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1. Purpose

The purpose of this document is to provide an introductory explanation of the kinds of chromatic aberration found in digital camera images and to describe the Chromatic Aberration filter used to remove this type of defect. The description includes an explanation of how to use the filter and its controls to best effect along with suggestions for what to do if you encounter troublesome images. Jump to section 3 to skip the technical detail.

2. What causes chromatic aberration and what does it look like?

Chromatic aberration is the term for an imaging system placing incorrect colors in at least some locations within the image. In conventional film cameras this is usually a lens defect but in digital cameras a number of effects contribute to chromatic aberration. To understand this better it is useful to examine the processing chain in a digital camera, which can look something like this.
The first step involves auto-focus, where lens chromatic aberration can occur, along with estimation of exposure. The exposure is determined for the scene as a whole or a portion of it and, where the scene contains very bright localized sources of light, the image sensor may receive an excessive amount of light. This leads to sensor blooming, which can cause color defects. The preprocessing step may include such things as defective pixel correction by interpolation, linearization of detector response, dark current compensation using masked sensors at the edge detector chip, and stray light (also known as flare) compensation. Prior to subsequent processing the color balance is adjusted so that the white point is correct for the scene. Neither of these two steps typically contributes to chromatic aberration. Demosaicing takes place after the white balance step and is one of the most compute intensive steps in the chain. Demosaicing is a process that compensates for the fact that different colors are typically sensed by different sensor elements and the responses must be combined to create a complete color response for every sensor, which then corresponds to an image pixel. A wide range of color problems can occur at this step. The color transformation step converts the color representation from one used internally in the camera to a standard color space, such as sRGB, which is suitable for subsequent computer processing, and does not normally contribute color errors. The postprocessing stage includes items such as color artifact removal, denoising and sharpening and can therefore affect color errors.

By the time the image arrives in the photographer’s computer it has undergone a wide range of processing, much of it proprietary, and can contain chromatic aberration from a variety of sources. Usually, the aberration is most pronounced near object edges of various types in the image, which are the best place to look for problems. The rest of this section discusses some of the major factors causing or influencing chromatic aberration, namely lens defects, demosaicing, sensor blooming and postprocessing.

**Lens Aberration**

Lens chromatic aberration is caused by light of different wavelengths being bent or refracted by the lens to different degrees. This phenomenon is responsible for the familiar ability of a prism to split white light into a rainbow of colors. The reason for it is the variation of the refractive index of glass with wavelength, which is shown at left. This variation causes the focal planes for different colors of light to be at different distances from the lens and the plane of the digital camera sensors. Light is in focus in some average sense. We can say that intermediate wavelengths (i.e. green) are in focus on the detector but shorter wavelengths (i.e. blue) and longer wavelengths (i.e. red) are focused on planes slightly above and below the detector plane. This is illustrated in the figure below. The lens can be thought of as made up of prisms with a continuously varying prism angle. The inset in the figure shows how this focus effect looks in a laboratory demonstration using a dark scattering background.
Lens chromatic aberration cause fuzziness at object edges because the different colors do not align exactly. Usually this is most evident at strong (i.e. high contrast or sharp) straight edges as a magenta, green, orange or blue band along the edge. Typical locations where this effect is observed might be door frames or windows. Examples of this are shown on the left. The central portions of the images have had their saturation drastically increased to make the effect still more evident. When the geometrical consequences of ray tracing through the lens are examined, it becomes clear that the edge misalignment increases with distance from the optical axis. As a result, the color banding at edges within the image is most pronounced near the borders of the image and far from the optical axis coincident with the center of the image. Image corners will show the most effect if there is suitable content in the image. This is illustrated below using the stripes on a zebra.

Sidestepping the deeply philosophical issue of whether a zebra is black with white stripes or white with black stripes, we will focus on white stripes and choose some at the left and right edges along with one near the center. The original image was 3072 x 2048 pixels in size and has been reduced in size for this document. The insets are shown at the original actual size. Again, the saturation has been drastically increased in the center portion of the insets to make the aberration easier to see. It is quite clear that the stripes
near the image edges have green borders on one side and blue borders on the other, while the central stripe is essentially homogenous in color. (Black stripes give the same result, of course, except for reversal of the colors.)

