing Photographic Gelatin 2006).

2.1.3 The Film Base

The gelatin emulsion was coated onto a piece of glass referred to as a dry plate.

However, the disadvantage of glass was that it was heavy and easily shattered. For this reason, the gelatin emulsion was applied to nitrocellulose (celluloid) film in 1888, and in 1889, the Eastman Kodak Company utilized celluloid's flexibility to produce film for motion pictures in roll form. The birth of roll film accelerated the spread and popularization of photographic film. Films made from acetate and polyethylene terephthalate (PET) were later developed and used for still and moving image photography.

2.1.4 Chromogenic Development

In 1914, Rudolf Fischer revealed the process of chromogenic development.[3)] In this process, substances called dye couplers react with an oxidized developing agent, producing various colors of dye (Figure 2). The couplers are resolved in an oil droplet, and the oil droplet is dispersed in gelatin. The dyes are produced inside the oil. When combined with silver halide grains that have been subjected to the spectral sensitization technique mentioned earlier, it is possible to produce three layers of color: cyan, magenta, and yellow, as a photoreaction to red, green and blue light, respectively.

Cyan PPd Developing Agent Cyan Dye

Figure 2 An example of chromogenic development (cyan) (Ohzeki 2016)

2.2 Film Preservation and Life Expectancy

2.2.1 Stability of the Image

Listed below are the types of chemical reactions that can cause deterioration of the color images created by a coupling reaction. To inhibit this deterioration, vigorous research has been carried out into coupler improvement and discoloration-inhibiting agents.

- Discoloration due to hydrolysis (mainly affecting yellow)
- Discoloration due to oxidization (mainly affecting magenta)
- Discoloration due to reduction (mainly affecting cyan)

Meanwhile, silver images are prone to deterioration due to sulfide reaction (where sodium thiosulfate residue from the fixing agent causes the formation of silver sulfide), silver formation (where silver particles form from silver halide residue during storage), and oxidization reduction (where silver atoms are transferred due to the presence of oxidants in the environment). Countermeasures include ample fixing and rinsing, together with isolation from redox agents.

2.2.2 Stability of the Base

Paper is a typical base. Its main constituent is cellulose (Figure 3), which gives it stable characteristics that are utilized, for example, in traditional Japanese paper. Paper photographic bases include Baryta paper, where the paper base is coated with a gelatin emulsion of barium sulfate, and resin-coated (RC) paper, where the paper base is coated on both sides with polyethylene, with the emulsion side containing fine grains of titanium dioxide. Even a stable medium such as paper can be affected by an application of rosin (a sizing agent) or aluminum sulfate (a fixing agent), suffering discoloration by oxidation or acid hydrolysis. Modern sizing agents are neutral or alkaline, and in general, the paper medium no longer influences the longevity of the photograph; however, it is necessary to take care with older photographs.

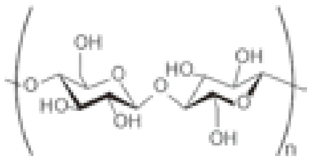


Figure 3 Cellulose

Nitrocellulose, in which some of the hydroxyl groups in cellulose are replaced by nitro groups (resulting in ca.11% nitrogen group), was used as a base from 1889 until the 1950s. Nitrocellulose is highly flammable (designated as a class 5 hazardous material under the Japanese Fire Services Act), and it caused several cinema fires. It is also susceptible to deterioration from hydrolysis. Safer, non-flammable films such as diacetyl cellulose (DAC) and cellulose triacetate (TAC), in which hydroxyl groups are replaced with acetyl groups, were used to overcome these problems. It was confirmed, however, that the gradual progression of hydrolysis in TAC media, which is accelerated by temperature and humidity, leads to the formation of acetic acid and the drastic deterioration referred to as vinegar syndrome. Thus, more stable bases using materials such as polyethylene terephthalate (PET) and polyethylene naphthalate (PEN) were developed. When storing film, care must be taken to consider the type and production era of the film base.

2.2.3 Stability of the Binder

The principal constituent of the binder that contains the image is gelatin. Gelatin can be stored for long periods in a dry form without degeneration, but it is vulnerable to high humidity. As gelatin is basically a processed form of protein, it is vital to avoid contact with catabolic enzymes or the generation of any bacteria or molds that might produce catabolic enzymes. The growth of such molds increases at a moisture content of over 16% in gelatin.

2.2.4 Physical Characteristics

In terms of film preservation, robustness and the physical characteristics of structure are important in image, base, and binder. Film is composed of many layers, and it is necessary for the bond between layers to be sufficiently strong. In particular, the base and photosensitive layer must be firmly attached. A hardening agent is added to the gelatin binder to ensure that it remains sufficiently robust.

It is also necessary to ensure that the surface of the photosensitive material does not stick to the back of the film when it is wound. Keeping the film at a low temperature and humidity is better for preventing adhesion, and rewinding the film in conditions of low humidity is an effective countermeasure. In addition, spherical latex is added to the surface and back of the film to reduce the chance of adhesion.

