



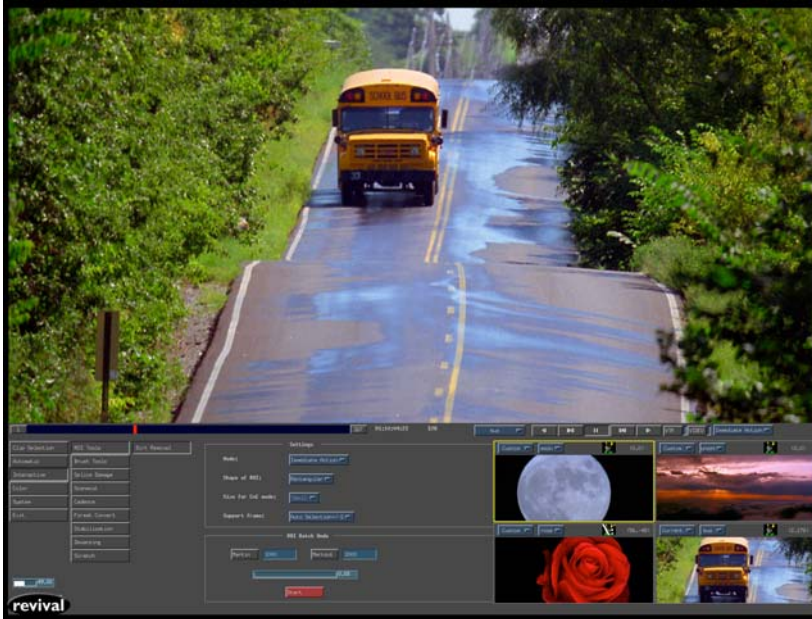
da Vinci's Revival® and its Workflow Possibilities within a DI Process

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Until recently, restoring aging film was a time-intensive, cost prohibitive process. Because of the expense, only films with wide audience appeal - and hence only those guaranteeing a high return on investment - were being restored to their original pristine condition. There is an obvious business case for restoring classic films, many of which were box office hits, and re-mastering them for a new audience. Justification can also be made for restoring other types of films as well. For instance, newsreels and other topics of educational or historic nature should be preserved for future generations.

But besides restoration of old film, digital restoration techniques are now also being used on more recent and even new works. Old film may get damaged in any number of ways - scratches, dirt and dust accumulation, missing sound elements, staining, fogging, fading, warping, etc. -- and so it is readily apparent why restoration is required. With new works, problems mainly arise due to artifacts of digital processing and handling -- and almost everything today eventually gets some sort of digital processing. Content may originate as digital film or digital HDTV video. A film may be scanned into digital format for "digital intermediate" (DI) processing, and most films will eventually end up in a digital format for DVD and broadcast release. Today, the same tools developed for film restoration are also very important tools for correcting problems that arise during the digital film and video production process.

OVERVIEW OF THE DA VINCI TOOLS



Revival - GUI

da Vinci's Revival image restoration system provides a set of sophisticated, software-based digital restoration tools that eliminate many of the tedious, time consuming, and expensive tasks involved in restoring film by automating the most challenging parts. Addressing a wide range of film and video mastering requirements, Revival is resolution independent, supporting 8 or 10 bit images in 2K or 4K resolution, as well as industry standard video resolutions. An optional video I/O interface handles SDTV and HDTV video applications.

Revival supports two modes of operation: Automatic and Interactive (manual). While many of the laborious tasks are handled automatically, by far the most important aspect of repairing images is in the interactive or manual phase. When working with older film, it is generally not possible to obtain the "zero visible defects" level one achieves with new film without spending a great amount of manual time.

Revival's automated toolset is designed for the efficient repair of specific problems in the film image, and the automatic process can generally resolve 75-80 percent of found issues. The Revival operator will review the images and set a range of adjustments, based on experience, for a number of automatic processes. These can be set-up in a 'Batch Process' queue so the system can work on frames independent of constant operator supervision. Some of these processes include Dirt/Dust Removal, Stabilization, Grain and Noise Reduction, Vertical Scratch Repair, and DeFlicker of Image, discussed later in this article.

Revival's automatic mode uses artificial intelligence and the power of multiple CPU's to analyze and compare pixels. These "PowerHouse" systems are scaled at installation time according to the frame or data size being used and the time requirements for repair. It is common for six to eight CPU's to be used to process SD material, ten to twelve CPU's for HD material, and for data (2K or 4K), systems with up to 16 CPU's can be dedicated to one Revival system.