Lens chromatic aberration typically increases with the lens aperture since light rays farther from the optical axis can be captured with a larger aperture. Telephoto and zoom lenses are often more prone to this defect than other lenses. The effect can be more pronounced in digital cameras as compared to film cameras since the camera sensor is smaller than a conventional film frame. The next section discusses an effect found only in digital cameras.

Demosaicing

With the exception of chips such as the Foveon, digital cameras have sensors that simply respond to light without regard to color. To extract red, green and blue color information, separate sensors must be devoted to the detection of light of different colors. This is done by placing a color filter array (CFA) over the detector chip so that only light of a specific color range is measured by particular sensors. The most common filter arrangement is the Bayer pattern, shown at left. It has twice as many green as red or blue patches since the eye sees detail mostly in luminance and green contributes most to the perception of luminance. The red or blue component at each green sensor element (subsequently an image pixel) has to be determined by interpolation of adjacent pixels, of which there are two of each type next to a
green element of the array. Similarly the green component has to be interpolated in the red or blue pixels, each of which is surrounded by four green pixels. (Other arrangements of sensors than a rectangular grid are used in some cameras, as are different colored CFAs, but similar problems persist.) Interpolation over unequal gaps in the different color locations has certain unpleasant consequences, which are illustrated with a concrete example (best viewed enlarged to 200% or 300%).

The top row shows at left an imaginary original image, which is overlaid with the Bayer CFA in the center. At right is the exemplary result of an extremely poor step-wise bilinear interpolation, naturally subject to severe interpolation errors. The next three rows contain in left to right order the colors under the Bayer mask, the channel values under the Bayer mask and the results of interpolation for the red, green and blue channels respectively. At the bottom the original and interpolated results are shown after two-fold enlargement so that details can be better seen. Naturally, camera manufacturers use far better interpolation methods than the one described here as an example. Details are proprietary but interpolation techniques directed along edges, preserving color ratios or hue, using gradients, preserving local homogeneity or matching patterns may be used. These approaches all have some limitations. More sophisticated algorithms are available
but are generally too complex for the current computational horsepower. As a result, color defects do occur during demosaicing. While the illustrative example was extreme, the shape and color of characters really is affected by surrounding image content during demosaicing, as shown in an actual example below of painted letters on a shop window.

Other types of interpolation defects occur too, such as the following showing gaps in a suspended telephone wire. Another type of defect involves color variation along nearly horizontal or vertical edges such as those in the next three images.

Other interpolation errors involve colors that depend on the orientation of edges. The following example shows an edge of a building (originally vertical but rotated for ease of
presentation). The edge itself is clean, showing some sharpening. However, protrusions from this edge have systematic color errors.

The following building parts – two sets of windows, a roof support with light fixtures, and a railing – provide some additional examples of interpolation errors. The colored boxes contain enlargements to show the problems more clearly.

The reflection from the tuba on the left and the palm frond on the right are other examples. The lower half of the palm frond inset illustrates a moiré effect, which arises
when the periodic pattern of the color filter array interacts with periodic image feature that has a similar spacing on the detector. Some instances of interpolation errors involving moiré are shown below. Strands of hair or fine fabric patterns can also show this effect. In the camera moiré is often dealt with by slight defocusing of the lens, which makes moiré reduction a compromise with image sharpness. Because of the larger spacing of red and blue sensors, moiré normally appears as a color pattern (usually blue and yellow or orange) rather than a luminance pattern. Consequently, in some cases correction can be achieved by replacing color data with luminance data. Despite the efforts of the camera manufacturers, demosaicing can contribute a variety of errors. Other than moiré, these effects tend to be of small scale, comparable to the Bayer array pixel mapping. More serious is sensor blooming, which can extend over larger ranges.