2.2.5 Assessment of Film Storage and Film Life Expectancy

As explained thus far, much research has been conducted into the many aspects of film preservation. As a result, it has been possible to standardize storage methods and measures of film life expectancy. Table 1 lists the various ISO standards related to photographic film. ISO 18911, in particular, pertains to film storage methods. As shown in Table 2, when film is stored in suitable conditions, its life expectancy, according to an Arrhenius-type prospective study, is estimated to be roughly 100 years for color images and 500 years for silver images. In the latter case, life expectancy is thought to be limited by the base rather than the image itself.

3. Storage of Digital Images and Motion Pictures on Photographic Film

3.1 A Warning on the Storage of Digital Motion Pictures

Regarding the storage of digital data, immense volumes of data are needed to record motion pictures, and the storage of this data has been a significant problem. The Academy of Motion Picture Arts and Science (AMPAS) released "The Digital Dilemma"[4) (Academy of Motion Picture Arts and Science 2007) in 2007 and "The Digital Dilemma 2"[5) (Academy of Motion Picture Arts and Science 2012) in 2012. These research reports highlight the lack of a suitable long-term storage method for digitized motion pictures. The weakness in digital technology lies in this absence of suitable storage methods.

"The Digital Dilemma" describes the following merits of photographic film:

- It is a worldwide standardized medium.
- It guarantees access for over 100 years.
- It is possible to produce a master version.
- It retains quality at least as good as that of the original camera negatives.
- It is not affected by changes in the technological platform.
- It allows interoperability.
- It has immunity from escalating financial investment.

The general consensus in the report is that no digital archiving master format or

Table 1 Various ISO Standards related to photographic film.

ISO No	Publication	Title	Previous No
10356	1996	Cinematography – Storage and handling of nitrate-base motion-picture films	
18901	2002	Imaging materials – Processed silver-gelatin type black-and-white films – Specifications for stability	10602
18902	2007	Imaging materials – Processed imaging materials – Albums, framing and storage materials	10214
18903	2002	Imaging materials – Films and paper – Determination of dimensional change	6221
18904	2000	Imaging materials – Processed films – Method for determining lubrication	5769
18906	2000	Imaging materials – Photographic films – Specifications for safety film	543
18907	2000	Imaging materials – Photographic films and papers – Wedge test for brittleness	6077
18908	2000	Imaging materials – Photographic film – Determination of folding endurance	8776
18909	(1993)	Photography – Processed photographic colour films and paper prints – Methods for measuring image stability	10977
18910	2000	Imaging materials – Photographic film and paper – Determination of curl	4330
18911	2000	Imaging materials – Processed safety photographic films – Storage practices	5466
18913	2003	Imaging materials – Permanence – Vocabulary	
18915	2000	Imaging materials – Methods for the evaluation of the effectiveness of chemical conversion of silver images against oxidation	12206
18916	2007	Imaging materials – Processed imaging materials – Photographic activity test for enclosure materials	14523
18917	(1993)	Photography – Determination of residual thiosulfate and other related chemicals in processed photographic materials – Methods using iodine-amylose, methylene blue and silver sulfide	417
18918	2000	Imaging materials – Processed photographic plates – Storage practices	3897
18920	2000	Imaging materials – Processed photographic reflection prints – Storage practices	6051
18922	2003	Imaging materials – Processed photographic films – Methods for determining scratch resistance	-
18924	2000	Imaging materials – Test method for Arrhenius-type predictions	15640
18931	2001	Imaging materials – Recommendations for humidity measurement and control	-

Table 2 Film storage methods shown in ISO 18911
NC=nitrate, TAC=triacetyl cellulose, PET=polyethylene terephthalate
*According to ISO 10356.

<table>
<tr><th></th><th>Base</th><th>Max. Temp.</th><th>RH</th></tr>
<tr><td rowspan="5">Black and white film</td><td>NC*</td><td>2°C</td><td>20–30%</td></tr>
<tr><td rowspan="3">TAC</td><td>2°C</td><td>20–50%</td></tr>
<tr><td>5°C</td><td>20–40%</td></tr>
<tr><td>7°C</td><td>20–30%</td></tr>
<tr><td>PET</td><td>21°C</td><td>20–50%</td></tr>
<tr><td rowspan="3">Color film</td><td rowspan="3">TAC/PET</td><td>-10°C</td><td>20–50%</td></tr>
<tr><td>-3°C</td><td>20–40%</td></tr>
<tr><td>2°C</td><td>20–30%</td></tr>
</table>

processing method yet exists that has a lifespan comparable to that of photographic film for periods over 100 years. The report proceeds to recommend the production of film separation masters (three-color separation and storage on black and white film) as a method of long-term preservation. In this context, efforts have been made to store digital images and data on conventional photographic film.

3.2 Three-Color Separation and Storage on Black and White Film

It is possible to combine digital technology and conventional film technology. Images on film can be scanned to produce digital copies, and digital images can be recorded on photographic film using a digital recorder. Today, scanners with a resolution of 4K or greater have become common, and photographic film itself has resolution greater than 4K.

