Focus Stacking

Last Updated: 18-Jun-2023

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What is Focus Stacking?

Focus stacking is a way to get sharp images of subjects that require more depth of field than you can obtain from a single photograph. It works by examining multiple images with different focus points and combining the sharpest parts of each one.

Focus stacking is frequently used in macro and micro photography to capture images of 3-dimensional objects. In macro photography, the higher the magnification factor, the narrower the depth of field, so unless you want just one bit of the image to be sharp, you need to focus stack.

Focus stacking is also used in landscape photography to get sharp images with extended depth of field. While you can increase depth of field by using smaller apertures (higher f stops), beyond a certain point this softens the entire image due to diffraction. Sometimes the only way to get both foreground, background and everything in between sharp at the same time is to use focus stacking.

Step 1 -- Focus Bracketing

Before you can focus stack, you need to take a series of images with focus points ranging from the closest to the furthest parts of the scene you want to be sharp – this is called focus bracketing. Some cameras include a focus bracketing feature to automate this process. Or you can do it manually either by rotating the focus ring or by moving the camera between shots.

Step 2 -- Focus Stacking

The next step is to merge the images by combining the sharpest parts of each one – this is called focus stacking, and it is normally performed by specialized software.

Depth of Field

When you take a photograph, you focus your camera on part of the scene – this is called the focus point. Ignoring diffraction, field curvature and the quality of your lens for now, the part of the scene you focused on as well as other parts of the scene at the same distance from the camera will appear acceptably sharp while parts of the scene closer or further away from the camera will be blurred to some extent. Establishing a criterion for how much blurring you will tolerate and still call the image sharp (called the circle of confusion) defines a range of subject distances that will be in focus, and this range is called the depth of field. Depth of field is generally asymmetrical, with more of the scene behind the focus point being in focus than in front, although exactly how much of a difference varies greatly.

In general, the following things increase depth of field:

- Larger f stops (smaller aperture size)
- More distant focus point
- Shorter lens focal length (wider angle lenses)
- Looser sharpness tolerance (larger circle of confusion)

Here are some factor that make getting an extended depth of field difficult and consequently become candidates for focus stacking.

- Diffraction – using too large an f stop (too small an aperture) will blur the entire image. Using a smaller f stop to avoid diffraction reduces the depth of field.

- Macro Photography – short distances between the camera and the subject mean very narrow depth of field. If your subject is not flat, this can be a problem.

- Using Telephoto Lenses – long lenses inherently have narrower depth of field.

- High Resolution Camera Sensors – as digital cameras capture finer and finer detail, you need to use a smaller circle of confusion to take advantage of the full camera resolution.

- Very Deep Scenes – the popular style of landscape photography that uses a wide angle lens to capture subjects very close to the camera in the foreground but are also sharp all the way out to the distant background.

Macro Focus Bracketing

Moving the Lens vs Moving the Camera

For macro photography, there are two ways to focus bracket – by turning the focus ring or by moving the entire camera closer to or further away from the subject, typically by mounting it on a macro focusing rail. Both methods work and produce similar results, but not quite the same way.

Turning the focus ring changes the distance between the lens and the sensor. The range of possible focus points runs from the closest focus distance of the lens all the way to infinity, but the step size gets larger as you focus further away and the magnification changes slightly as you re-focus. If your camera can do focus bracketing, use it to automate the process. If not, you need to adjust the focusing manually which is much harder to do precisely and consistently enough.

Moving the camera changes the distance from the camera lens to the subject. The range of focus points is limited by the distance you can move the camera, but the step size remains consistent as you move, and the magnification remains constant. However, as you move the camera, the perspective changes slightly.

Some macro systems let you mount the lens on a bellows attached to a focusing rail while the camera body remains fixed. This is like turning the focus ring, but you have much finer control over the increments and a greater range of motion.