**Sensor blooming**

The sensors in a digital camera detector are a pattern of photodiodes overlaid with a CFA. The photodiodes convert light into electric charge and the electrons from this charge are captured in a well that is maintained using an applied electric potential. More and more charge is accumulated as light continues to fall on the sensor. On completion of exposure the charge is read out by changing the electric potential inside the chip with an applied voltage. In a CCD detector the charge is converted to a voltage using an external amplifier while in a CMOS sensor amplifiers associated with each photodiode provide a voltage directly. This voltage is ultimately digitized to a red, green or blue channel value making up the digital image. The digital camera meters the exposure of the scene so that in the brightest regions as much charge is accumulated as possible without overflowing the potential well, so giving the best dynamic range and a response that depends directly on the amount of light striking the photodiode. The exposure control normally works well but the metering of the scene is done in some average sense. If the scene contain small regions where the light is extremely bright compared to the scene average, these bright regions lead to a very large amount of light being incident on the camera sensor. This light causes charge to build up in the sensor until a sufficiently large amount accumulates that it begins to leak out of the sensor well into the
surrounding sensors, much as a bucket under an open faucet begins to overflow. It is possible to create special structures in the chip to carry away this overflow charge and prevent it contaminating adjacent sensors such as the lateral overflow drain in the image below.

As can be seen from the cross-section of one sensor within a detector, this type of overflow control uses space on the chip, which in turn reduces the space that can be devoted to the photodiode. The loss of space has the effect of reducing the sensitivity of the detector to light, which becomes increasingly problematic as more (and smaller) sensors are packed into a chip to achieve high megapixel detectors. This makes it hard to solve the blooming problem.

When charge leaks from one photodiode well into surrounding photodiode wells, the result is a spuriously higher signal in the surroundings. That spurious signal will be particularly noticeable if the surrounding sensors should be producing no signal because the scene is dark in these regions. In other words, we might expect to see the effect of blooming most strongly at sharp transitions from light to dark. We have already seen that lens aberration will cause the blue and red components of bright white light to appear at incorrect sensor positions. Charge leakage magnifies this effect by spreading the sensor response further from the true position, and the positional error is additionally potentiated by demosaicing. On this basis we can even make a guess at how sensor blooming will appear in an image. Suppose we have a very bright white point in the scene surrounded by darkness, for instance a distant street light in a night scene, and the light from this point falls on a green sensor. As shown on the left in the diagram below, in a perfect imaging system we expect a value of green 255 at this sensor and values of zero for the
surrounding sensors. However, charge leakage along detector rows or columns as shown by the arrows will raise the red and blue sensor responses above the correct value. Our perception of lightness can be roughly estimated as 30% red plus 59% green and 11% blue. Consequently the enhanced red and blue values contribute little to increasing the brightness of the image but give it a purple hue. If light from the point were incident on a red sensor instead of a green one, we would have the situation on the right of the diagram. Leakage of charge would increase green values. While this would change the hue somewhat, the main contribution would be an increase in lightness since green contributes so heavily to the perception of lightness. (The same holds true for a blue sensor, of course.) Thus, we would expect sensor blooming to lead to a spurious purple color in darker regions of the image and – if we define purple broadly as varying mixtures of red and blue – this is borne out in reality so that the effect is often referred to as purple glow or purple fringing. The image below shows samples of this effect.

Violet, purple, magenta, blue and red shades are by far the most common. Green and orange are rare and yellow is exceedingly uncommon though these may occur with specific sensor or CFA types. In some cases the blooming aberration may be virtually colorless, but even in such a situation the Chromatic Aberration filter is capable of correcting it. An example is given below.
It is also possible for the same image to contain multiple aberration colors as sensor blooming interacts with lens aberration and interpolation errors. The image below is an extreme but real example.

The strength of the blooming effect is strongly dependent on brightness as expected from its origin and shown in the examples below. However, the effect can still be present to a reduced degree at lower brightness levels if there is a large brightness difference.
This is shown in the next image, where a distinct and broad purple-blue band appears across a large brightness transition, but which is absent where the transition is small. Where there is a medium brightness difference, a weak barely perceptible narrow blue band can be seen.

Since sensor blooming augments any lens chromatic aberration, it is not uncommon to find higher levels of the blooming defect where we would expect to find a lens aberration defect. The image at left shows this. The arrow is the radial direction from the center of the image pointing outwards towards a corner and the effect clearly increases in this direction. The section of image shown was taken from a corner region of the image. Image corners are often the best place to look for a blooming defect if
there is high contrast in those areas. A common case where this is encountered is tree branches against the sky.