Many of the automatic tools of Revival also have complementary interactive or manual tools for the repair of the most difficult problems. For these operations a "Region of Interest" (ROI) is generally selected to reduce processing time and the brush tools, Reveal, Luminance, Clone and Paint, come into their own. Splice damage, scene cut errors and Cadence issues can also be reviewed and repaired interactively. There is a color module for RGB lift, gain, and gamma adjustments as well as PowerWindows for secondary color corrections.

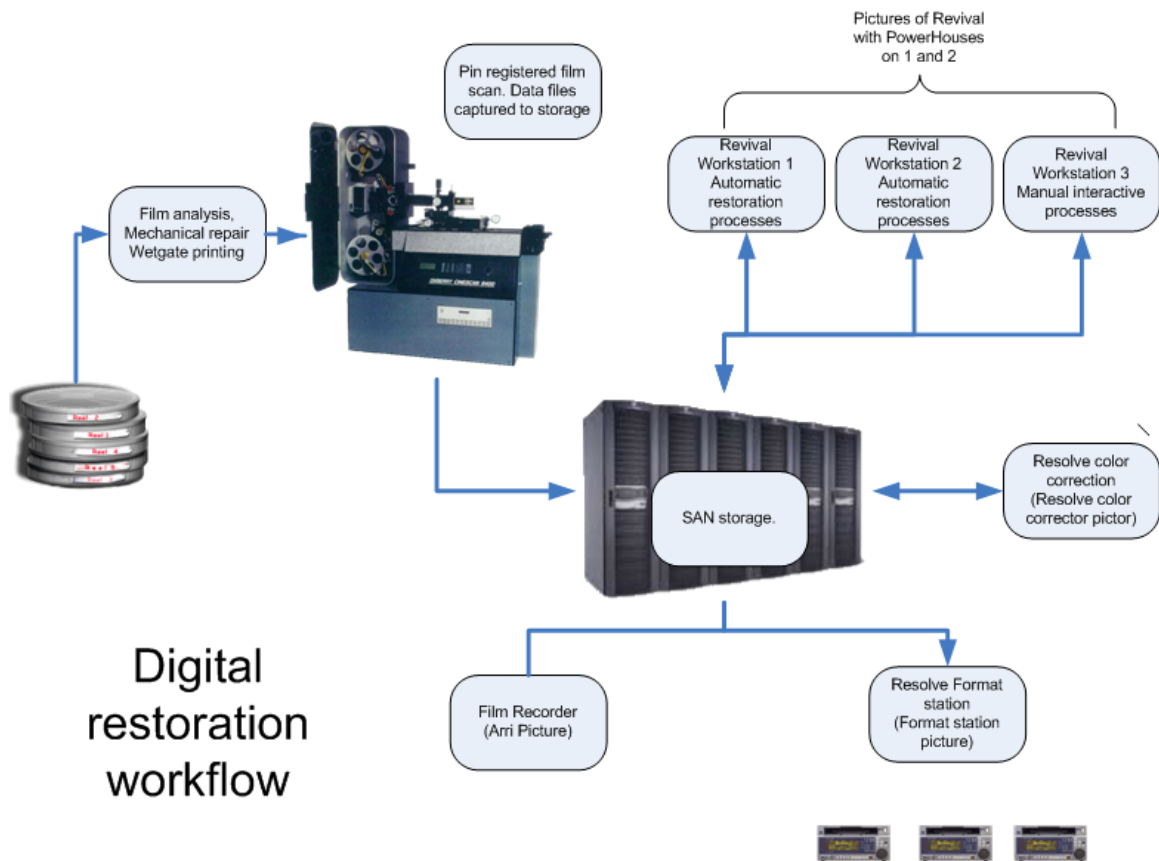
FITTING REVIVAL INTO A DI WORKFLOW

The Digital Intermediate (DI) process is revolutionizing filmmaking, both artistically and economically, and restoration is an important part of that process for both new and old film. da Vinci's Revival brings the speed and versatility found in digital video production to the film world while maintaining the highest standard of quality and resolution. It takes the tedious, time-consuming tasks involved in restoring aging film and automates the most

challenging parts, affording more time for the creative process. Additionally, access to all frames of a film in any order allows for best color look matching, greatly expediting the restoration process.