Under these conditions, moving images can be split into the three colors: blue, green, and red (BGR). These three versions of the image are then recorded on three separate black and white films (Figure 4). This method of three-color separation and storage using black and white film has the following advantages:

- The color images are converted into long-lasting silver images.
- Color separation is executed at the time of image production and is free from any image deterioration due to dye degradation over time.
- The image is analog and can thus be reproduced optically. It can also be re-digitized using future scanner technology independent of that on which the digital image was originally recorded, without the need for migration techniques.
- The silver film used in three-color separation contains thinner layers than color film has, with smaller grains and no dispersed oil content, leading to less image deterioration due to optical scattering (Figure 5).

At the NFC, we have preserved *The Documentary Video of The Main Shrine of the National Treasure Izumo Taisha* (March 3, 2013), a recording of the Izumo Taisha Great Shrine Moving Ceremony that is performed every 60 years, made by the Broadcasting

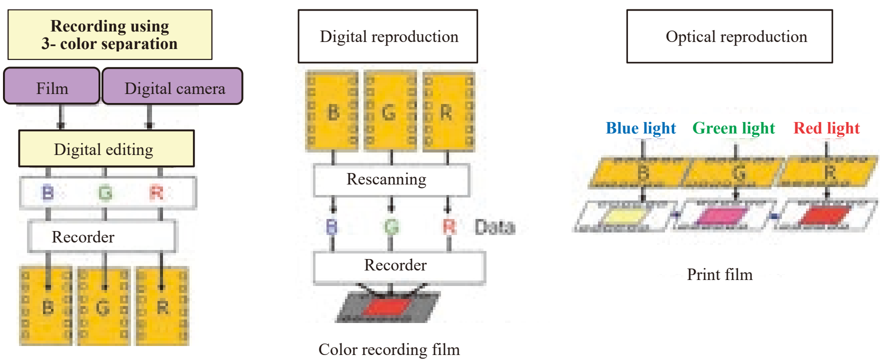
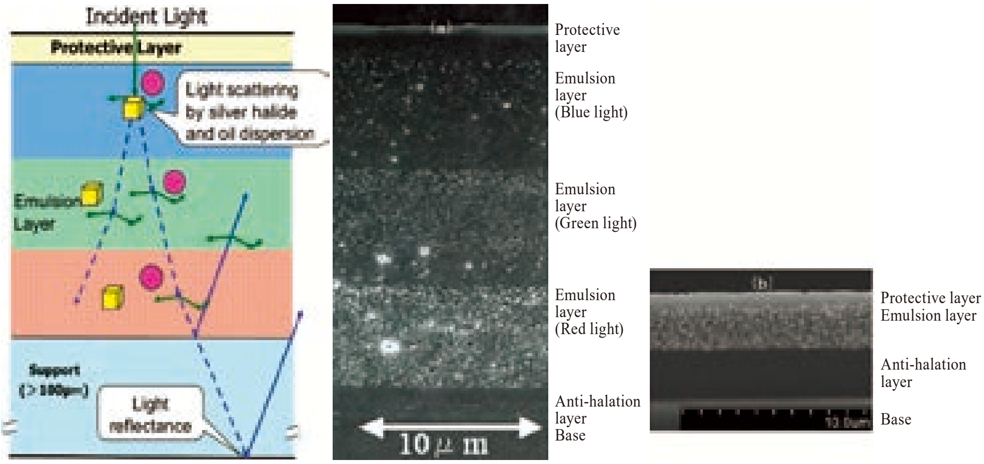


Figure 4 Recording and restoration using three-color separation (Ohzeki 2016).



(a) Color intermediate film (b) Black and white separation film

Figure 5 Cross-sections of photographic film magnified under a scanning electron microscope (Ohzeki 2016) The cubes and spheres in the figure on the left represent grains of silver halide and oil droplets, respectively. The white dots in the electron microscope images are grains of silver halide.

Rights were not granted to include this image in electronic media. Please refer to the printed journal.

Photo 3 The Main Shrine of the National Treasure Izumo Taisha.
The left half of the image is from the original recording, while the right half was reproduced by scanning and recombining images of the three-color separate black and white film.
The original image was shot with 4K resolution by Broadcasting System of San-in.

System of San-in with 4K resolution, using the three-color separation technique. After color separation onto black and white film, we re-digitized the images and compared them with the original recording. The results of this comparison are shown in Photo 3. The left half is from the original recording while the right half is an image reproduced from the three-color separation. We have also preserved other films at the NFC using color separation technique, including the experimental film *Ginrin*, directed by Toshio Matsumoto, and works by director Yasujiro Ozu. According to the previously mentioned “The Digital Dilemma 2”, the “studio also ran a set of digital seps, that is, 35 mm YCM archival separation shots from the rendered final DI files. These cost between $70K and $90K” (Academy of Motion Picture Arts and Science 2012: 87).