**Postprocessing**

Postprocessing does not usually contribute chromatic aberration. Indeed the purpose of some of this processing is to reduce color errors. However, sharpening operations can cause some unexpected changes in appearance of image edges, which can sometimes interact in an unfortunate way with some of the phenomena previously discussed. Below is an image of a yellow object with a dark hole, partly covered by a blue object in front. The image on the left is the original. The dark region has slightly darker pixels at its edge and is surrounded by a lighter halo. However, the boundary between yellow and blue is very soft. This points clearly to a sharpening step in the camera that uses only luminance. In this process the blue color has advanced somewhat into the dark region. The image at right is the original in which the blue-yellow channel has been sharpened. There is now a sharp transition between yellow and blue and the halos are not as desaturated, though some interpolation errors are now visible. Sometimes desaturation in halos can be beneficial since it tends to reduce the visibility of lens aberration. In any case, postprocessing affects the detailed appearance of color at edges.

A combination of several elements can contribute to the final chromatic aberration observed in an image. Consequently, its correction is not easy to accomplish. In terms of defect severity, postprocessing usually affects the image on a very small scale – say one to three pixels – so the effect is not very visually apparent. Demosaicing defects also typically occur on a small scale but the large color errors sometimes associated with these defects can be quite apparent despite their small scale. Moiré patterns extend over regions that are very large compared to image details and are very hard to eradicate. With good lenses, lens chromatic aberration is usually limited except near the borders of the image. It also tends to be rather diffuse and weakly saturated so many people are not very sensitive to it. Sensor blooming is normally the defect to which people respond most strongly. In modest cases it may be of small scale but, because it occurs in many similar places in the image, its aggregate effect can be very noticeable.
Severe instances create color errors much larger than image details and the error is extremely distracting. The image below illustrates how visible even very small areas of sensor blooming defects can be. The original image was 10 times larger in each dimension than the image shown and the tracery of the Hotel St. Marie sign was between 1 and 3 pixels wide in the original, with a maximum width of 5 pixels. Nonetheless, even at a size where only 1% of the original image pixels remain, the incorrect blue color of the tracery is very evident. The enlargements on the right show that virtually all the offending detail in the small image is sub-pixel in size. The Chromatic Aberration filter was run on the original image and produces a very satisfactory and natural result, with appropriately reconstructed colors. Note that the blue color on the building on the left is not affected.

3. What can the filter do and how does it work?

In your images, search for lens chromatic aberrations at the borders and corners at sharp edges. Look for sensor blooming in image corners and around any very bright regions. Examples of the latter include:

- the sky seen through tree branches or leaves
- edges of windows in interior shots that admit exterior light
- city lights or fireworks at night photographed with large apertures
- fluorescent light fixtures or bare light bulbs
- reflection of the sun or lights in water
- specular reflections from chrome or shiny objects
- the edges of backlit objects
- sunlit white shirts against a dark background

If you find such color errors the Chromatic Aberration filter will help you correct them.

The Chromatic Aberration filter can eliminate or reduce all of the color defects described in the previous section. The overall approach is for the user to supply a sample of the aberration color by marking a region of the image. Then the filter searches for all instances of similar aberration color in the image and replaces them with a suitable substitute color. It is important to note that the color selection is not simply a Magic Wand, Select Color Range, or Select Similar algorithm in disguise. Instead, the filter performs a sophisticated color analysis and the color is compared to the characteristics
of different types of aberration. This enables the filter to be extraordinarily selective as to the regions of the image it affects. The selectivity is illustrated with the following image, which contains purple glow of several shades along with very similar authentic purple detail.

Threefold enlarged patches show in detail what the filter does.

Patch 1 illustrates removal of the purple aberration from around the lights without affecting the purple sign at bottom right. In patch 2 a pink region in the highlight is
removed from the chin. The dark red aberration is eliminated from the edge in patch 3. Patch 4 shows the removal of a pink halo from the edge of the shirt while maintaining the color of the face in the background. The purple fringing above the light is reduced in patch 5 without affect on the purple sign above.

Once the regions to be corrected are determined, the filter performs an intelligent interpolation of color so as to substitute the aberration color with one that is appropriate. This is quite different from conventional correction techniques such as desaturating the aberration color. Consequently the filter can provide plausible and natural-looking replacement colors even in difficult situations such as the image at left. Here the image has many JPEG artifacts and several aberration colors, some of which resemble authentic colors in the branches.