WORKFLOW FOR RESTORATION OF OLD FILM

The basic workflow for the digital restoration of film is shown in Fig 1.



Quality Control

The DI workflow for restoration begins with an analysis process where many reels of film are scrutinized for quality. Often some of the reels of film have been damaged beyond repair, so alternate versions are sought and often found in film vaults throughout the world. The replacement reels can often be from a print or some other requirement of the original film makers. These reels are

first chemically cleaned, and various processes such as wetgate printing are used to produce the best quality starting images.

Ingest

Whether the film is negative, IN, IP or print, a high quality, real-time telecine or film scanner is required to produce an image for digital capture. If there is an Original Camera Negative (OCN), then the different exposures of the multiple reels will have to be addressed, and with all film the operator will need to adjust the telecine light levels, Dmin and Dmax settings to extract the full extent (contrast) of the image. The reels of film are scanned at a suitably high resolution, and the image files are captured to storage.

A central storage area is ideal so that the image files can be accessed for use by several different restoration processes at once. Some of these processes can be done automatically, and others require user interaction. In the workflow above, a number of Revival workstations may be operating on the images controlled by a single user. The interactive processes use a single operator who views the images for problems not repaired automatically. Detailed descriptions of both the automatic and manual toolsets are described later. Some of these tools, however, improve the quality of the images' original color, which helps during the color correction process.

Use of Restoration Tools

During the image restoration phase, also known as the Image Analysis phase, a list of restoration tools required for restoration processing is created. This list part of a "restoration log," which outlines the required automated processes along with a list of damages that will be manually repaired. To speed this along, Revival imports a second list, independent of the scene cut list, for the purposed of QC or problem correction. When this list is imported into Revival, a series of marks in the clip timeline may be used to quickly jump to problem locations.

Accessing material on the SAN without transferring it, the Restoration Log is put into action by locating marks on the clip timeline and beginning automated repairs. After the automatic processes are complete, the operator will use the interactive mode to work on individual frames that require further work. Often this includes further dirt and speck removal, or for some scratches, manual touch ups.

Lower resolution images can be generated from the restored full-resolution images and sent to the offline editing system, or third-party editing stations can directly access images on the Restoration SAN, again with no need for transfer of the data. At this point the images are combined to produce the edit order that matches the original film reel's compilation. The final edit is not done at this stage as the material can be conformed during color correction.

Color Correction and Conform

A full-length feature of 120 minutes can require between two to ten days to color grade, depending on the extent of the enhancements required and the finished result desired. It is vital to the visual quality of the finished product that the restoration of old film not be compromised by rushing this vital re-mastering process.

It should be noted that in a nonlinear workflow, such as is DI, the color correction process can begin as soon as material is placed on a SAN. When a colorist begins work, with the right tools he or she can view the material playback from the SAN in full resolution and in any edit order. Because the actual order of many DI processes is not critical and stored data is randomly accessible, colorists can work on varying restoration and color steps at any given time, based on what resources are available.

Using the EDL generated by the offline suite, the high-resolution restored images are conformed by a nonlinear color corrector, such as da Vinci's

Resolve® system. During the Conform phase color enhancements are applied in the traditional manner to each scene. Reference images are grabbed into a reference store and continually used to ensure the color remains consistent throughout the film. Other processes, such as sharpness enhancement for example, can be completed to restore the image to its original look.

Finally the images are rendered through the conform station (Resolve) back to the storage device or SAN to produce the finished digital master. Titles, if required, will be added in external compositing stations.

Restored Deliverables

The digital master can be sent to a film recorder for production of a new film master. Video deliverables are often required, however this can be produced from the digital master in the formatting station. During color correction, 3D LUTs are used in the visualization monitor to create the same color space and look that will be provided by the film print. Resolve Formatter is able to burn in the same LUT, thus reproducing the same look for the video releases. The format station will produce the necessary video versions which will be recorded to tape.

Now that the DI workflow has been addressed, it is important to identify some common obstacles that are encountered the restoration process. Revival provides the tools and features to meet these challenges head on.

WARPING

Warping is a problem caused by film shrinkage, sprocket damage, or scanning errors that results in film image distortion, usually with stretching or compression. Revival's deWarp tool rectifies this problem by first estimating the deformation that damaged the particular image, and then applying an opposite deformation to restore the image to its original state.