3.3 Storing Digital Data (Bit Streams) on Film

There has been an effort to expand existing film storage techniques to preserve digital data on a film medium (“Bits on Film”). For the purposes of digital data recording, some redundancy has been added for error correction as a countermeasure against deterioration. Apart from the content data itself, information on formatting and coding as well as instructions for reproducing the digital data can be stored on the film in analog form. The bit data stored on the film can be read when enlarged. “Bits on Film” thus represents a very complete storage system in the context of OAIS (see section 4.2). Below are two examples of this system.

- Monolith (Wassmer and Fornaro 2013) is a “Bits on Film” system developed by the University of Basel in Switzerland (Photo 4). Apart from the content data, the program and an explanation of the program content are recorded on the film in analog form, and it is thought that the data could be decoded in isolation without reference to any external information in the future. The formatting information is recorded first. The bit data is recorded using a pseudorandom method as a countermeasure against possible film damage. The pseudorandom method, as well as the formatting structure and content, are recorded as text on the film. The data can also be recorded in PDF/A format (a PDF format standardized for long-term archiving).
- The ARCHIVATOR project (Plata and Bjerkestrand 2012), meanwhile, was developed by a consortium of photosensitive materials producers led by CINEVATION AS (now Piql Preservation Services, a Norwegian company). The project received an injection of public funds (€9 million over three years) from the European Union. As a result, a system in consideration of OAIS and the SIRF of SNIA (see section 4.2) was developed and commercialized (Brudeli and Drake 2014). There has also been an effort to store film in an archive at the North Pole.[6)]

Christoph Voges et al. at the Braunschweig University of Technology in Germany have conducted publicly funded fundamental research into “Bits on Film.” These include the MILLENIUM Project (Voges, Margner, and Fingscheidt 2009) and the CineSave Project[14)] (Voges and Frolich 2012). According to Voges et al., data can be recorded onto commercially available black and white film at a net density of 0.052 GB/ft. Thus 12,000 feet of film (equivalent to the length of a two-hour movie) can store 0.6 TB of data. Given that the Digital Cinema Packages (DCPs) used to show movies in cinemas store roughly 0.4~0.5 TB, the length of film needed to record digital images is roughly

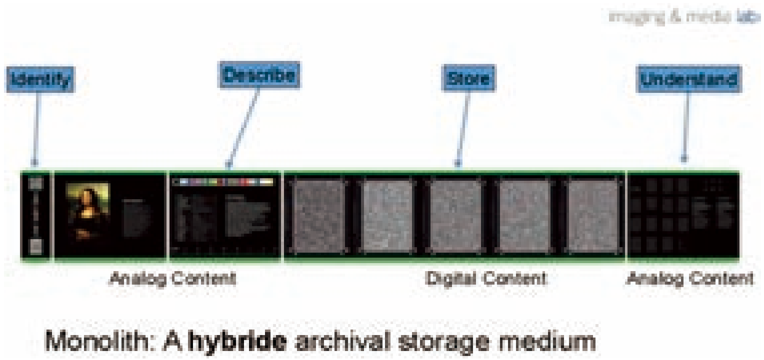


Photo 4 The Monlith "Bits on Film" system.
The digital data is stored on film together with any information necessary to decode it. The film also records examples of the information and images that should be obtained by reproduction.[7)]

equivalent to that of analog images (Voges and Fingscheidt 2009) (Voges 2016).

According to Professor Peter Fornaro of the University of Basel, "Bits on Film" is expected to enjoy only limited use and is most suitable for recording digital audio and metadata when storing color images using color separation for the following reasons.[8)]

- It will be difficult to obtain physical film in the future.
- Storage capacity is limited, at a resolution of about 6 microns, which is the resolution confirmed for normal black and white film recording data.

The resolution mentioned above is largely dependent on the recording device, and the film itself can hold a greater density of detail. An even greater density of information storage is possible using technology such as holograms. Examples of high-density recording have been reported using smaller silver halide grains than those used in normal black and white films and holographic technology (Solomon et al. 2015). Smaller silver halide grains translate to smaller silver particles after the film is developed, however, and care must be taken to maintain the stability of the silver image (see following section).

3.4 Stability and Life Expectancy of the Silver Image

The resolution of photographic film and the density of digital information that can be recorded on it vary inversely with the size of the silver halide grains. Smaller grains imply greater resolution but also smaller particles of silver after the film is developed. On the other hand, the stability of the silver particles themselves decreases with smaller grains as the surface energy increases. To ensure the longevity of the image, we investigated the relationship between the size of developed silver particles and image stability. The size of the developed silver particles is proportional to the size of the silver halide grains. Films were developed with varying sizes of silver halide grains. These were subjected to conditions of high heat and humidity. As a result, the films with smaller grains showed greater variation in image density. It was also found that when the