While the filter is much more selective than simple color selection tools, it cannot avoid making incorrect choices in some circumstances. For example, if an image shows reddish lens aberration on some green leaves while other leaves in a similar image environment have changed to red and brown autumn colors, there is really no way to distinguish the two cases without the intervention of human scene understanding. A further complication is that the aberration correction involves modifying small image regions around 1 to 10 pixels in width in an image containing several millions of pixels. Incorrect color adjustments are consequently very hard indeed to spot, especially since they may be thousands of pixels away from the region being corrected at high zoom.
The image above illustrates the problem. Using the color samples shown, the purple fringing in the branches is well removed (orange box). However, some of the objects hanging on the figure also undergo change (yellow box), especially the purple one which matches the first swatch closely. Both of these objects are only one or two pixels in width. Even with a great deal of self-discipline and systematic searching it is very easy to miss a tiny spot in a sea of pixels that has been not been corrected or, worse, that has been incorrectly modified. It is extremely frustrating to discover many steps into the image processing chain that the red leaf aberration correction also destroyed part of a car tail light for example. For this reason the filter contains two features that help cope with unanticipated modifications. First, the filter provides a means of displaying differences between the original and corrected image to help spot unexpected changes. Second, the filter allows output on a new layer. That way, even if something is missed during the correction of aberration, the defective part of the corrected layer can be erased to restore the original image.

While these features mitigate the problem of modifying few pixels among many, this problem bears on how to use the filter most efficiently. Generally, it is not a good idea to try and use the filter to correct one-pixel-wide color errors near edges. The colors of such defects vary widely from one part of the image to another, necessitating many samples. With many samples of different colors it is hard to avoid incorrect changes somewhere in the image, even if only a few pixels may be involved. The same is true of using few samples but assigning a large color range to them. There are nevertheless cases where the Chromatic Aberration filter provides unique correction abilities for this type of error but this is likely to be at the expense of having to erase regions of improper correction on the new layer. It may be quicker to use alternative tools like Saturation Up/Down or Change to Target for small region touch-ups. Where the Chromatic Aberration filter is most effective and most selective is in the correction of aberrations
due to sensor blooming, which are also the most common and most visible problem and the most difficult to correct convincingly by other means. Ultimately, the best approach is a compromise between one's patience with the Chromatic Aberration filter and one's familiarity with the different retouching tools in Paint Shop Pro.

4. How do you use the filter?

When the filter is run for the first time the dialog looks like the one on the next page. In addition to the customary controls the filter has a Radius and a Range control, along with Show Differences and Result on New Layer checkboxes. In the default state no color samples exist so the Range control is not active and the filter performs no correction. Color samples are created by dragging with the cursor in the left preview. Zooming to 200% or, better, 300% is strongly recommended prior to dragging out a sample to ensure accurate placement. While the cursor is being dragged a dashed box is drawn, which becomes solid when the mouse is released. The box can be moved by dragging the center and resized by pulling the sides or corners. Neither dimension of the sample box is permitted to be smaller than two pixels so a box may be deleted by dragging it smaller than this size. Sample boxes may overlap but doing this is pointless. The maximum number of samples is ten and at this point an existing sample must be deleted before another can be added.
As a sample is created it is added to the sample droplist shown on the left. Each sample is numbered and shown with a mnemonic average color swatch to the left of the name. The active sample is highlighted in the droplist and has control handles in the image. (Inactive samples are shown dashed in the image.) The Range control displays the color range of the active sample in arbitrary units and allows manual adjustment of this quantity. At the same time a Range swatch shows an approximate visual indication of the colors in the sample. A highlighted sample can be deleted by pressing the Remove button. (This is generally much quicker than deletion by dragging the sample to a negligible size.) As the sample includes more colors the Range value increases, which is shown below.
When positioning a color sample it is important to include only the colors that need to be eliminated. This ensures that the filter is as selective as possible. While it is possible to manually reduce the Range of an inaccurately placed sample, a mean color identical to that of a correctly placed sample is not guaranteed in this case. Sometimes it can be hard to decide exactly where to place a sample. In that case, the following guideline should be used. Better and more selective results are usually obtained when the sample includes too much dark color (below left) than when it contains too much light color (below right) even though the Range may be essentially identical in both cases.