Because it reduces changes in perspective, you will generally get better results using the focus ring to bracket rather than a macro rail, especially if the subject you are photographing is relatively large. For smaller or flatter subjects where only limited travel is required, a macro rail can be a better choice since it can be easier to make the necessary tiny steps.

Choosing the Step Size

For macro photography, depth of field is computed using a different formula than for normal photography. At close distances, depth of field depends only on the f stop (f), the size of the circle of confusion (c) in millimeters, and the magnification (m). Magnification is easily determined by photographing a ruler and dividing the sensor width in mm by the field width in mm. The circle of confusion value determines how sharp you want to image to be.

Depth of Field in mm = $2 * f * c * (m + 1) / m^2$

As magnification increases, depth of field decreases, requiring a larger number of smaller steps.

Note that f is the effective f stop which changes as you increase the lens extension, according to the following formula:

f' = Effective f-value
f = Indicated f-value (as set on the camera)
fl = Focal length of the lens in mm.
ex = Extension in mm.

f' = f * (fl + ex) / fl

While it may be tempting to use f/16 or above to increase depth of field, choosing too high an f stop will soften all the images due to diffraction. The details of computing the ideal step size for a given camera and magnification are beyond the scope of this document. In practice however, you will soon develop a feel for what step size to use for different magnifications.

Framing

As you either adjust the focus from close to far or move the camera closer, the subject will get larger, and anything near the edge of the frame will be cropped. For this reason, you need to leave a little extra room around your subject, assuming you are starting with the near focus point. This is only an issue with macro photography and does not apply to landscape focus bracketing.

Focusing

Photographers who shoot subjects like live insects sometimes use a hand-held technique to capture images as quickly as possible before the subject moves away. To make this work, set your camera to burst mode and slowly lean forward as you take a series of pictures to advance the focus point a little between each frame. It helps to turn on image stabilization as well. This method is hard to master and rather hit or miss, but it can be great when it works.

Alternatively, you can use a macro focusing rail that lets you advance the camera in small steps between photographs. For more information on manual and automatic macro focusing rails, see Recommended Equipment and Software below. When working outdoors, watch out for wind or anything that causes subject motion as this can easily ruin a focus stack.

Landscape Focus Bracketing

For landscape photography, your only option for focus bracketing is to adjust the focus since a focusing rail will not work.

Some cameras have a focus bracketing function and if yours does, it is probably best to use it. Unfortunately, this feature is usually documented poorly in the manual so it may take some trial and error to understand how it works and how best to use it.

If your camera does not have automatic focus bracketing, you will have to focus bracket manually. You can do this a couple of different ways. If your camera lets you tap a spot on its viewscreen to set the focus point, you can use this to set focus points on parts of the scene at different distances. A more systematic method is to enable focus peaking and start by setting the near focus point using the focus ring. Then take a series of shots, turning the focus ring a little between each one until the furthest part of your subject is in focus. To make it easier to identify a sequence of focus stacked images, some photographers take a picture with their hand in front of the lens to mark the beginning of a sequence. If it is windy or your subject is moving for some other reason, the focus stacking software is likely to produce ghosting, so try to avoid this.

If in doubt, use focus steps smaller than you think you may need since capturing too much information is better than too little. Longer lenses have less depth of field and thus require more images with smaller changes in focus between images. For wide angle lenses the opposite is true and you may be able to get away with a small number of focus steps. Try to avoid f stops greater than about f/11 or f/16 as diffraction will soften your images.

Focus Stacking

The goal of focus stacking is to produce an image that has more depth of field than any of the individual images.

Focus stacking software merges a set of focus bracketed images by aligning all the images and combining the sharpest parts of each one. This process is a lot more complicated than it sounds since the magnification changes as you vary the focus point, and finding the sharpest parts of an image can also be ambiguous.

While some cameras can perform focus stacking internally, and some image editing programs such as Lightroom and Photoshop can perform basic focus stacking, software specifically designed to perform this task such as Helicon Focus or Zerene Stacker gives you more control over the process and can often produce better results.

