Focus stacking is a powerful technique for managing, usually extending, the apparent depth of field in a photograph. An advanced application of this approach can also be used to selectively manage the depth of field rather than just extend it. This represents a powerful variation of the technique and is one I use when wanting full control over the depth of field in a photo. It is however rather more complex and I therefore have left covering it in detail to the end of this guide.

When used to simply extend the depth of field focus stacking is perhaps best known as a technique for close-up and macro photography. This is where I predominantly use it but it can however also be used very successfully for landscapes (as above) and indeed any genre of photography where the depth of field provided by the lens is insufficient.

The traditional approach adopted by photographers for extending the depth of field is to ‘stop down’ the lens to its smallest possible aperture or f-stop. Smaller apertures or higher f-stops increase the depth of field however the smallest aperture a lens can achieve is often insufficient to render everything required in focus.
While this is a simple and effective technique, choosing a higher f-stop also has its disadvantages. It increases the necessary exposure time, and in extreme cases, it can also reduce image sharpness due to diffraction. Focus stacking provides a technique to achieve almost limitless depth of field (and control over the depth of field) without especially expensive or complex lenses.

The approach has a number of applications but three common ones are:

- **Landscape photography** - where you may wish to achieve a significant depth of field and avoid softness of the image caused by diffraction. This can also permit a much larger and sharper print than would otherwise be possible.

- **Macro photography** – where you may wish to achieve a greater depth of field than otherwise obtainable using the lens’s maximum f-stop. Some specialist macro lenses can only achieve a depth of field of fractions of a millimeter at high magnifications even with high f stops.

- **Low-light photography** – where you may wish to avoid a prohibitively long exposure time yet still achieve an extended depth of field without resorting to using a flash.

**Background**

Focus stacking is not a new a technique, it has been known and used for many years. It pre-dates digital photography and I used it in the mid 70’s to produce some macro photos of lichens with a very high depth of field. It was however very expensive and complex and it is only with the advent of modern software and digital images that it has become a more popular and cost effective option.

The technique relies on selecting the portion of the image that is sharp and combining it with another photo of the same object where another section is sharp and so on to make a complete photo. Before digital images this was either achieved by scanning film to produce digital images or using complex masking to remove areas of a photo that were out of focus and replacing them with areas from other photos which were in focus.

The modern digital approach thus requires a number of images of the subject deliberately taken at different points of focus. These are then combined using software to form one complete image with a greater depth of field than any of the individual source images.

**Limitations**

Although this is a very powerful technique it has one obvious drawback in that it will only work for stationary (or relatively stationary) objects. Since each images is taken at a different point in time and then combined it is essential that there is no relative movement of either the subject or camera.

It is theoretically possible to use a variation of this technique for moving objects by using a specialist (currently experimental) lens called a plenoptic lens. A plenoptic, or lenticular lens is an array of mini lenses each set to form an image with a different focal point. All these lenses are then combined in one compound lens, similar to some insect’s eyes. With this highly specialist lens you take a single photo and then combine the separate images formed by each micro lens.
using software, either in the camera or in a computer during post processing, to form a single image. Manufacturers are experimenting with this exciting development and it is likely that it will appear in the future, initially probably in point and shoot cameras. It will make it possible to produce a camera where there is no focus control, the focus range being either infinite or able to be manipulated in post processing software in a similar way to that used to manipulate white balance and exposure in RAW images. This is however not a technique available to the normal photographer at present.

Another approach to achieve greater depth of field for moving objects is to use specialist and expensive tilt and shift lenses. Whilst these are readily available now both these approaches are beyond the scope of this guide.

**Principal**

The starting point for focus stacking is a series of images captured at different focal depths so that in each image different areas of the sample will be in focus. While none of these images will have the object entirely in focus they collectively contain all the data required to generate an image which has all parts in focus. Post processing software with advanced computational techniques such as edge detection or fourier analysis is used to select automatically the in-focus areas. In software such as Photoshop individual layers are generated each with its own layer mask masking out areas not in focus. These various layers are then blended together to generate the final image.
Considerations before you start

Before you set up the camera or start out on a particular project there are a number of things you need to consider.

- The number of separate photos required depends on the level of detail you are looking for and/or the complexity of the object. It could be just a few but can be dozens in more complex situations. It is very important that you select the appropriate and optimal number of images. The key is to ensure that the depth of field for each subsequent photo overlaps with the depth of field from the prior photo. This way no softness will be present in the final composite image. As a guide more closely spaced focusing distances often produce more consistent and natural looking sharpness. This can however take a lot longer to capture and requires more storage space and computational power so try to avoid ‘overdoing it’.

- You may also want to use a lower f-stop or wider aperture to achieve sharper images or cause the focus to fall off fast at the edges of a defined range. This is perfectly possible but remember that it will require more images as each will have a shallower depth of field. (See section later in this guide re more discussion re advanced management of the focus range.)