When creating a color sample it is acceptable to include several closely related colors in the same sample as shown below on the left. However, it is preferred to make separate samples whenever distinguishable colors can be perceived, as illustrated on the right.
In both the pictured examples, the resulting correction of the leaf is equally effective. However, using two samples makes the filter more selective and reduces the chance of damage to other regions of the image where aberration does not exist. In order to determine which parts of the image are being modified by the filter, check the Show Differences checkbox. The right preview will then change to show differences as white areas on black. The brighter the area, the greater the degree of modification. Auto Proof or Proof will show also the difference on the image if Show Differences is enabled. In this case, applying the filter will write the aberration-corrected result to the image even if differences are being displayed in the preview or are being proofed. There are two things to bear in mind when using the Show Differences mode. First, the filter shows the regions of the image that have been modified. This does not necessarily mean that the image color is significantly altered in these regions. In some cases the intelligent interpolation determines a replacement color that is very similar to the original color. This is most likely to happen for colors at the extremes of the sample range. Second, you should resist the temptation to zoom out and look at the differences for the entire image. Because the modified regions are frequently just a few pixels in size, the resampling during zooming can cause these regions to disappear when a significant fraction of, say, a 6 megapixel image is being displayed. The much safer technique is to use a zoom of 100% (or even higher) and to pan the image around to inspect the changes. This is laborious but is the one sure way of finding the needle of change in the haystack of pixels.
When at least one sample has been placed in the preview, you can tune the reduction in aberration by using the Range and Radius controls, and by adding more samples or replacing the ones you have. The sampling and Range control have already been described. The Radius control is a certain kind of measure of the size of the aberration. Values of the control in the range 4 to 20 are the most useful and the default value of 10 is typically very appropriate. Values larger than 10 can be useful if you have very a wide sensor blooming (purple glow) defect that is not being completely removed where it is widest, usually in the image corners. Values below 10 may be helpful in two cases. One is when you are trying to remove a narrow one or two pixel error caused for instance by demosaicing. The other is when you are dealing with a small image, say less than a megapixel. In general, using the smallest Radius that removes the aberration can increase the selectivity of the filter. The Radius control is global and not specific to any aberration color.

Pressing the Reset button will restore the controls to their defaults and clear the sample color drop list. Since like other Paint Shop Pro filters the filter remembers its previous settings you will generally want to press Reset before you start correcting a different image. While the colors from a prior correction can be reused, it is normally much better from a selectivity standpoint to sample the current image. When you save a preset, the settings of the Radius control are stored along with the sample color definitions. However, the locations of the samples in the image are not stored. If you are consistently working with a camera that you know well, you can probably create presets
for the typical sensor blooming aberrations you encounter, which can save you time because you can avoid the effort of sample creation.

In giving overall advice on how best to use the filter it is somewhat difficult to know where to start. This is because people seem to fall into two camps. The first is looking to remove the most distracting aberration without regard to changes elsewhere in the image. Speed and convenience are key for this group. The second camp is very critical and desires extremely selective removal of aberration without damage elsewhere in the image. Ultimately, the best way to use the filter depends on the effort you are prepared to make and the quality of result you want. Existing competitive solutions leave much to be desired. Some are oriented towards lens aberration and do little for sensor blooming. Others attempt to deal with sensor blooming but make changes in other parts of the image. Despite this there are people who are happy with these approaches, so there is definitely an appetite for quick and approximate correction.

**Quick and approximate approach**

This will commonly be used for sensor blooming aberration, since this is the most noticeable color error. The procedure is to drag out a color sample over the problem area or use a preset color for your camera. Leave the Radius at 10 and adjust the Range setting to the minimum at which the aberration just disappears. If the aberration is very clearly of two colors, use two samples and follow the same procedure. You may wish to output the result on a new layer in case there are undesired changes elsewhere in the image. By later erasing portions of the new layer you can eradicate these changes. The image above illustrates this quick and simple approach using a single brown color sample. A more complete correction would also include the crossed-through green sample but, since the green error is not noticeable, it is not required. A thumbnail of the full scene image is shown on the left.
Maximum selectivity approach