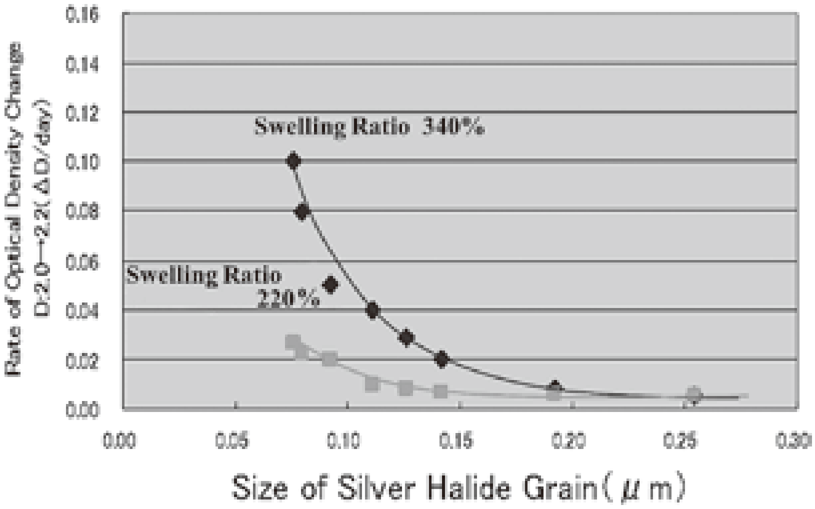


Figure 6 The relationship between silver halide grain size and developed silver stability (Teshima and Ohzeki 2013). At 80˚C and 60% RH, the rate at which the silver concentration varies in the image increases as the silver halide grain size decreases. A smaller swelling ratio reduces the speed of variations in image density.

gelatin binder was hardened to reduce swelling during film development, the variations in image density decreased in severity (Figure 6). When this phenomenon was examined under an electron microscope, it became clear that in films with high swelling ratios, the developed silver would form in filament-shaped particles first, then would gradually become more spherical over time. In films with low swelling ratios, however, the developed silver would form in roughly spherical particles from the start, leading to less variation in image density (Figure 7). The design of the latest black and white film used for storage in the three-color separation technique is based on these findings.

Table 3 shows the results of an Arrhenius-method estimate of silver image life expectancy for films with differing silver halide grain sizes. An image life expectancy (defined as the time before a 10% variation in image density) of over 1,000 years may be obtained for film that uses silver halide grains of 0.11 μm. It has been inferred that the rate-determining process for this reaction is the oxidization of silver atoms on the surface of the developed silver (Teshima and Ohzeki 2013). These results are temperature-dependent at an ambient humidity of 60% RH. Lower humidity would increase life expectancy. Conversely, care must be taken as the presence of oxidizing materials is thought to increase the reaction rate.

4. Problems in Digital Data Storage

In the sections above, the storage of digital moving images and bit data using photographic film were discussed. Since the turn of the century, however, the supply of film stock has decreased dramatically as digital technology has become more prevalent

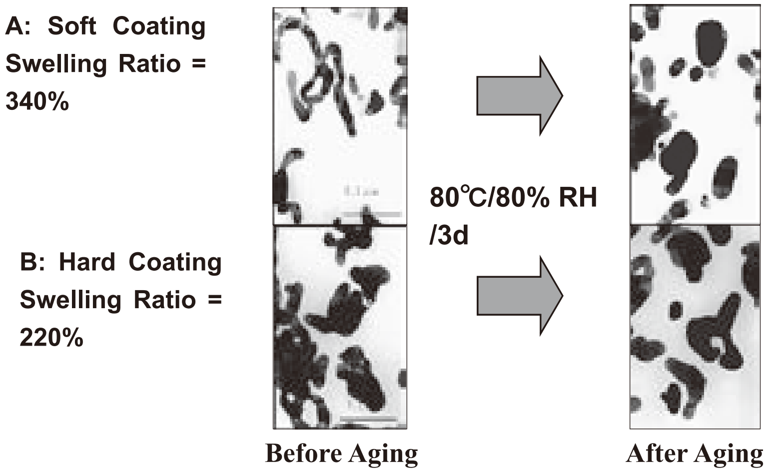


Figure 7 Morphological changes in developed silver under conditions of high heat and humidity (Teshima and Ohzeki 2013). Silver halide grain size 0.07 μm, aged for three days at 80˚C, 80% RH. When film A (swelling ratio 340%) is developed, long thin strands of developed silver form, which change shape over time. The developed silver in film B (swelling ratio 220%), however, is roughly spherical and does not significantly change shape over time.

Table 3 Silver image stability in films with differing silver halide grain size and swelling ratios. Life expectancy is calculated using the Arrhenius method (Teshima and Ohzeki 2013).