The most important first step Revival takes in the deWarp process is to identify the location of warping motion. In the deWarp process, motion seen in an image sequence is classified into three categories. Global motion is normally caused by movement of the camera. Local motion is often caused by foreground objects moving, such as a person walking. Both global and local motion are valid and should be preserved during the deWarp process. The third category, warping motion, can be caused by a variety of circumstances, including physical damage to the film and defects generated during the film scanning process. Warping motion is unwanted, and herein lies the goal of the deWarp process: to remove warping motion while preserving global and local motion.

To perform motion estimation, Revival uses a feature tracking tool. This tool can quickly and automatically estimate all motion in the images. However, it is not always able to differentiate between the three types of motion. To help identify and preserve local motion, features that correspond to moving foreground objects should be isolated by the Revival user. This means that any remaining motion estimated by the tool will be global or warping motion. To preserve global motion, two reference frames must be set. These reference frames are assumed to be undamaged, and the motion estimated from the undeleted features provides Revival with information about the global motion. Revival can then deduce the warping motion and use this to restore the warped images.

The deWarp tool was designed to handle image distortion which may be caused by shrinkage or film splices that disturb the precision of the film scanning process. Shrinkage causes the film to not maintain the exact size and shape of each frame over time. Damaged or enlarged sprocket holes will also exhibit a nonlinear image, which will look like a stretching or compression of the image. Some scanning systems can cause a similar problem when a splice rolls through the equipment. This will cause the speed of the film to change slightly, resulting in a stretching and/or compression of the image over several frames.

While the actual image on a film may be perfect, the scanning process at higher resolutions requires extreme precision of film transport at seemingly slow speeds. When a splice rolls through the mechanism, the speed and geometric positioning of the film may get disturbed, causing several types of image distortion. Sometimes this problem can be as simple as a subtle bump, while other times it can be a dramatic stretch and twist of the image. The deWarp tool will analyze the distorted image using good reference frames adjacent to the damaged frames to calculate range of distortion. With these calculations, Revival restores the image in an automated process by proportionately warping it in the opposite direction of the deformation..

The process of adjusting distorted frames to match good frames with current industry graphics programs may take hours on a given sequence. With Revival, this can take a mere five to 15 minutes, depending upon the motion. Even brand new motion pictures have problems when they scan cut negative film. A few frames after each scene may be distorted. Revival is used extensively to correct these problems during the digital intermediate process.

STANDARD DEWARP WORKFLOW

Revival's deWarp is a semi-automated process, meaning, it will perform the tasks of motion estimation and deWarp, while it relies on the user to distinguish between warping motion and local motion.

After damaged frame(s) are located, the user identifies one to two good frames near the damaged frames since they will be used as reference for estimation of global motion. The mark-in and mark-out range is set to include all of these frames.

Once the range has been set, Revival can track all three types of motion: global, local, and warping. Revival will automatically preserve global motion estimated from the two reference frames, and it will track local motion of user-identified features with help from the *Extract Features* and *Track Features* tools.

Occasionally, manual deWarping steps (as described in the Advanced Workflow Section) are required due to tracking errors, some of which follow:

- ∞ **Mis-tracked features.** Grain, flicker, and dirt can potentially cause features to be mis-tracked. Sometimes, features may also mis-track because of repetitive patterns in the image, such as a checkerboard. Usually, it is sufficient to delete these features and allow Revival to use the other good features to deWarp the frame.
- ∞ **Insufficient features:** Revival is able to reliably extract and track features near corner points in the image. However, if the image contains large regions that do not have corner points, say in an image with many vertical stripes, then there would be insufficient features in this area to estimate the warping motion.
- ∞ **Features following local motion:** Features around moving objects may be influenced by local motion. Such features must be deleted, or the local motion will be removed by deWarp.
- ∞ **Incorrectly estimated global motion:** Revival automatically estimates global motion from the two reference frames. The global motion for the damaged frames is linearly interpolated from the global motion between the reference frames. The most common form of linear motion is a camera panning in a straight line. If the camera does not move in a straight line, then the pan is considered non-linear and the global motion estimated will be inaccurate. In order to reduce such non-linear motion problems, it is advisable to deWarp only short image sequences. That means the mark-in and mark-out frames should not be too far apart. If a long image sequence is damaged, it can be restored with division into short sub-sequences.