While it is quite complicated internally, by and large, focus stacking software is relatively simple to use – you load the set of images you want to stack, tell the program to stack them, do some retouching if necessary, and finally save the result. If problems do show up, you can vary some of the settings and try again.

An Example Using Helicon Focus

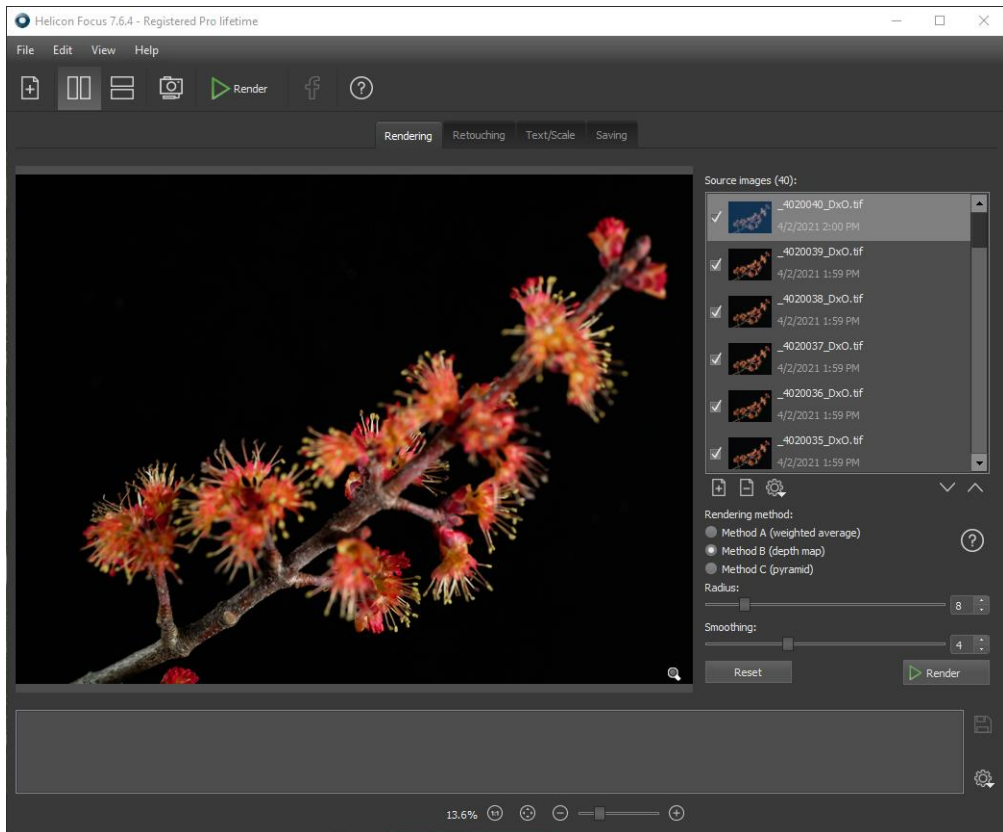Here is an example of focus stacking using Helicon Focus.