Grain Size (μm)	Swelling Ratio (%)	Time Required for 10% Density Change (day: 80℃/60% RH)	Life Expectancy (year: 20℃/60% RH)
0.07	340	2.0	150
0.07	220	7.5	540
0.11	220	21	1500
0.11+0.18 (RDS)	220	>40	>2900

(Figure 8). Not only is film stock itself becoming scarcer but developing and screening infrastructure is also gradually being lost, and the continuation of film technology—including the training of skilled personnel—has become an important issue. Meanwhile, it would be impossible to store all digital data on film. This data must therefore be stored using a digital system. The USA Academy Film Archive, together with the Library of Congress, has been engaged in a project to construct a storage system for digital motion pictures (Academy of Motion Picture Arts and Science 2010).[9)] Open-source software has been used as much as possible to reduce reliance on any corporate technology. The project was hailed as an ideal ground-breaking effort but encountered many hurdles, and the proposed system was eventually abandoned.[10)] I will conclude by discussing the problems posed by digital data storage.

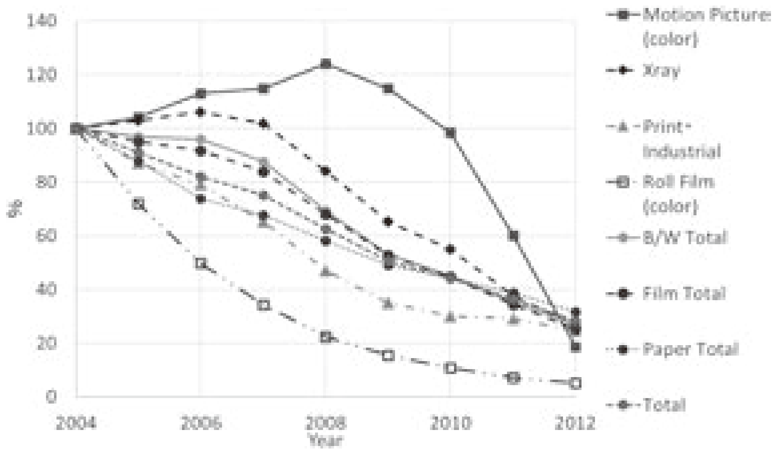


Figure 8 Changes in the Japanese domestic supply of photographic film (shown as a percentage of the supply in 2004). Domestic supply is equal to domestic production, plus imports, minus exports (based on the Japanese Ministry of Economy, Trade and Industry, Science and Industry production statistics, Ministry of Finance trade statistics, and estimates by the Photo Market Company).

4.1 Choosing a Storage Medium

Media capable of recording digital data include magnetic tape, optical discs, magnetic discs, and semiconductors. Magnetic tape, in particular, has a high capacity for data storage, and with the LTFS file system, it is now commonly used to store motion pictures. It has been reported that Linear Tape Open (LTO)—a typical magnetic tape—has a life expectancy of around 30 years (Chiba et al. 2015). Optical discs, meanwhile, have been commercially produced for archiving purposes in stacks of 11 or 12 discs.[11)] Each disc is capable of double-sided recording of 300 GB of data and—based on standardized life expectancy estimations (ISO/IEC 16963: 2015; JISX6256)—has a life expectancy of 1,000 years (at 25˚C) (Sony Corporation and Panasonic Corporation 2015). They are also reputedly able to be read using outdated standards. The Japan Image and Information Management Association (JIIMA) has released “Archiving Guidelines Using Magnetic Tape” (Japan Image and Information Management Association 2015) and “Archiving Guidelines Using Optical Discs for Long-Term Storage” Japan Image and Information Management Association 2013). Magnetic discs allow speedy access to data but require large amounts of energy. These discs have a useful life of only about five years[12)] and storage systems have been designed premised on regular replacement of the storage media. These systems are supported by virtualization technology. Semiconductor memory has no moving parts, and is thus energy efficient. Long-term data storage is possible using this technology, provided a sufficient charge is accumulated (Kobayashi 2012). The amount of charge required, however, tends to decrease as storage density increases. Many estimates have been made of the life expectancy of an average semiconductor storage medium. After rewriting the data 1,000 to 10,000 times, however, the useful life is only thought to be about 10 years, even in relatively long cases

(Matsukawa 2011). Some memory chips on the market are reputed to preserve data for 100 years if it is not rewritten.[13)]

A technique has also been developed to engrave digital data in quartz glass using femtosecond pulse lasers. These engravings are then read using optical tomography. It is estimated that data could be stably preserved in quartz glass in this way for hundreds of millions of years (Watanabe et al. 2016).

4.2 Maintenance of Stored Data

The life expectancy of data stored in the ways mentioned above is not only dependent on the longevity of the storage medium itself but also on the longevity of the reading device, the availability of software support, and the initial format of the recorded data. LTO systems can only read tapes from the past two versions released, and as system alterations are made every three to five years, it is necessary to transfer (migrate) data onto the latest system at regular intervals (Ejiri 2015). Many issues, including the increasing complexity of systems, are expected to emerge in relation to the preservation of data.