Start by examining the aberration carefully at a zoom of 200% to 300% to determine how many perceptually distinct colors it contains. If the image contains aberrations of distinct hue families, for instance a range of red aberrations and a range of green aberrations, you may find it helpful to run the filter twice, once to deal with the reds and once to handle the greens. Start with the Radius control at a setting of 10 and drag out a sample exactly over one of the distinct aberration colors, erring on the side of a darker shade if positioning is difficult. Usually it is best to start with the color that is in the widest zones of aberration. Observe the result in the right preview and reduce the Range to the minimum value that still produces the desired correction. Toggle the Show Differences mode and pan the image around to see which parts are being affected. There will almost certainly be some unexpected responses. Some of these will be authentic aberration areas that were missed in your initial examination. Others may be the result of mischaracterization by the filter. When correcting sensor blooming watch out for changes in or near other areas of the image with very bright white content, for instance a sign with a white background or a white flag with colored stripes. Toggle the Show Differences mode off to see if there is any important color change in the altered regions. Such changes might be hard to spot, which means they are safe to ignore. The really picky individual will pan the right preview image very slightly. While the mouse is depressed and moving the preview will show the original image, which will update to the corrected result when the mouse is released. This sudden change will help you detect very subtle alterations in color. If there are some regions which are incorrectly modified, lower the Radius control to the minimum consistent with correcting the aberration to see if this eliminates the error. One effective technique that can be used to improve selectivity is to avoid trying to completely eradicate the aberration color, aiming instead to reduce its visibility to an insignificant level. This may arise particularly if you are trying to correct indistinct demosaicing or lens aberration errors that are a pixel or two in width. Once the first sample has been optimally adjusted, drag out a second sample in a distinct and different color region and follow a similar fine-tuning procedure. If you work from the widest aberration zones down to narrower ones you will not have to fiddle much with the Radius control. Sometimes changing the position of a sample to a different region that appears identical in color can make the filter slightly more selective. That is a matter for experimentation by the very demanding. The image below shows a sensor blooming aberration in different sections of the same photograph. This is an instance of the aberration being in one hue family but where optimal selectivity is achieved with multiple samples instead of a single sample with a wide range.

An example of an image which could benefit from multiple passes of the filter is given below. It has a green lens aberration that is enhanced by sensor blooming and spread as a result of being out of focus. There is also a pronounced and wide sensor blooming error involving purple and magenta shades. Elsewhere in the image there is a more
subtle narrow color aberration in red and brown shades, whose precise origin is hard to
determine. Even when the image is resized to 20% of its original size for this document
the green and purple aberrations are readily perceptible.

Using three runs of the filter – green, purple and red – with around five samples in each
case produces a very satisfactory result without any damage to aberration-free regions.
Even the hard to remove (and rather unnoticeable) slight red-brown aberration can be
reduced without damage to the brown or red areas of the birds. Most people would
probably settle for correcting only the green and purple aberration, which could be done
in a single run of the filter if necessary. A detail of the green and red corrections is
shown below. This type of correction shows what is possible with the filter but, given the
effort involved, is probably best saved for critically important images.
5. What the filter will not correct

First and foremost the filter will not correct the shape of image features that have been destroyed by sensor blooming. Some examples are given below with orange guidelines added to make the change in shape more evident. The filter will remove the color error in such images but cannot restore content in which the original image information has been replaced by white or a very bright color. The Clone tool is one solution for fixing incorrect shape.

Second, the filter will not perform well when the aberration has the same color as the surroundings and the aberration regions differ from the surroundings only by lightness.
The photo fragment above shows some blue aberration on tree branches against a blue sky. The lightness channel shows a difference between the branches and the sky but the hue channel is essentially constant everywhere except where the branches are green and so free of any aberration. This causes the illustrated selectivity problem for the filter.

When a sample is placed as shown by the yellow box the result color Range is 32. The chromatic aberration is removed from the branches but the sky becomes desaturated, even when the Radius is set to a very low value. The only solution within the filter is to manually reduce the Range setting to achieve a better compromise between removing the aberration and preserving the color of the sky. In this case a reasonable result is obtained at a Range of 18. The sky is changed little and the aberration, while still present, is nonetheless significantly reduced. At first sight this seems to be a minor problem since we are examining the image at 400% zoom. However, the crown of a dense tree can end up surrounded by a ring of desaturated sky if one does not pay attention to this pathological situation. A multi-step solution to this problem is to allow the correction to spill into the sky and output the result on a new layer. Then make a mask from the inverted source luminance of the layer using Layers > New Mask Layer > From Image > Source Luminance, checking Invert Mask Data. The resulting mask will leave the dark branch regions visible while turning the incorrect sky transparent to expose the unmodified sky in the layer below. The exact appearance of the result can be tuned by apply the Histogram Adjustment filter to the mask layer, for instance to increase the contrast. The result of this technique is shown below for the same image.
Third, the filter will not remove moiré patterns since these are not localized in small regions of the image. In some cases these can be removed by recoloring to the surroundings using the Change to Target tool. In other cases, greyscale information can be used to replace the regions of color channels where moiré exists.