Step 1 – Start Helicon Focus
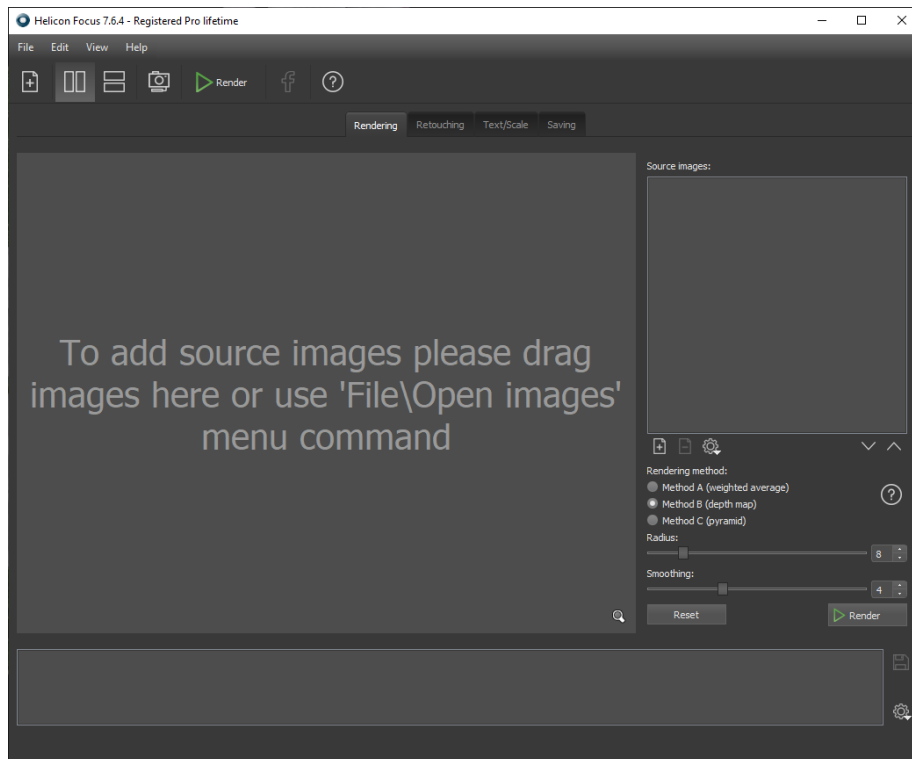
This opens the main window. To start, make sure the Rendering tab is selected as shown above.

Step 2 – Load the Images

Either drag and drop the images on the Helicon Focus window or use the File/Open Images command. Keep the images in sequence, either front to back or back to front.

The first image is displayed and a list of all the images is displayed on the right. You can review other images in the stack by selecting them from the list.

In the lower right corner you can select the rendering method you want to use and various settings for each method. Here is the information about the rendering methods from the Helicon Focus manual:

Method A -- This method works better for short stacks and preserves contrast and color.

Method B -- This method imposes strict requirements on the order of images - it should always be consecutive. Perfectly renders textures on smooth surfaces.

Method C -- Gives good results in complex cases (intersecting objects, deep stacks), though it increases contrast and glare.