- If you want to cover the entire distance from your camera to the distant background, e.g. in a landscape, you’ll need to ensure that you’ve chosen a span of focusing distances that renders all of this in sharp focus.

Process

The process itself has three distinct steps.

1. The individual photos are taken gradually changing the either the focusing distance or the distance of the camera from the subject.
2. These photos are then aligned so that their content is overlaid pixel by pixel. This step is necessary even when using a tripod, since changing the focusing or camera distance will always causes misalignment.
3. A blended composite image is then created based on the sharpest regions from each of these separate photos. This, as with the alignment process above, can be accomplished manually but is better undertaken using specialist software such as Adobe Photoshop (CS4 or later), Adobe Elements or other specialized software packages such as Helicon Focus, TuFuse or CombineZM.

All this used to be complex but if like me you use Photoshop it is now completely automated. See section on ‘Combining images in Photoshop’ photos later in this guide.
Setting up the camera

It is essential that there is no relative movement between the camera and the subject thus each ought to be fixed.

This is probably easiest for the subject although you need to be careful e.g. when photographing a plant outside that the wind doesn’t cause it to ‘wave about’. One device I find very useful here is called a Plamp manufactured by Wimberley and available from most good photographic suppliers. One end (the black clamp) is clamped to a stationary object such as a tripod leg and the other end (the green clip) to the plant stem. The ‘Plamp’ is flexible permitting almost any position to be achieved and held.

For the camera a tripod is essential as is a cable release but it is also essential to decide if you will opt to vary the focus or the camera to subject distance to achieve images with a different focal point.

If you opt to move the camera a focusing rail is imperative. This is a device that fits between the camera and tripod. The camera slides back and forwards (and sometimes also side to side) along rails. Good quality rails have graduated sliders so you can advance the camera by predetermined distances. Advanced ‘robot controlled’ versions are available where the rail travel is controlled by an electric motor and computer which advances the camera takes a photo and advances it again. You simply set the distance between images and the number of images and leave the ‘robot’ to take the photos. One supplier of such systems is Cognisys - http://www.cognisys-inc.com/stackshot/stackshot.php. More details of this device are provided at the end of this guide.

If you opt to vary the focus using the lenses focusing ring you may find it useful to use the camera’s "live view" rear LCD feature for more consistent focus control. For more advanced stacks, if your camera supports it, you can connect your camera to a laptop and make use of the enlarged preview and finer control over focusing. This is discussed more at the end of this guide together with automated software solutions.

When explaining this process to fellow photographers I suggest that there are 6 rules to ensure success namely:

- always use tripod to minimize camera movements
- use the widest aperture possible, this will make DOF smaller and will increase precision
- if possible use a long lens and increased subject to camera distance for maximum depth of field drop off
- use low ISO to minimize noise and good lighting to keep shutter time as short as possible
- always use manual focus and ensure that depth of field for each subsequent photo overlaps with the depth of field from the prior photo
Combining the images in Photoshop.

As recently as just 2 or 3 years ago the process of aligning the images and combining them even using sophisticated software packages was complex and difficult requiring much manual intervention. There were many different and competing software packages, some free and some costing substantial sums of money. Deciding which package to use and then learning how to get the best from it was a nightmare and whilst it was worth the challenge it was not for the feint hearted. I personally found the CombineFM package managed most of the sets of photos I wanted to combine as long as you obeyed the rules I have given above i.e. took sufficient photos and ensured that each subsequent photo overlapped the depth of field of the previous photo. An additional key advantage of this package is that it is free!

Modern versions of Photoshop (CS4 and above - the full version not Elements unfortunately) contain all the tools to make focus stacking very straight forward and easily within the reach of everyone. In this guide I am only going to cover how to perform a focus stack in Photoshop CS4 and CS5. If you haven’t these versions or have only Elements you will have to continue to use the CombineFM package as indeed I have for many years. It is however free, relatively easy to use and there are plenty of guides and videos to help you on the web.

For this example I am going to use the following 8 photos. The subject matter is not inspiring but does make it easy to follow the theory which can be applied to much more complex examples.

The eight photos were all taken using a focus slider to vary the focal point. I have added the dark red lines afterwards to indicate the centre of the region in sharp focus. You will notice that these move steadily from the nose of the fish to the end of its tail.
Step 1 – Alignment

The first thing you need to ensure is that all the images are the same colour balance and exposure. If you took them all with a manual exposure settings this should be OK if not and you process them from RAW in e.g. Adobe LightRoom be sure to apply the same corrections to all the photos.

Alignment of the images is a simple process in Photoshop. As with all Photoshop tasks there are a number of approaches you can use but I find the best is the following.