Fourth, the filter performs selective color modifications to remove chromatic aberration. This does not, however, mean that it will behave sensibly if you try and use it to modify arbitrary colors in an image. The filter makes judgments about aberration color and does not simply select similar colors. The results of applying the filter to non-aberration colors may range from no change to what appear to be quite arbitrary changes in unexpected locations. It is therefore recommended that you only use the filter for its intended purpose.

### 6. What to do when you have problems

Here is some general advice for what to do when you encounter problems with the Chromatic Aberration filter. The filter typically works very well but if problems do occur they fall into the categories of modifying too many colors, or less commonly, not removing enough aberration. In dealing with problems it is important to pick a strategy that wastes as little time as possible instead of endlessly fiddling with the filter.

#### Too many colors modified

If colors are modified where you don’t want them to change, try the following suggestions.

- Ensure the color sample includes only the authentic aberration and not also some surrounding color.
- Pan your way around the image in Show Differences mode to make sure there are no changes that you will be unhappy to discover much later.
- Once you know where to look for issues, manually reduce the Range setting.
- Lower the Radius setting to below 10.
- Strive to significantly reduce the visibility of the aberration rather than eliminating it entirely.
- Allow the image to change in incorrect areas, output the result on a new layer, and then erase the problem regions.
- Run the filter on a selection since the filter respects selections. Selections do not have to be very accurate, only sufficient to exclude content that is very similar in
color and image environment to the aberration but which you don’t want to change. Because lens aberration and sensor blooming are often greatest near the edges and corners of images, the following technique can be effective. Make a circular selection in the center of the image, give it a large feather so there are no abrupt color transitions in the corrected image, invert the selection and then apply the filter.

- If you are experienced with the filter and come across a problem image, don’t waste your time fiddling too much with the filter. Use the erasure or selection technique instead.

**Not enough aberration removed**

In some cases aberrations might be hard to remove. The following advice may help.

- Make sure you have the color sample positioned on the most representative color in the aberration.
- Increase the Range setting to see if more aberration can be removed.
- Increase the Radius setting. If you have to go above a value of 20 you probably have suboptimal color samples.
- If there is section of aberration along an edge that is not corrected even though elsewhere along the edge there is a good correction, place another sample at the location of the most representative color of the uncorrected section.
- If you find yourself trying to place more than 10 color samples run the filter twice, once to correct one aberration hue and then to correct a different one.
- If you find yourself with close to the maximum number of samples when there is a single aberration hue, some are almost certainly redundant and too conservative. Delete one of any two samples that have similar average colors in the droplist and expand the range of the remaining color in the pair.
- If all else fails, try deleting some sample colors and placing new samples at similar colors but in a different portion of the image.
- Accept that some types of aberration might be hard to correct. This is most likely to happen for very weak aberrations in a very narrow zone, such as might arise from demosaicing or sharpening problems. The color of such aberrations might not be sufficiently distinct and unique to separate them from other image content. (This also makes the aberrations hard to see of course and leaving them uncorrected may not be a serious problem.) The quicker and more efficient approach might be to swipe the area with a retouch brush such as Change to Target or Saturation down.

**Weird colors appear**

Very, very rarely weird (i.e. inappropriate) colors may appear in an unexpected part of the image. In such a case try the following actions. The first is the most likely issue.

- Make sure you have the color samples positioned on what are actually aberration colors and not some other colors you have mistaken for chromatic aberration. (The examples at the start of this document should help you judge this.)
- If you are trying to correct aberrations of distinctly different hue, don’t correct different hues at once. Instead correct one hue family first and then run the filter again to correct the other hue family.