Step 3 – Merge the Images

Click the Render button in the lower right corner (or the one in the main tool bar) and sit back and watch as Helicon Focus processes the images. This may take some time depending on the size and number of images.
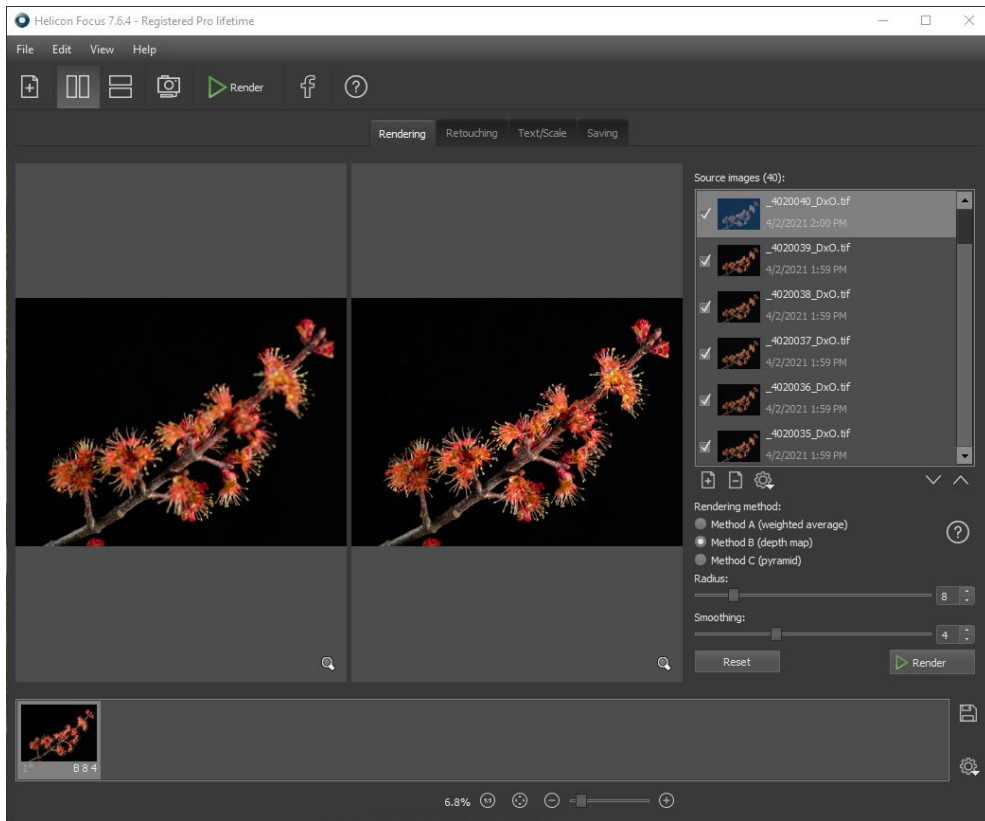

When the dust settles, the split screen display shows the current input image (as selected from the list on the right) and the focus stacked output image side by side.

If you are unhappy with the results, you can start over using a different rendering method or with different settings. Usually, this does not make much of a difference, but it may help with some images.

Step 4 – Retouching

Retouching lets you selectively clone parts of one or more of the input images over the output image. If the stacking algorithm did not select image data from the right input image, this lets you correct the errors manually. To perform retouching, select the Retouching tab. For more details, see the Helicon Focus manual. If you are happy with the output image, you can skip the retouching step and go directly to saving the result.
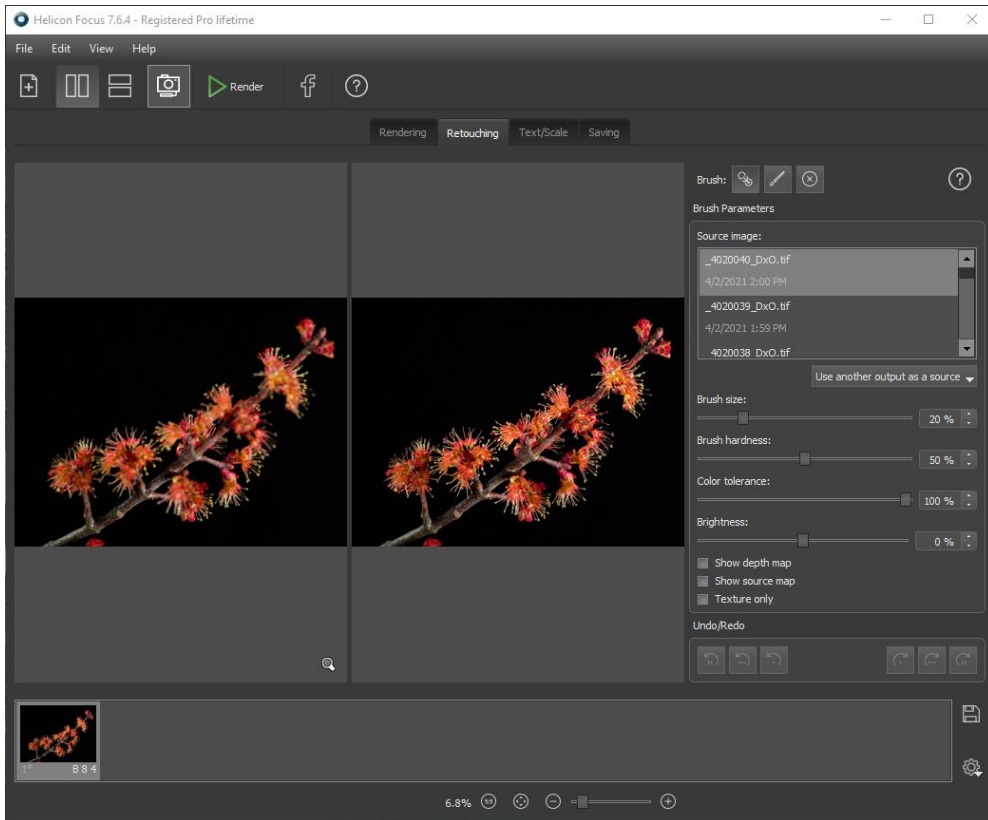
Step 5 – Saving