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Tracking Constraints

The goal of imposing tracking constraints is to enable Revival to automatically detect and correct wrongly tracked features, thereby reducing manual work. In many cases, this can lead to substantial time savings. To use the various constraints features on Revival, the user must identify the type of warping motion seen in the damaged images and then select a constraint that best describes it.

By default, the deWarp tool already imposes the *Smooth Constraint*, which works in any direction (horizontal, vertical, and zoom) by smoothing the object changes from frame to frame. In addition to the Smooth Constraint, Revival also offers a *Horizontal Constraint* for warping damage that occurs horizontally only. Any warping motion in the vertical direction is considered to be either local or global motion and would be preserved. Also offered is the *Vertical Constraint*, for damage occurring vertically only, and any warping motion in the horizontal direction is considered to be either local or global motion and would be preserved. The *Pan Constraint* can be used when the entire image is shifted by the same amount. Telecine jitter is an example of a type of damage that can be corrected with this constraint. Lastly, Revival offers an option for *no constraints*, when the warping motion is assumed to be exactly as it was estimated by the feature tracking tool.

Reusing warping motion measurements

From the user's point of view, estimating the warping motion is probably the most time-consuming task in the restoration process. In the situation where many frames are damaged in a similar way, Revival provides a way to save the warping motion calculations and then use them to deWarp other similarly damaged frames. The measurements are saved as Action Items and can be applied to any marked range.

The deWarp tool is ideal for repairing damaged film frames where the image linearity has been compromised. Assuming that good frames with similar features exist, the bad frames can be repaired. This tool prevents the need to use frame reconstruction resulting in complete loss of the original image.

COLOR REGISTRATION

Revival's Color Registration Tool automatically aligns RGB image layers. The Color Registration tool, unique to Revival, corrects a specific problem unique to films printed in three separate YCM or RGB film strips. These three films often suffer from inconsistent rates of shrinkage or sprocket damage, and simply do not align in registration. This variable-rate shrinkage results in color "fringing" of the red, green and blue channels. The alignment distortion is not limited to just an X and Y offset; different parts of an image may misaligned differently.

Since the deWarp algorithm has the capability of moving and bending images based on a good reference, the same technology is also applied to the RGB layers. Revival can accomplish an alignment, or registration, through a series of algorithms that in essence weave and warp the channels back together, thereby avoiding cropping off the edges. The Color Registration tool takes film in this condition and "re-weaves" the colors back into alignment, and with one click, color layers are in synchronization without loss of any material from the original image's individual color channels.



Revival Color Registration Tool

The Color Registration tool automatically detects the alignment between the Red, Green, and Blue layers. On a single frame, using the Green channel as a reference, Revival is able to move and/or bend the Red and Blue channels as necessary to line up all three channels. This is done on a frame-by-frame basis, and as necessary, zones of the image are adjusted differently from others. This is done as a completely automatic process. Additionally, this adjustment is not merely horizontal and vertical, but may offer different corrections throughout the frame. Most other software methods can perform X and Y adjustments, however Revival has the capability of analyzing and adjusting different regions of a frame independent to the others.

Additional Features of Revival Important in the DI Process

Parallel and Automatic Processing

The DI restoration workflow continually progresses with Revival's parallel and automatic processing. Revival allows users to process many clips, scenes, and projects at the same time while interactively and manually repairing other

images, thanks to PowerHouse processing taking place entirely in the background. Automatic processing is used for Dirt, Dust, Grain, Noise, Splice, Scratch, Flicker, Stabilization and Stain. Revival's Automatic toolset is designed for efficient repair of specific problems in the film range. Each automatic process allows setup parameters to be determined by the operator. Processing speed is a factor of the number of available rendering CPUs. After each automatic pass, the processed material is evaluated in a QC phase to determine if that expected results were achieved.

Grain and Noise Reduction Tool

Revival has high quality, resolution-independent tools for the reduction of grain and noise from an image. In addition to noise reduction capabilities, when dealing with large areas of flicker and dye fade between RGB channels, the resulting repairs with this tool are unmatched. With HD material, it is recommended to use hardware-based grain and noise reduction, however, special circumstances require the use of Revival's Grain or Noise Reduction tool.