NASA has proposed the Open Archival Information Service (OAIS) as an attempt to realize the goals of long-term data storage and access to digital data (ISO 14721: 2012).[14)] OAIS is a conceptual model, consisting of a functional model (Figure 9) and an information model (Figure 10). The functional model is composed of data in three "packages"—submission, archival, and dissemination—while the information model contains content information as well as preservation description information. Content information includes information on the stored data and details of information on representation necessary to read the data. Preservation description information meanwhile is composed of six functional entities: ingest, archival storage, data management, administration, preservation planning, and access. OAIS is a purely conceptual model,

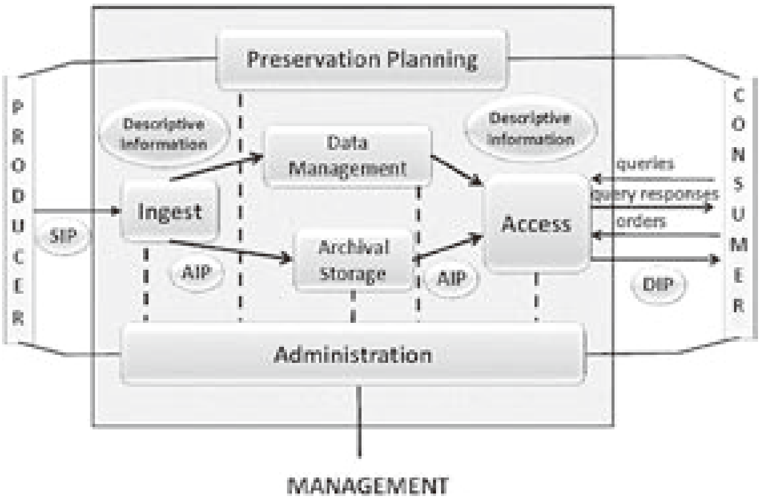


Figure 9 The OAIS functional model (ISO 14721: 2012)

Figure 10 The OAIS information model (ISO 14721: 2012)

and the issue of actual implementation remains dependent on individual circumstances. It is vital to find a concrete form to package the information on representation necessary to decode the data several hundred years into the future. Meanwhile, the Storage Network Industry Association (SNIA) has researched and proposed the Self-Contained Information Retention Format (SIRF) as a standardized storage format independent of corporate support and capable of being reproduced in the future by systems that do not exist today (Cohen et al. 2014).

4.3 Choosing What to Store

Digital motion picture is recorded in many different formats, from RAW data (dependent on the hardware maker) to formats used to disseminate and broadcast that data (National Film Center 2014). There are also intermediate processes such as changes of format and data compression (Figure 11). A choice must be made about what to store to avoid the production of endless versions. To make this choice, it is necessary for the institution storing the data to have a decision policy. From the perspective of an art museum, for example, a decision policy might focus on preserving data on the initial viewing of artwork. At the same time, in order to respond to the development of image recording technologies such as high resolution (4K, 8K), high dynamic range (HDR), and high frame rate (HFR), it is preferable to preserve all information from the time when the images were shot.

4.4 Choosing How to Utilize the Data

With continuing advances in digital technology, it is becoming much easier to produce and access still and moving images. Metadata has been structured to allow users to discover images, and research has been conducted into technologies such as Resource Description Framework (RDF) (Kanzaki 2010) and Resource Description & Access (RDA) (Ueda and Kanise 2014). Various schemas have also been developed for the construction of databases. In the field of cinema, the revised *FIAF Moving Image Cataloguing Manual* was released in May 2016 (Fairbairn et al. 2016). This manual is based on the *Functional Requirements of Bibliographic Record*s (FRBR). It is thought that standardization and cooperation will become important for utilizing the archived database in the future.

Moreover, it is increasingly important to consider storage in conjunction with usage. This is because the rise in storage costs has made it difficult to raise funds for storage of data that has no prospect of being used. We need a model whereby data usage generates