To save the results, click the Saving tab and then click the Save… button to select where you want to save the file and in what format.
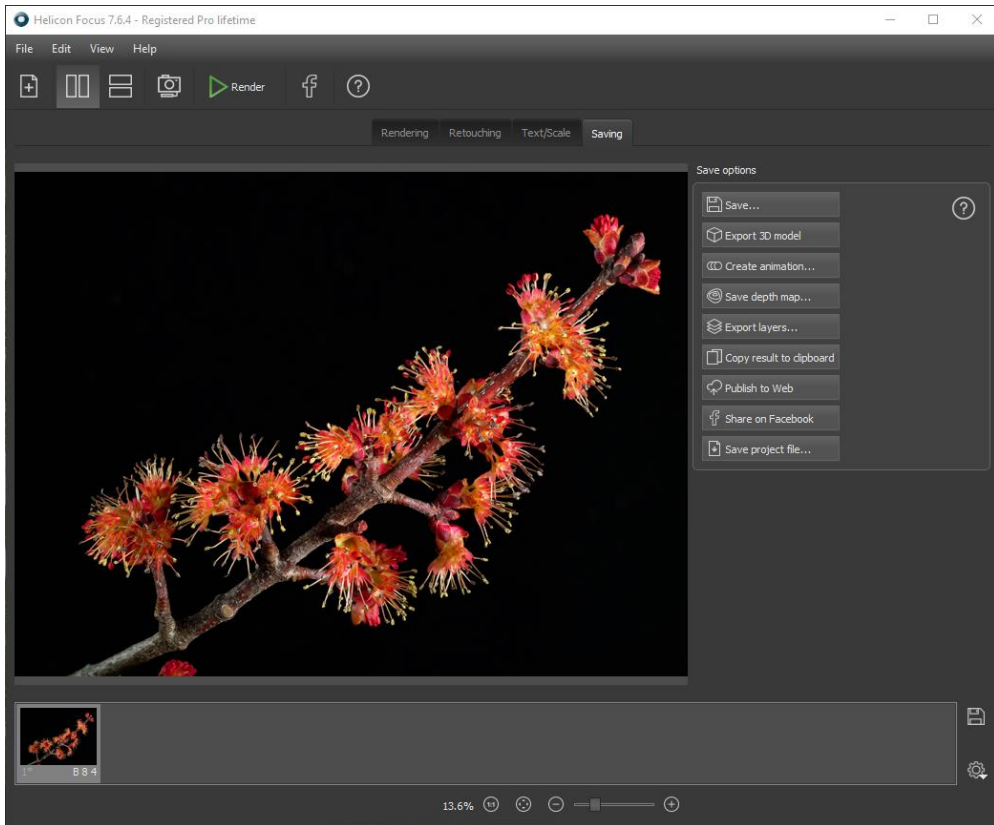
Focus Stacking Problems

While focus stacking is a powerful technique, it is not always successful. Here are some of the problems you may encounter.