1. Ensure all the JPG images are in the same directory.
2. Open Photoshop and select the following menu option
3. When the screen opens ‘browse’ to where the JPG’s are stored and select all of them.
   N.B
   Be sure to select Auto and ‘untick’ the box ‘Blend Images Together’
   Click OK and wait – for slower computers this can take some time.
4. Once the process has been completed the following screen will be presented to you. Note that all the images have been loaded as separate layers and as they were taken at different focal points once they have been aligned there is an area around the edge of the combined image that is not included on all layers. It shows up as various different shades of pink around the edge of the image below. Simply crop the image to exclude this as in the inset.
Step 2 – Combining images to form the stack

5. The next stage is to combine the images to form a stack. This is simply undertaken by first selecting all the layers in the layers pallet then the following menu options below.

6. When presented with the following select the options shown here and click OK.

Simply wait whilst Photoshop does its magic and you will be presented with a complete focus stacked image.
7. A careful examination of Photoshops Layers Pallet will show how this has been achieved. Photoshop has created a set of layer masks corresponding to the areas in sharp focus in each image. If sufficient images were chosen and care taken re the overlap of the areas of focus as suggested there should be no aberrations in the final image. If any aberrations are present these can be corrected by editing the layers masks in the normal way i.e. painting over the relevant areas of the masks with white of black.

**Step 3 – Merge the layers**

8. All that remains is to merge or flatten the layers and save the final image. It may be sensible to save a PSD version of the image without the layers merged just in case you want to edit any individual layers later on.
Once you have mastered the technique there are a number of aspects you can try adjusting to achieve even better results. I used to find that you needed to make adjustments to almost all stacked images to get pleasing results with older software. However my experience with the modern software solutions, such as that included in Photoshop, is that as long as you follow the guidelines I have set out you will seldom experience these problems. As with any form of photography it is still worth experimenting however and worth perhaps trying the following:

- Experiment with higher magnifications and note the number of images you need at different magnifications. Depth of field depends strongly on magnification and it is as well to have an idea of the number of images you will need at a given magnification before you are under pressure in the field or studio to produce an image.

- Different lenses perform differently and your lens may not perform best ‘wide open’. It is therefore worth shooting a test sequence to determine the aperture that gives highest resolution and best image.

- Once you have determined the optimum aperture for your lens/camera arrangement; note it and shoot a series of test images at different distances to determine the depth of field for that aperture. Older lenses used to have a scale printed on the lens that helped you determine the depth of field for a given f-stop. This is sadly missing from more modern lenses but you can find on line calculators on sites such as http://www.dofmaster.com/dofjs.html.

  If you own a smart phone you can obtain depth of field calculator apps which are really very good. A good one for the iPhone is Simple DOF Calculator available from the iPhone shop or at http://itunes.apple.com/app/simple-dof-calculator/id301222730?mt=8

- Experiment with different lighting arrangements including flash and fixed lights. For extreme macro I used to use fibre optic lights like the Sony setup opposite. These are very expensive and the same result can now be achieved very cheaply using the USB computer lights – the kind that come on a flexible stem and plug into a USB port on a computer. You can obtain several for a few pounds and power them with a self-powered USB port to provide truly portable fibre optic lights.
The most serious problems you are likely to encounter are caused by overlapping detail in the subject. Where part of the subject passes in front of another part even the good software solutions can have difficulty deciding exactly which features are truly in focus. There are two common manifestations of this problem:

1. Blurring around sharp transitions in depth of focus where the software has difficulty resolving the edge.

2. Halo effects which occur when strong contrast occurs between the subject and an out of focus or a particularly smooth background. The software detects the edge of the blur circle in unfocused frames, and incorrectly treats it as detail to be preserved. This is most obvious and most likely to be a problem with smooth black backgrounds. It can be minimized by using a less contrasting background colour, by using a slightly textured background or by shooting frames close enough together.

If none of these solutions work you can resort to manually editing the relevant layer mask or with some of the non-Photoshop packages, such as Helicon, editing some of the parameters in the package. The latter is however very complex and no real guidance can be given; it is more trial and error. This was more of a problem with older packages and put many people off using the technique. My experience with Photoshop, however, is that the common problems have largely disappeared and, as mentioned elsewhere in this guide, if you follow the simple rules I suggest then it can be minimized further.

Be very cautious in applying JPEG image compression and image sharpening. Images used for stacks that have been compressed too far – or over sharpened - can cause the software to detect "detail" where in fact there was none. What works and what gives problems depends on your camera, subject, and how you use the software, so you’ll have to experiment to see what you can get away with. When in doubt, set your camera to produce the highest quality images that you can afford to store and don’t process it before performing the stack.

Advanced techniques

There are a number of more advanced techniques you can use but for this guide I will concentrate on one which I have used to good effect namely how to achieve complete control over depth of field.