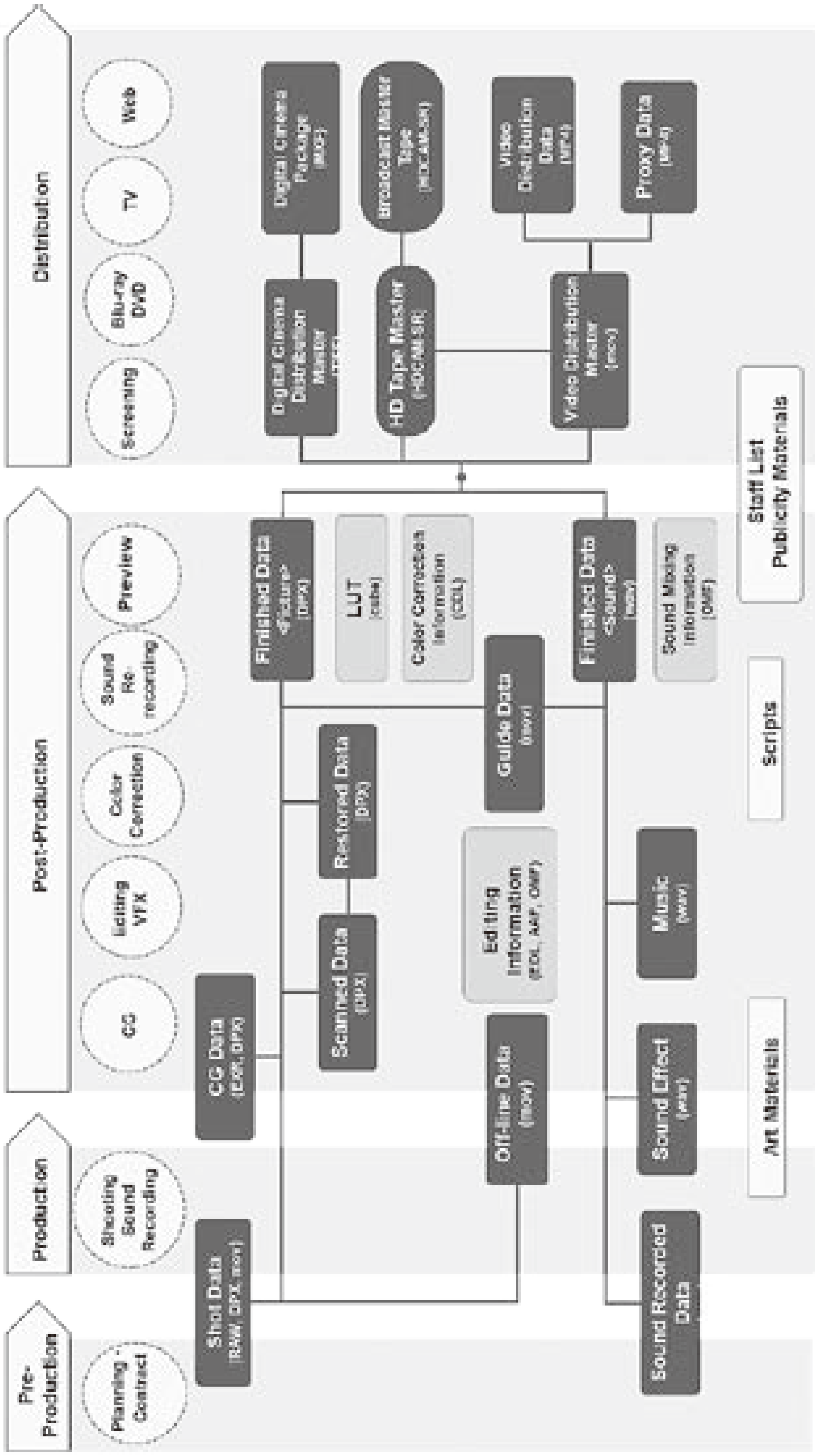


Figure 11 Various types of data produced during the motion picture production process. (The figure was made by Mr. Miura, a member of BDC project.)

the funds to meet storage costs.

5. Conclusion

It has been proposed that a true archiving system should allow data to be decoded after it has been created, forgotten about, and later rediscovered (Lunt et al. 2013). Photographic film is a system that satisfies this requirement. For digital data, however, we have seen that data life expectancy is often determined not only by the life expectancy of the storage medium but also by the lifespan of the system. Present-day digital systems are predicated on data migration. In effect, this means that digital data will be lost when it is forgotten about. When data is stored digitally, it is necessary to implement emulation technology even if the long life expectancy of the storage medium itself could be achieved. For this reason, it is necessary to employ measures such as recording the data using open source software (OSS) where the source code is publicly available, standardizing the data format and metadata, and using a public agency to store this information.

Notes

1) National Film Center (NFC) has got independent from the National Museum of Modern Art, Tokyo, and has become National Film Archive of Japan (NFAJ) since April 1, 2018.
2) “Preservation” in this paper designates “keeping something in its original state or in good condition”.
3) German Patent 253,335 and 257,160
4) http://www.dmc.keio.ac.jp/digitalarchives/ro3mup000000151z.html
5) http://www.momat.go.jp/fc/wp-content/uploads/sites/5/2016/04/DigitalDilemma2_JP_NFC.pdf” (accessed October 18, 2018)
6) http://time.com/4722651/norway-doomsday-vault-svalbard/ (accessd October 18, 2018)
7) http://www.jts2010.org/jts2010/0503/3.Peter_Fornaro.pdf (accessed October 8, 2019)
8) Private communication
9) https://www.oscars.org/science-technology/sci-tech-projects/long-term-management-and-storage-digital-motion-picture
10) Interview in USA Academy Film Archive under the BDC Project of the National Film Center, The National Museum of Modern Art, Tokyo.
11) http://news.panasonic.com/jp/press/data/2014/03/jn140310-1/jn140310-1.html (accessed October 18, 2018)
12) https://www.hgst.com/ja/products/hard-drives/ultrastar-he10 (accessed October 18, 2018)
13) http://dc.watch.impress.co.jp/docs/news/376355.html (accessed October 18, 2018)
14) https://public.ccsds.org/Pubs/650×0m2.pdf (accessed October 18, 2018)

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