Not Enough Images

If the step size between images is too large, parts of the resulting image may not be as sharp as you would like. The solution is to use a smaller step size when you focus bracket.

Camera or Subject Motion

If the camera or subject moves while you are taking the series of photographs, this will create problems as the images may be blurry and will not line up. By removing one or more of the images, you may be able to improve the situation somewhat.

Foreground / Background Overlap

While it sounds simple to just combine the sharpest parts of all the images, sometimes no matter how many images you capture, detail in parts of the scene cannot be recovered.

Here is a pair of images that illustrate this problem:
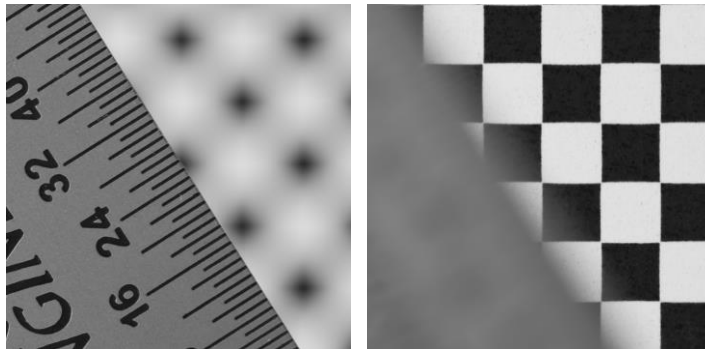
These are two photographs of the same scene -- a ruler suspended a couple of inches above and parallel to a black and white checkerboard pattern. The first image is focused on the ruler and second on the background. We might expect that a simple case like this would be easy to focus stack, but this is not the case.

Here are the results of focus stacking the two images with Helicon Focus using its Methods A, B and C.

| A | B | C |
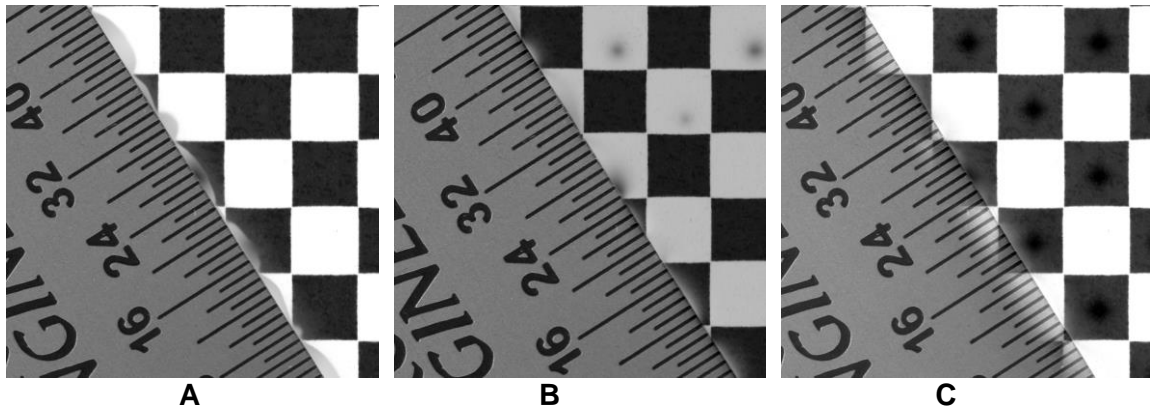
First notice the problem that shows up along the edge of the ruler where it overlaps the background. The nature of the artifacts depends on the stacking method. The reason for these artifacts is that in the image with the sharp background, the blurry ruler obscures background detail near the edge of the ruler. The image with the sharp ruler has a blurry background as well so there is no way for the program to recover background detail immediately adjacent to the edge of the ruler. These types of artifact are commonly called halos and, as you can see, different stacking methods produce different kinds of halos.