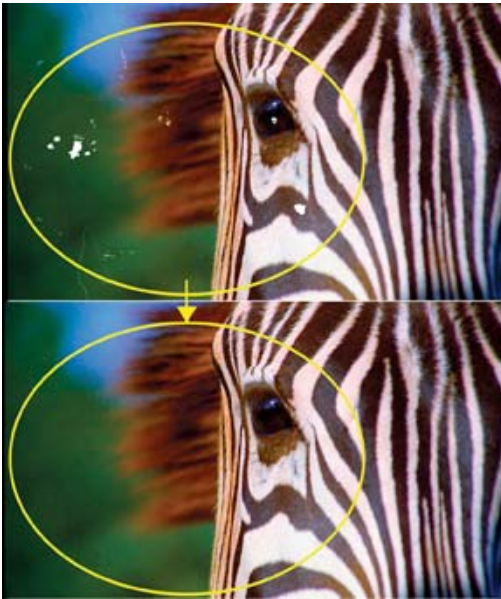
This tool has a dual purpose; both grain and noise reduction each independent of one another. For grain reduction, spatial controls are used which blend the image pixels to smooth out grain. For noise reduction, larger pixel groups are smoothed out over a group of frames. When there is a slow drift of the image level over many frames, the Noise reduction tool will automatically correct and average the image over many frames. This can even be used to balance color drift between the channels.

deFlicker

Flicker may be local (image level variations within the frame) or global (image level variations from frame to frame) in nature. Flicker in an image can be caused by numerous reasons including emulsion or color dye fading over time, long term exposure to heat and humidity, fogged film due to chemical processing problems, as well as stains and scratches.

Some older two- and three-stripe (Technicolor) films could have different flicker or level shifts between channels when printed. Revival can smooth out these channels independently, providing a solid level and color balance. Revival has settings to accommodate both local and global variations along with motion compensation. In addition, deFlicker is “scene based,” requiring a reference frame for each scene to be defined. For faster setup, Revival defaults to the middle frame of each scene to set as an initial reference. An added benefit is the ability to process in either direction from the defined reference frame.

Dirt/Dust Repair



Revival Dirt and Dust Repair

Dirt and dust repair is the benchmark of Revival processing and is generally the fastest of all restoration tools. Even with new film, dirt and dust will appear due to handling, and those imperfections can easily be removed in the DI process. The restoration operator is offered many settings regarding size, type, and nature of the dirt in the image. Automatic processing will apply those settings to the reel. Revival's processing fixes only the part of the image where dirt is located, leaving the remainder of the image unaltered. There are Region of Interest (ROI) controls to help guide where processing is or is not to take place.

Scratch Repair



Revival Vertical Scratch Repair

Vertical scratches in the film image are very difficult for any computer algorithm to repair, mainly due to lack of support imagery information needed to generate a proper replacement. Usually scratches are repaired using spatial filters that analyze pixels on either side of the damage. Identical scratches are usually not found throughout a film, and they mostly appear in groups of frames, rather than entire scenes and reels.

Revival has two methods for repairing scratches. Automatic Scratch repair is used where there are 10 or less scratches of a similar nature. A ROI is drawn around each scratch, and then all scratches are repaired using the same control settings. If more than 10 scratches are necessary to repair, or if there are different kinds of scratches, Revival has the Interactive Scratch tool that provides for many more ROIs in one scene, and offers DI technicians the ability to have different adjustments for each scratch, with the added benefit of separate controls for each. Additionally, Scratch processing may be limited to individual red, green, and/or blue channels to provide the best and fastest possible result.

Stabilization

Instability of an image is usually the result of one or more of the following:

- ∞ Worn sprocket holes causing accurate placement in the scanning gate to be compromised
- ∞ Multiple printing generations without exact alignment of sprocket holes each time
- ∞ Edge damage or film shrinkage preventing the film from positioning repeatedly in the scanning gate

Automatic Stabilization uses an advanced algorithm to determine which objects are to be tracked or stabilized, and Interactive (manual) Stabilization allows the DI technician to select which objects are to be stabilized.

Revival plays a dynamic role for DI facilities' remastering projects, assuring the highest quality results and reducing the time and cost associated with the restoration process. Its sophisticated set of restoration tools, including deWarp, deFlicker, and Color Registration, allows users to remove scratches, dirt, and other undesirables in the fastest, most efficient way possible. With Revival, films from all ages can be brought back to life, preserving a precious and valuable part of cinematic history.