You may feel that the rest of this guide has covered this and that is true to a degree but by extending some of the techniques previously discussed to their logical conclusion you can achieve much more marked and pleasing effects. The photo to the right is just one example.
The aim in this photo was to isolate the toadstools from their woodland background and to draw links between them and trees both as upright subjects. The toadstools are also very clean crisp finely defined subjects, almost like porcelain, and the photo needs to capture this crispness against the rough pine needle strewn forest floor.

The normal process of opening the lens up so that the depth of field just included the toadstools might have worked but wouldn’t have given quite such a clear delineation between the in focus and blurred areas.

The plan view right shows the approach used. First a series of photos were taken with a very wide aperture and hence very narrow depth of field. These were limited to a set of focus points that:

- fell no nearer the camera than the front of the nearest toadstool and
- no further from the camera than the rear of the furthest toadstool

A large number of photos were taken with small changes in focus to ensure a set which included every part of the toadstools in focus in at least one frame but none of the background in sharp focus. If, however, these were then combined just as they are the background would be so far out of focus and the trees wouldn’t have appeared as required. A further photo is needed for the stack where the depth of field is just wide enough to give the required level of focus to the background trees.

This was then added to the stack, aligned and combined. Throughout the process care needed to be taken to ensure that the exposure was right and the required depth of field was achieved.

**Tethered shooting**

Whilst it is perfectly possible to manually adjust the focus or camera to subject distance there are times when there may be benefits to be had from automating this.

There are various approaches the easiest being to link the camera to a computer (tethering) if your camera supports this mode. Canon provide free software with their cameras to do this but for Nikon owners it requires a separate purchase. Whilst the Canon product is very good an excellent third party product is produced by the company Breeze Systems and is called DSLR Remote Pro (http://www.breezesys.com/DSLRRemotePro/index.htm). This does however only works with Canon. Nikon owners will need to look at the options from Nikon and I am afraid I haven’t much experience of these but will try to update this guide with more information when I have researched it for Nikon further.

The process is very straightforward and extremely powerful. I will describe it making reference to the Canon software.
The camera is linked to a laptop or PC using a USB cable. The software run up, a few steps taken to ensure that the camera is recognised and that’s all there is to it. I cover this in more detail for Canon users in one of the guides on my website but it is very simple and also explained well in the Canon manuals.

Once the software is running the PC/laptop screen displays:

1. A control panel allowing you to adjust, on the PC screen, the various camera based controls e.g. aperture, shutter speed etc.

2. A live view of the scene allowing you see the effects of the adjustments in the control panel and provide the ability to adjust the focus in fine increments using your mouse. Useful information such as the image’s histogram is displayed in the window. You can also display a depth of field preview which is incredibly helpful in judging exactly what is and what isn’t in focus for a given f-stop.

Clicking the shutter button on the control panel takes the photo and stores it. This might seem a complex arrangement but once mastered will prove very valuable indeed.

It is extremely easy to make small and measured adjustments to the focus on the live view screen but users of the Breeze Systems software get one further tool, a script which automates this. You simply set the nearest and furthest focus points and dial in the number of photos required and the script does the rest. It amends the focus takes a photo then repeats the process over and over until all the photos are taken. Whilst this might seem the height of laziness it does have the advantage of taking the series precisely and quickly, very helpful if you are trying to ensure limited variation e.g. in exposure between shots.

With modern small laptops or netbooks it is perfectly possible to use this technique in the field and achieve much greater control over the process. I do and it works really well.
The extreme approach if you have the money to afford it is offered by a company called Cognisys, www.cognisys-inc.com. They produce a product called StackShot which is ostensibly a motorised focus rail controlled by a dedicated controller.

The camera is mounted on the focus rail just as with any other similar rail. The controller then takes over advancing the camera with an electric motor, taking the shot and advancing it again.

According to the manufacturers the benefits are as follows:

“StackShot is an electronically controlled macro-rail that coordinates the movement of the rail and the triggering of the camera. StackShot’s simple user-interface automates the entire image capturing process.

The clear advantages of Stackshot are:

- **Accuracy**: Rail adjustment from 100mm to less than 0.01mm.
- **Repeatability**: An “automatic return” feature allows adjustments to the exposure settings between stacks captured with the same position and step size as the previous run.
- **Speed**: No more manually adjusting the rail position, pressing the shutter button, and hoping you didn’t bump the camera. Everything is automated and fast. This enables focus-stacking for critters that may not be willing to stay in the same position for very long.
- **Completely Configurable**: Virtually everything can be adjusted by the user (if they so desire). Trigger times, number of pictures per step (useful for HDR – or even an HDR focus-stack!), maximum speed, ramp time, camera settle time, etc.”

I have not used one of these but have seen it used and have to say it is fascinating to watch and does bring a level of control not available even in a tethered shooting arrangement but it is expensive.