Here is a real-world example of halos caused by overlap, and the fix which is to carefully clone some of the unobscured background over the halo:

Areas without detail mischaracterized as out of focus

If part of the scene lacks texture, focus stacking software may be unable to determine if it is in focus or not. Cameras have a similar problem when trying to autofocus on a featureless blue sky because it looks the same either in or out of focus.

This problem is more obvious with methods B and C, namely that the focus stacking program cannot determine whether areas of solid color in the checkerboard squares are in focus or not, since it infers how sharply focused an area is from the amount of texture it has.

As a result of this problem, the focus stacking software may blend part of the blurry background which it misconstrues as in focus with the sharp background which it misconstrues as out of focus, creating blobs in the centers of the checkerboard squares, and in the case of method B, darkening the entire background.

This ruler and checkerboard example is designed to be a focus stacking worst case scenario, and many focus stacked images do not exhibit these artifacts, at least not to such a noticeable extent. Particularly troublesome however are foreground elements that overlap a more distant background, so watch out for these kinds of subjects as they are unlikely to stack well. The further the foreground object is in front of the background immediately surrounding it, the worse the halos are likely to be. When evaluating the results of a focus stack, it is therefore a good idea to closely examine the image around any areas of foreground overlap.

Recommended Equipment and Software

Manual Focusing Rails

A manual focusing rail attaches to your tripod head and your camera in turn mounts to the rail. A knob on the rail turns a gear that moves the camera closer to or further away from your subject. To focus bracket, you move the camera in small steps between each exposure. Note that this method cannot be used to focus stack an object whose depth exceeds the length of the focus rail, typically about 4 to 6 inches. While Really Right Stuff and Kirk both make very nice ones, you can also find similar products on eBay that are much less expensive although they may not be quite as smooth.

Really Right Stuff   Kirk

Import

On most focusing rails, you can rotate the quick release clamp 90 degrees in case you want to mount a camera body directly to the rail rather than attaching a lens foot. You do this by removing the screw holding the clamp to the slide, rotating the clamp and then re-attaching the clamp.

Automatic Focusing Rails

For serious macro focus stacking, especially at high magnifications, nothing beats an automatic focusing rail. This is basically a manual focusing rail with a stepper motor driving its leadscrew and a controller box that connects with one cable to the motor and with another cable to your camera's remote shutter release. You can set the step size, number of steps, starting and ending focus points, and the time delay between shots to let the camera settle. Once you start it up, it fires the camera repeatedly, moving the camera by one step between frames until the sequence is complete.

There are several options:

StackShot (https://cognisys-inc.com)

StackShot has been around for a while and supports a number of options such as an optional rail with longer travel and a separate battery box for use in the field. It works fine, but the interface feels a little like some engineer's weekend project.

Novoflex Castel Micro (https://www.novoflex.de/en/focusing-rack-castel-micro.html)

The Castel Micro is a newer, more highly engineered product featuring a touch screen and a nicer interface. There are various accessories available including a bellows that lets you focus stack by moving the lens while keeping the camera fixed as well as specialized macro lenses for high magnification. Also, you can conveniently snap two standard Canon camera batteries to the back of the controller to use it in the field.

WeMacro (https://www.wemacro.com/)

The WeMacro is a less expensive Chinese macro rail that was recently reviewed on the Luminous Landscape web site. You control it via a smartphone app instead of using a dedicated control box.

Others

There are other automatic focusing rails about which I have no information.

The MVE (Murzins Video Equipment) from Belgium is available on eBay:

There has been at least one Kickstarter project and there are also DIY kits and instructions for the more adventurous.

Focus Stacking Software

There are two programs recommended for focus stacking.

Helicon Focus (https://www.heliconsoft.com)

Zerene Stacker (https://www.zerenesystems.com)

Both programs work well, produce similar results and cost roughly the same. Helicon Focus seems to be a little more popular, but some prefer Zerene Stacker. There are also some free programs such as CombineZP and Tufuse, but neither of these appears to have been updated for some time.